UTTAR PRADESH JOURNAL OF ZOOLOGY

41(18): 1-12, 2020
ISSN: 0256-971X (P)

QUALITATIVE PATTERNS OF MORPHOLOGICAL CHARACTERIZATION IN THE FEATHERS OF FLYING AND FLIGHTLESS BIRDS

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors contributed equally. Author PPS designed the study protocol and edited the manuscript. Author CP wrote the first draft of the manuscript and statistical data. Authors KRN and SS managed the analyses of the study. Authors NL and SN managed the literature searches. All authors read and approved the final manuscript.

Article Information

Editor(s):
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Reviewers:
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Received: 15 August 2020
Accepted: 21 October 2020
Published: 19 November 2020

Original Research Article

ABSTRACT

Feathers are the vital structure of the outer covering and flight surface of all modern birds. Feathers are branched structures consisting of β-keratin—a rigid protein material formed by pleated β sheets—with a hollow central shaft. Feathers can perform flying, heat regulation, Bracing, sending visual signals, eating, Aiding digestion, Foraging etc and make birds a unique one. The aim of the current study is the comparison of shed feathers collected from flying and flightless birds as well as documentation of feathers for the detailed examination of their structural parameters. The microscopic images were captured to study the pattern, kinking, pigmentation, nodes, barb size and interlocking pattern of barbules. The barbules were analysed and feather comparison was done by using stereo microscopic and Scanning Electron Microscopic images. For easier comparison as well as documentation, selected features were divided into different taxonomic orders of birds. Types of feathers collected for the study include wing contour, body contour and Semiplume and tail plumages from different birds. Shed feathers of flying and flightless have been described qualitatively based on the morphological investigation using stereo and SEM images. The feathers are grouped into various orders on the basis of flying and flightless. Flying birds are of the order *Psittaciformes, Accipitriformes, Stringiformes, Gulliformes*. Flightless birds are of the groups *Struthioniformes*, *Rheiformes and Cassuariformes*. No two orders share all the characteristics. However, they may share some of the similar characteristics. Each feather differs in their interlocking pattern, pigmentation and length. Variant shed feathers of different birds are critical to the study. Although identification is confusing, this work might be helpful in various fields such as forensic investigation, illegal wildlife trades; where this document may use as a key/tool for identifying birds based on the plumage parameters.

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Keywords: *Accipitriformes; Psittaciformes; Sruthioniformes; Stringiformes; Gulliformes; Rheiformes; Cassuariformes*; Scanning Electron Microscope (SEM).

1. INTRODUCTION

Feathers are the clearest, complex, and varied integumentary derivatives of birds. They are one of the defining characters of the Class Aves, even though they were also present in the early Cretaceous dinosaurs, *Protarchaeopteryx robusta and Caudipteryx* zoui [1] Feathers are about 90% protein, mostly beta-keratin. The mass of feather keratin is nearly half-hour lower than that in scales, beak, and claws [2]. The keratin even varies in organic compound composition among feather elements, involving physical properties needed at each site. The rest of a feather consists of various element non-keratin compounds and little amounts of lipids and significant metals, particularly mercury [2].

Feathers cover the entire body of most adult birds, except for the beak, lower legs, and feet. It is evident that the feathers did not evolve only for flight. They evolved with some other action and were later modified for flight. Feathers in birds, which serve more than 20 different functions, including thermoregulation, protection, etc [3]. The flight feather evolution is the most advanced type of feather development in the bird's evolution because the powerful flight of birds is made possible by flight feathers. In-flight feathers the aberrant shapes of the vanes along the rachis that aero-mechanically enable birds to fly. These feathers are elongated and asymmetrical to a varying degree. The leading or anterior edge of a flight feather is the narrow side which allows the bird to cut through the air.

Ideal, contour feather consists of a central shaft and a broad, flexible vane on each side. The main shaft is split into two halves: the solid higher part that provides rise to the vanes is named the rachis; the hollow lower finish below the vane is named the Calamus. At the bottom of the calamus is a gap known as the inferior bellybutton, through which blood and nutrients flowed to the feather throughout its development. Once the feather is developed, this gap is closed by plate like structure. The different feathers are counter feather or feathered feather, down feather, powder down or powder feather, semiplume, filoplumes and bristles [4].

Contour or feathered feathers: Contour feathers embody each of the feathered feathers that cowl the body and therefore the flight feathers of the wings and tail.

Down feathers: Down feathers are small with a poorly developed rachis and no interlocking barbules (and hence are downy). Down feathers cowl offspring birds and supply insulation in most adults. They lie underneath the contour feathers.

Powder down or powder feathers: The barbs of powder feathers disintegrate, providing a fine powder that's thought to assist in preening and waterproofing the other feathers. They are the individual feathers that grow ceaselessly and are never moulted.

***Semiplumes*:** Semiplumes is intermediate in structure between the fledged contour feathers and the vaneless down feathers. Semiplumes have a brief rachis however are softly webbed and downy. They lie beneath the contour feathers and supply insulation and contribute to sleek body contours.

***Filoplumes*:** Filoplumes are long hair-like feathers with tiny barbs at the tip and a sensory corpuscle at the bottom, and are scattered throughout the bird body.

***Bristles*:** They are stiff and thin hair-like, consisting of a central rachis while not vanes, and supply each protecting and sensory functions. Bristles occur most conspicuously around the eyes ("eyelashes"), the lores, the nostrils, and round the gape (corners) of the mouth. Not all birds have bristles [4].

The coloration of a feather could vary because of the presence of pigments (chemical coloration) or because of the physical properties of the feather (structural coloration) or both. There are three principle pigments found in birds: Melanin (blacks, greys, and browns), Carotenoids (reds and yellows), and Porphyrins (reds, browns, and a few greens) [5]. Comparison between flying and flightless and flying bird feathers may bring about the differences in structure as wells as the adaptation of integument. It also reflects on the ultimate perspective, i.e. evolution of birds as well as feathers. It also might be helpful in various fields such as forensic investigation, trades; where this document may use as a key/tool for identifying birds based on the plumage parameters. The qualitative morphological parameters include colour patterns, type of interlocking, the position of interlocking, length of the rachis, sub pennaceous length, barbules length, plumulaceous nodes, kinking, prongs, pigmented nodes, and so on.

2. MATERIALS AND METHODS

For this study, we collected shed feathers of eight flying and four flightless birds from the Zoological Park, Thiruvananthapuram, irrespective of their types of feathers. It includes contour feathers (remiges and retrices) as well as non-contour feathers like semi-plumes. Different types of feathers have been collected from different bird species. Based on the different type of feathers collected from the field birds of flying and flightless are placed in various orders. In flying category, the birds of order *Psittaciformes, Accipitriformes, Stringiformes and Gulliformes* are considered and in the flightless category the *Struthioniformes, Cassuariformes and Rheiformes* were selected for analysis.

2.1 Flying Birds Selected for this Study

2.1.1 *Psittaciformes*

1. **Electus parrot (*Eclectus roratus*, Statius Muller, 1776)** - It is unusual in the parrot family for its extreme sexual dimorphism of the colors of the plumage; the male is having a mostly bright emerald green plumage and the female a mostly bright red and purple.
2. **Green Winged Macaw (*Ara chloropterus*, Gray, GR, 1859)** – This family exhibits a deep vibrant red on the head, shoulders, and breast with a greenish band below the shoulders and wings. The green band transits to dark blue on the wings, and there is light blue on the lower back and the tail feathers. Besides, the green-winged macaw has characteristic red lines around the eyes formed by rows of tiny feathers on the bare white skin patch. The tail feathers appear in red and tipped in blue.

2.1.2 *Accipitriformes*

1. **Pariah Kite (*Milvus migrans*, Boddaert, 1783)** - Black kites are opportunistic hunters and are more likely to scavenge. Their angled wing and forked tail make them easy to identify. The upper plumage is brown, but the head and neck tend to be faded. The patch behind the eye appears darker. The outer flight feathers appear black, and the feathers have dark crossbars and are spotted at the base. The streaked appearance of the body is beaus of the dark feathers over the body.
2. **White-bellied sea eagle (*Haliaeetus leucogaster*, Gmelin, JF, 1788)** - The white-bellied sea eagle has a white head, rump and under parts, and dark or slate-grey back and wings. The legs and feet appears yellow or grey, with long black talons (claws). There is no seasonal variation in plumage. These are of an opportunistic carnivore category and consumes a wide variety of animal prey, including carrion.

2.1.3 *Stringiformes*

1. **Barn Owl (*Tyto alba*, Scopoli, 1769)** - The barn owl is a medium-sized, pale-coloured owl with long wings and a short, tail. The shape of the tail is a means of differentiates the barn owl from typical owls when seen in the air. Other distinguishing features are the swirling flight pattern and the dangling feathered legs. The pale face with its heart shape and black eyes give the flying bird a unique appearance.
2. **Spot bellied eagle owl (*Bubo nipalensis*, Hodgson, 1836)** - The owl was a large, pale-yellow bird with light spotting and a pale yellow beak. Its breast was marked with thin 'v' shaped markings. Its primaries, secondaries and tail feathers were dark with heavy barring. The ear tufts were small. Its legs were a creamy yellow. The bird was confirmed as a juvenile Spot-bellied Eagle-owl.

2.1.4 *Gulliformes*

1. **Peacock (*Pavo cristatus*, Linnaeus, 1758)** - This is included in the pheasant family and which appears in a Deep glossy metallic blue with greenish tinge; glossy green tinge on scapulars and tertials; secondaries and greater secondary coverts, glossy blue-black to green-black; primaries and primary coverts, pale buff-brown. Breast, deep glossy metallic blue with greenish tinge; belly, vent, and under tail, brown; under tail-coverts and feathers of thighs, pale buff, speckled brown.
2. **Ring-Necked Pheasant (*Phasianus colchicus*, Linnaeus, 1758)** - The body plumage is barred bright gold or fiery copper-red and chestnut-brown plumage with a dazzling brightness of green and purple, but lower back seems sometimes blue. The wing coverage is white, or cream and black-barred markings are common on the tail. The head is bottle green with a small tuff and distinctive red wattle.

2.2 Flightless Birds

2.2.1 *Struthioniformes*

Ostrich (*Struthio camelus*, Linnaeus, 1758) - Unlike most birds' feathers, ostrich feathers are loose, soft, and smooth. The feathers of the ostrich have hooked aberrantly from other birds which give ostrich a fleecy

look. The lack of a special gland in ostrich disables the ability to waterproof their feathers while preening. Adult male ostriches appear in a black and white plumage; immature ones and adult females have greyish-brown feathers.

2.2.2 *Cassuariformes*

Emu (*Dromaius novaehollandiae,* Latham, 1790) - Individual emu feathers have a loose and simple design. Just like hairs, feathers grow from follicles. Most birds have one feather per follicle, but the emu grows a double-shafted feather from each follicle. Emu's feather barbs are widely spaced and do not have the usual hooks that attach to the other barbs. Instead, each barb hangs loosely and gives emu feathers a hair-like an appearance. Emu feathers are less water-resistant than other bird's feathers. Its tail feathers are not so soft.

2.2.3 *Rheiformes*

Brown Rhea(*Rhea pennata*, d'Orbigny, 1834)– The giant bird in America weighs typically 50 pounds and five feet tall. Its plumage has a brown and grey coloured shade with black and white speckling and posses a prominent black ring around the neck. Males are little bigger as compared to females, and slightly greyer and have a noticeable neck ring. Immature rheas appear in greyish, with black stripes. Rheas cannot fly even though it has long wings. Wings are mainly used as rudders while running. It has stout legs, each of which ends in three toes, as well as keen eyesight and hearing.

White Rhea (*Rhea americana,* Linnaeus, 1758) - These are large flightless birds, but smaller than ostrich appear in white or pure white colour. The adult rhea stands 4-5 feet height and weighs 40-50 pounds. They are omnivorous and can utilize a wide variety of plant and animal foods. Rheas are polygamous-polyandrous that is Rheas do not form lasting pairs, and males incubate the eggs and raise the young.

2.3 Methodology

All the feathers were cleaned in compressed air and those that were to be mounted for SEM twice in warm water and rinsed after each wash in warm water. The feathers were then washed in 70% ethanol and allowed to air dry. The entire image of the feather also includes Light microscopy and was conducted on OLYMPUS Stereomicroscope having 0.6-4.5x magnification. Feathers were divided into three portion- upper, middle pennaceous portion and lower sub pennaceous portion. Images of all the feather under above-mentioned orders were captured using LUXEO 6Z camera system and MICAPS Micro view software producing fully focused images of the three-dimensional specimen by combining a series of images taken at different focal planes termed optical sections, thereby overcoming the problem traditionally associated with the inadequate depth of field.

The parameters such as pattern, barb size, nodes, nature of barbules, pigmentation, nodes, kinking, interlocking pattern of barbules can be observed by microscopic images. The barbules were analysed, and feather comparison was done using stereo microscopic and SEM images. For easier comparison as well as documentation, selected features were divided into different orders. Types of feathers collected for the study include wing contour, body contour, semi-plume and tail plumages from different birds.

A small portion of contour feathers (one from flying and one from the flightless bird) was cut 32 off, each of them representing order, and treated in 70% ethanol. Then mounted for SEM analysis using double-sided adhesive tape and barbules were coated with approximately 70 nm of gold using gold scutter coater. Samples were examined in secondary electron mode at 15KV using a scanning electron microscope. Some of the mentioned parameters are compared based on the data from the stereo image as well as from SEM (Scanning Electron Microscope) images of the selected specimen.

3. RESULTS

3.1 Flying Birds

3.1.1 Order *Psittaciformes*

Eclectus parrot (*Eclectus roratus*, Statius Muller, 1776): Contour wing feather was collected from the Zoological park and analysed feather characteristics features. Both rachis and vanes were black. Calamus looks hollow and Pennaceous barbs were present. The feathers were stiffer and it possesses unequal halves of vanes (Fig. 1: A and B).

Green-Winged Macaw (*Ara chloropterus*,Gray, GR, 1859): Contour primaries and secondaries wing feather type were identified from the zoo. Primaries show the unsymmetrical distribution of barbs on either side of the stiff rachis and comparatively long. The tip was appeared pointed whereas in latter, looks like broad. On the ventral side reddish-brown colouration is seen and on the dorsal side bluish tinge merges with brown colour at the middle to the edge. Calamus was white and hollow. Barbs were compactly arranged (Fig. 1: C and D).

Fig. 1. Feather images of order *Psittaciformes* (A) Winged feathers of *Electus parrot* (B)Stereo image of *Electus parrot* (C) Wing feathers of *Green winged macaw* (D) Stereo image of *Green winged macaw.* B=Barb, R= Rachis, IBS= Interlocking barbules

3.2 Order *Accipitriformes*

Pariah Kite (*Milvus migrans*, Boddaert, 1783): Vane shows alternate bands of dark and white bands on the deep end. Rachis divides into asymmetric barbs on either side. White stiff Calamus merged into the dark at the middle. Primaries were long and tapering and secondaries appeared broad (Fig. 2: A and B).

White Bellied Sea Eagle (*Haliaeetus leucogaster,* Gmelin, JF, 1788): Identified wing feathers were wing contour and semi-plume. Stiff rachis to which asymmetric barbs were arranged. The shaft is whitish in Calamus portion and dark in the rachis. Plumulaceous barbs could be seen at the end of the vane. Vane appeared deeply greyish. Semi plume was entirely white including rachis. Calamus was thin, and the upper portion is pennaceous and lower plumaceous outgrowth (Fig. 2: C and D).

3.3 Order *Stringiformes*

Barn owl (Tyto alba, Scopoli, 1769): Black colour patches can be seen on the vanes present in either side of the rachis. Both wing and body feathers were coloured with golden buff and grey with black. Semiplume feather was white. The basal portion of rachis and calamus appeared white whereas the remaining portion was black. Both calamus and rachis are white. Plumulaceous barbs were seen in both body contour and semiplume feathers (Fig. 3. A and C).

Spot bellied eagle owl (*Bubo nipalensis,* Hodgson, 1836): It had a stiff bending rachis with the striking colour pattern. Alternate dark bands and white patches on the edge of the lower vane. Outer vane was serrated and had thick calamus. It with less degree of interlocking. Fluffy and white thin calamus (Fig. 3. C and D).

3.4 Order *Gulliformes*

Peacock (*Pavo cristatus,* Linnaeus, 1758): Wing primaries occur in brownish-black colour. Rachis was bending to form unsymmetrical barbs on either side. Ventral portion showed greyish colour. Barbs were slightly folded towards the dorsal surface. Secondaries were broad, and calamus was prominent. Semiplume is fluffy with short rachis (Fig. 4. A and B).

Ring-necked pheasant (*Phasianus colchicus,* Linnaeus, 1758): Feathers had long, brownish stiff rachis to which barbs are unsymmetrically arranged. Barbs showed the various degree of pigmentation patterns with dark and white patches. Calamus was strong and tapered. Rachis appeared thin and short. Pennacious upper part also shows varying colouration patterns (Fig 4. C and D).

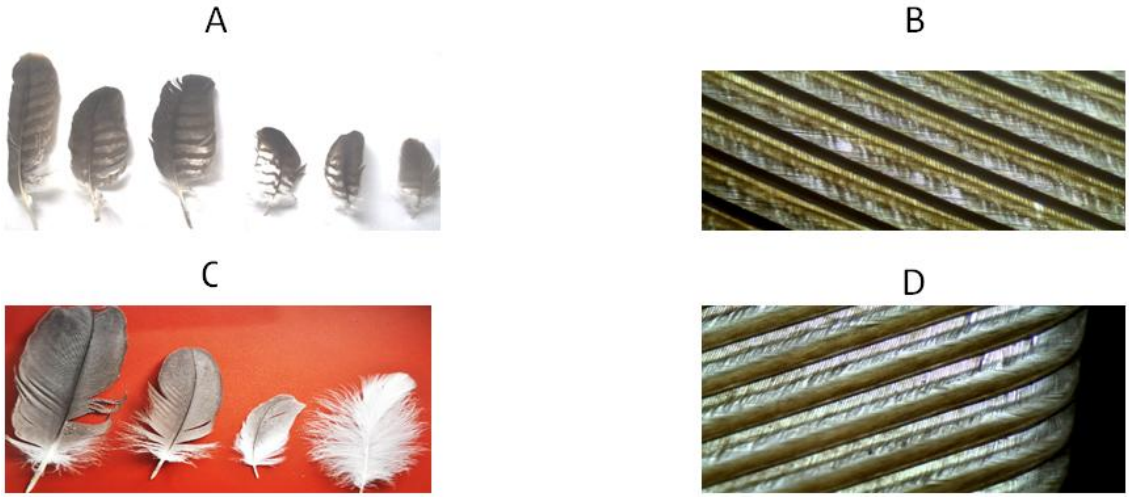

Fig. 2. Feather images of order *Accipitriformes* (A) Winged feathers of *Pariah kite* (B) Stereo image of *Pariah kite* (c) Wing feathers of *White bellied sea eagle* (D) Stereo image of *white bellied sea eagle.* B= Barb, IBS= Interlocking barbules R= Rachis, C=Calamus

Fig. 3. Feather images of order *Stringiformes* (A) Wing feather of *Barn owl* (B) Stereo image of *Barn owl* (C) Wing feather of *spot bellied eagle owl* (D) Stereo Image of *Spot bellied eagle owl*. B= Barb, IBS= Interlocking Barbules

3.5 Flightless

3.5.1 Order *Struthioniformes*

Ostrich (*Struthio camelus*, Linnaeus, 1758): Collected shed feather was body contour. It had long, darkish rachis to which loose, smooth and soft barbs were attached. Barbs are darkly pigmented. It showed Plumaceous outgrowth from pennaceous seems to be having several thin layered. Stiff rachis became fine at the pointed upper end. Calamus cream-like appearance barb spaces were prominent in the upper pennaceous region. Barbules were visible as the outgrowth of barbs (Fig. 5).

3.5.2 Order *Cassuariformes*

Emu (*Dromaius novaehollandiae*, Latham, 1790): The shed feather was also a body contour. Feathers collected are of different length. The unique

characteristic of the Emu is the double rachis. Rachis was slender, thin and long; from which symmetrical barbs arise. It shows a simple display of feather elements. Barbs were also thin with delicate, plumulaceous barbules outgrowth. Calamus looked thin and short with dark pigmentation. Length of the barbs was not uniform. Barbs were pigmented (Fig. 6).

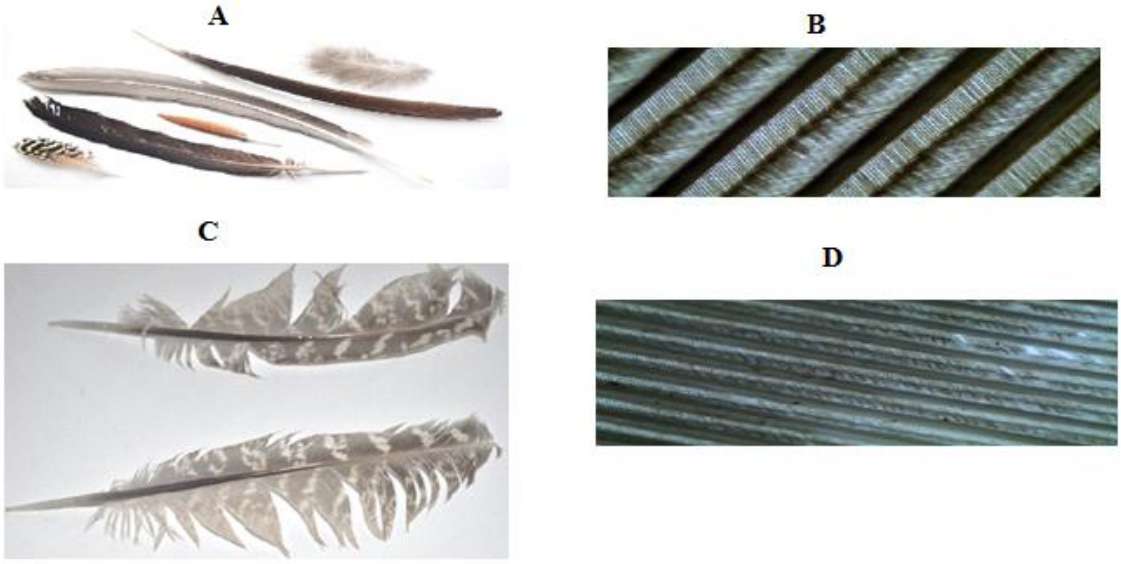

Fig. 4. Feather images of order *Gulliformes* (A) Wing feather of Peacock (B) Stereo image of *Peacock* (C) Wing feather of Ring necked pheasant (D) Stereo image of Ring necked pheasant. B= Barb, R=Rachis, C= Calamus, IBS= Interlocking barbules

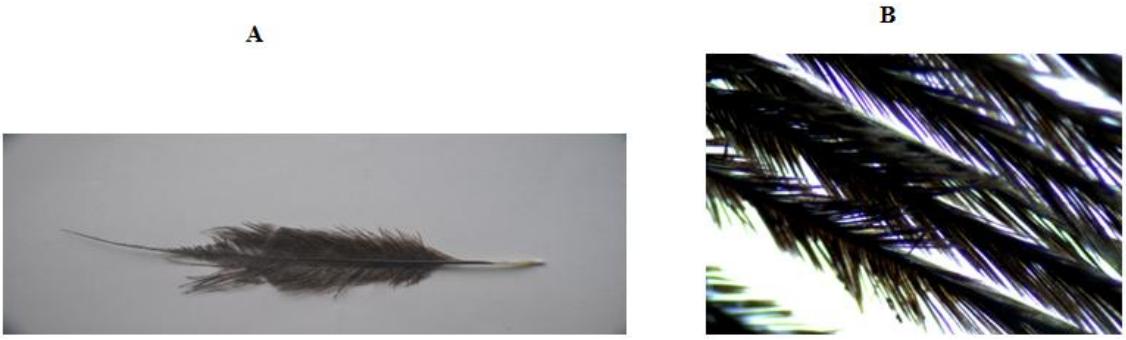

Fig. 5. Feather images of order *Struthioniformes* (A) Wing feather of *Ostrich* (B) Stereo image of *Ostrich*. B = Barb, R= Rachis, IBS= Interlocking barbules

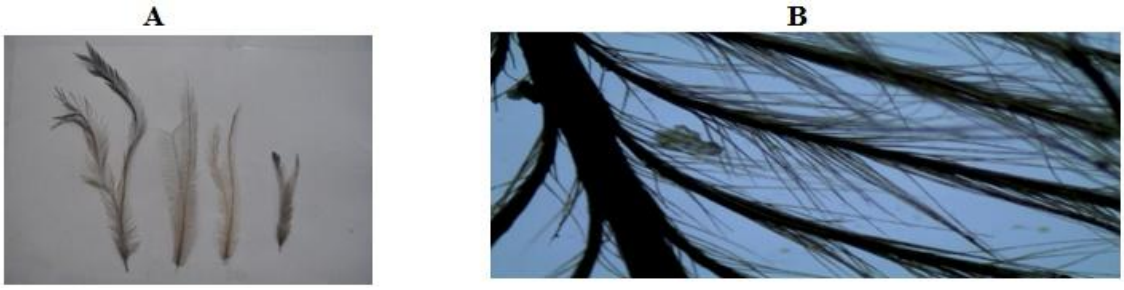

Fig. 6. Feather images of order *Casuariformes* (A) Wing feather of *Emu* (B) Stereo image of *Emu*. B= Barb, C= Calamus, R= Rachis, IBS= Interlocking barbules

Fig. 7. Feather images of order *Rheiformes* (A) Wing feathers of *Brown rhea* (B) Stereo image of *Brown rhea* (C) Wing feather of *White rhea* (D) Stereo image of *White rhea.* B= Barb, R= Rachis, IBS= Interlocking barbules, C= Calamus

3.5.3 Order *Rheiformes*

Brown Rhea (*Rhea pennata*, d'Orbigny, 1834): The feather identified was body contour. Upper half portion is brownish and lower half looked whitish in appearance. It also had a plumulaceous appearance with white calamus. Barbs were soft, loose, long, and bent forming twisted nature. Inter barbule space was visible hence no interlocking at all. Rachis was darkish with symmetrical barbs (Fig. 7A).

White Rhea (Rhea americana, Linnaeus, 1758): The identified feather was body contour. Rachis was long and bending with symmetrical barbs. Both are not pigmented. There has a hollow white Calamus. Plumulaceous barbules make it soft and loose. At the upper tip, barbs were short as in Struthioniformes. Calamus appeared hollow but stiff.

In this study, the comparison has been made based on each type of feather from different birds in a different orders No two orders share all characteristics similar; however, they may share some of the characteristics. Nature of barbules, interlocking pattern, pigmentation, Nature of rachis, nature of calamus etc. are the parameters taken among the study. Length and size of the feather are different in some species. Interlocking is served to waterproofing feather and enhances the insulating capacity. Comparison of wing contour of birds species included in the order of *Psittaciformes* displays different patterns of interlocking and pigmentation. Interlocking is slightly displaced from the centre in the Electus Parrot. These species show a smaller size and bluish tinge pigmentation. Three categories of medullary cells in the rami are known depending on the size of their vacuoles; the smallest of these are responsible for most cases of blue colours in feathers [6]. Green Winged Macaw is having larger wing feathers than Electus parrot. Also interlocking is in a similar pattern as in Electus parrot and Green-winged macaw and Barbs are distributed evenly. Internal ridges of cortex and septa in the middle stiffen the rachis against the dorsoventral movement, yet allow sidewise flexibility. Studies on the internal structure of shaft and barb suggest that cellular arrangement in medulla and cortex constitute taxonomically important character [5]. These configuration are constant within a species, differ from related species and include a basic pattern common to all species of a family.

On the order *Accipitriformes*, pariah kite shows displaced interlocking, and white-bellied sea eagle shows centred interlocking. All are having pigmented barbules and evenly spaced without gaps. Distal barbules of each barb cross over proximal barbules of next higher barb in the vane. Hooklets shaped barbicles of distal barbules grasp the dorsal flanks of proximal barbules. Birds such as Pariah kite and White-bellied sea eagle are having pigmented barbules and evenly spaced without gaps. The feather image of the White-bellied sea eagle shows little pigmentation and tightly centred interlocking barbules. Barn owl in order *Stringiformes* shows mesh-like overlapping interlocking [Table 1]. A set of barbules are converging together with their upper portion either touching the barb or parallel to the barb. But they were compactly arranged. Body contour of

Barn owl comparing with Spot bellied eagle owl (*Stringiformes*) reveals that barn owl shows interlocking of the entire barbules and the spot bellied eagle owl have displaced pattern of interlocking. Barn owl shows thin barbs with delicate barbules. Nodes and kinking were also visible. However, the feather of White-bellied sea eagle shows little pigmentation and tightly centred interlocking barbules. The barbules of Barn owl being little or loosely interlocked and pigmented. Wing contour of *Stringiformes* exhibit differences in barbule length and barb size. Both show tight interlocking without gaps in similar. Barn owl displays short barbules with thick barbs whereas Spot bellied eagle owl shows thin barbs with long barbules. Latter shows lesser pigmentation than former species. Outer vane at the edge of barn owl was smooth and surface regularly serrated for noise reduction. Barb density decreases towards the tip of the feather. Feather of ring-necked pheasant included in the order *Gulliformes* shows thin barbs with spirally and irregularly coiled solenoid barbules. Also seen inter barb space and both of the barbs are not pigmented. In wing feathers of Ring-necked pheasant, short barbules arise from thick barbs is interlocking at the centre and pigmented. Peacock displays similar locking pattern of barbules with Ring-necked pheasant; however, the peacock has thick barbs with very long barbules. Ostrich in order *Struthioniformes* as stiffer barbules and darkly pigmented [Table 1]. The barbules are somewhat smaller and more straightforward than the downy barbules on the primary feather.

In the order Rheiformes body contour of White rhea, is a long, delicate and regular arrangement of barbules. Neither of the flightless birds shows interlocking nor feather divisions like primaries, secondaries and tertiary. They have barbules space as well. Body contour of Brown rhea has thin barbs with long, slender and brownish irregular barbules it also shows no pigmentation. Emu (*draconidae*) has long, delicate and slender barbules as well as double rachis on a calamus. It is greyish too. The texture of after feather whatever its structure is entirely downy except in *Cassuariformes* and Emu; where it is coarse and lax. The barbules are somewhat smaller and more straightforward than the downy barbules on the primary feather. The transition of various parameters in flying and flightless categories helps to understand the potent factor for flight of birds. SEM images supports the detailed interpretation on these parameters.

Scanning Electron Microscope images of a flightless bird White rhea and a flying bird Pariah kite are also carried out during the study. It shows the feather elements in the ultramicroscopic level. Very fine hooklets arise from the barbules are uniform and regularly spaced. The number of hooklets may depend on the length of the barbules [5]. However, in White rhea, it shows barbular outgrowth called prongs on either left or right side at the nodes. Feathers enable thermoregulation as well as an aerodynamic surface for flying birds and are meant for thermoregulation in flightless birds.

4. DISCUSSION

The counter feathers of different birds species display different patterns of interlocking, pigmentation, barbular nature, calamus nature etc. The origin of hooklets permitted the origin of compacted closed and efficient aerodynamic vanes in large asymmetric contour feathers [7]. Length and size of the feather are different in different species. Distal barbules of each barb cross over proximal barbules of next higher barb in the vane. The hooks on the barbules of a feather, that interlock adjacent barbs Known as Barbicels [8]. Barbicels of distal barbules grasp the dorsal flanks of proximal barbules. Other part of barbules aid in making flexible, self-adjusting interlocking mechanism [9]. Considering the order *Stringiformes* the Barn owl and Spot bellied eagle owl indicate a varied interlocking and barbular nature. The distal end of base cells of barbules (Pennulum cells) variously swollen or furnished with tiny prongs. These shapes are often characteristics of order of birds and hence can be used for identifying isolated feathers [10].

Individual birds species have different rachis nature and calamus nature for their different feathers such as semiplumes, wing counter, body counter etc. Rachis of semiplume is longer than the longest barb [4] provide thermal insulation and fill out the contour of the body. Analysis of the structure of barbules and proportion of adult plumages of Ring-necked pheasant (*Phasianus colchicus*) suggest that primitive feather may have been contour feather with relatively large pennacious portion and simple pennacious barbule.

They are the second set of down in Barn owl, semiplumes in Rhea [4] Suggested that all these feathers be classed as mesophiles not just those with downy structure [11]. It also shows no pigmentation. The appearance of after feather whatever its structure is entirely downy except in *Cassuariformes* and Emu; where it is coarse and lax. The barbules are somewhat smaller and more straightforward than the downy barbules on the primary feather. After feather varies in different parts of a bird body, being relatively most enormous on feathers that are wholly or mostly downy and smallest or absent on remiges and retrices [4].

Table 1. Comparison of parameters of wing feather of different species

Order	Name of Birds	Interlocking pattern	Nature of barbules	Pigment	Nature of rachis	Nature of calamus	Nature of barbs
Psittaciformes	***Electuus parrot***	Displaced interlocking	Thin, long and slender	Slightly pigmented	Stiffened and black	Hollow	Evenly spaced
	Green winged macaw	Displaced interlocking	Unsymmetrical barbules	Highly pigmented	Long and stiff rachis	Thin and hollow	Compactly spaced
Accipitriformes	***Pariah kite***	Towards one side of the barb	Wavy and overlapping barbules	Pigmented	Stiff	Stiff	Asymmetrical barbs
	White bellied sea eagle	Centred interlocking	Thin and equally spaced	Pigmented	Stiff	Thin	Asymmetrical barbs
Stringiformes	***Barn owl***	Fully interlocked	Short barbules without gaps	Pigmented	Stiff and bended	Stiff	Thick barbs
	Spot bellied eagle owl	Displaced interlocking	Long and overlapped barbules	Pigmented	Stiff and bended	Thick and fluffy	Thick barbs
Gulliformes	***Peacock***	Centered interlocking	Overlapped barbules	Pigmented	Short	Fine	Long,thick and unsymmetrical
	Ring necked pheasant	Centered interlocking	Overlapped barbules	Darkely pigmented	Long and stiff	Hollow and stiff	Symmetrically attached
Struthioniformes	***Ostrich***	No interlocking	Stifffer barbules	Darkely pigmented	Long and stiff rachis	Stiff and hollow	Asymmetrical and short barbs
Cassuariformes	***Emu***	No interlocking	Long,fine,slended and irregularly spaced barbules	Dark pigmentation	Long,thin,slended and double rachis	Thin and short	Symmetrical and thin barbs
Rheiformes	***White rhea***	No interlocking	Small and delicate barbules	Not pigmented	Long and bended	Hollow and stiff	Asymmetrical and short barbs
	Brown rhea	No interlocking	Long, slender and irregularly overlapped	No pigmentation	Thick	Hollow	Thin,soft, loose, long and bende

The symmetry of vanes with closed pennacious texture, the apparent stiffness of rachis, with deep ventral groove, the obtuse end and short and wide suggests that it represents a remige or rectrice feather [12]. The geometry of the feather barb determines feather vane symmetry and vane rigidity; which are both critical to a feather's aerodynamic performances. The symmetry of vane width of flight feathers is primarily determined by barb length. Variation in barb angle determines vane rigidity [4].

Simplified pennacious and plumaceous barbules that have very reduced barbicels with even less differentiation are known as stylet barbules about their stiffness and slender pointed shape (Hampel, 1931). Stylet barbules are thought to resemble the primitive type of barbule from which both pennaceous and plumaceous evolved. In many birds, the distal portion of respective primaries and retrices are distinctly narrowed (notched, incised or emarginated). When wings are spread, the tip of these feathers consequently do not overlap but are separated by gaps or slots. This reduces the induced drag of the wing and allows the feather tip to twist and act as individual propeller blades [13]. The pennacious barbules are closely adapted to the operation of feathers and vary considerably within a vane. A typical adaptation is friction barbules, which are distal barbules modified by lobate distal barbicels [9]. Fraction barbules occur in those portion of flight feathers that overlap when a wing or a tail is spread. By rubbing against rami of overlapping vanes, they supplement the action of muscles and ligaments in keeping feathers from slipping too far apart. [13]. While remiges and retrices are adapted principally for locomotion, in some birds, they have become modified for display [14]. Or sound production [15].

Studies revealed that melanised feathers resist Feather degrading bacteria (FDB) more than unmelanised feather that supports more bacterial feather (Goldstein et al. 2004) However, unmelanised feather shows sexually selected trait. Melanin not only colour feathers but also make them firms and more resistant to wear and photochemical change. Uropygial glands play a specific role in regulating the abundance of FDB.

Bergmann (1982) provided qualitative evidence that ultraviolet radiation damages feathers, but quantitative evidence for relating exposure to damage is lacking. Thus primarily, feathers provide thermoregulation as well as aerodynamic surface (interlocking) for flying birds and provide only thermoregulation in flightless birds. Interlocking serves to waterproof feathers too. Besides these, habitat affects barb and barbule density oiliness needed for water repellency and resistance to water penetration may influence feather structure. Gliding and soaring flight select for low barb density. In both these cases, limited bending of the feather into the airstream of a flying bird is essential to the function of the feather. Too much bending would create excessive turbulence and reduce aerodynamic efficiency.

However, several characteristics of feathers are ideally suited for flight. Feather keratin is lighter than the keratin that covers the bill and feet. The elliptical shape of the rami allows the barbs to flex only toward the tip of the feather and the thickened dorsal and ventral surfaces of the rachis allow only slight lifting of the feather tip into the airstream above the wing. The slight lift creates a thin layer of turbulence over the wing, which helps hold the laminar flow of air on the wing at slow speeds. Such control of the airflow enables the bird to lower its stalling speed and thereby manoeuvre and land at low, safe speeds.

5. CONCLUSION

Feathers have different striking colour patterns that enable birds to perform various activities. In our study, we have collected feathers from eight flying and four flightless birds and qualitatively compare the morphology within its limits as well as document those feathers with stereo based images and description. The parameters have been compared are nature of barbules, the difference in the interlocking pattern whether wavy, overlapping or slender, the thickness of rachis, the relation of the size of the barb to the length of barbules, pigmentation and nodes/ prongs if any. We also provide feather description by observing characteristics using the naked eye. It may also help identify regional and local birds.

Firstly, we have placed feathers in appropriate orders. Then compare each available feather types with those of other species of the same order or among orders. However, we have two feather types from a species of specific order; that also been compared appropriately In some species, interlocking is precisely at the centre of the adjacent barbs whereas; it is displaced toward barbs in several other species. Some show structural colouration due to reflection and scattering of light but some have actual pigmentation. Length and size of feathers in order is also different. Example**:** Eclectus parrot has smaller feathers than green-winged macaw. It is also noted that the thickness of rachis influences the length of barbules. Some bird species show the inversive or negative effect of thickness of rachis on increasing the length of barbules. However, there are exceptions.

In Emu, it shows double rachis on a calamus whereas Ostrich displays several layers of barbs and

primulaceous barbules tightly joined as well. Body of flightless birds shows several layers of body contour arranged irregularly.

Comparison with flightless birds reveals that interlocking is a must for flying high, giving up air resistance. Barbs are delicate without hooklets that provide thermoregulation. SEM images of flightless and flying reveal ultrastructural unit of feather element barbules. Uniform and regularly arranged hooklets in flying whereas prongs, barbules outgrowth, are seen at the nodes of flightless birds.

ACKNOWLEDGEMENT

We thank Kerala Biotechnology Commission, YIPB Programme, KSCSTE; HRD scheme, Dept. of Health Research-Start up Grant, Govt. of India and the University of Kerala Plan Fund.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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