Iridescent colour production in hairs of blind golden moles (Chrysochloridae)

Holly K. Snyder1, Rafael Maia1, Liliana D’Alba1, Allison J. Shultz2, Karen M. C. Rowe3,4, Kevin C. Rowe3,4 and Matthew D. Shawkey1,.*

1Department of Biology and Integrated Bioscience Program, University of Akron, Akron, OH 44325-3910, USA
2Department of Biology, San Diego State University, San Diego, CA 92182, USA
3Museum of Vertebrate Zoology, University of California, Berkeley, CA 94720, USA
4Sciences Department, Museum Victoria, Melbourne, Victoria 3001, Australia
*Author for correspondence (shawkey@uakron.edu).

Relative to other metazoans, the mammalian integument is thought to be limited in colour. In particular, while iridescence is widespread among birds and arthropods, it has only rarely been reported in mammals. Here, we examine the colour, morphology and optical mechanisms in hairs from four species of golden mole (Mammalia: Chrysochloridae) that are characterized by sheens ranging from purple to green. Microspectrophotometry reveals that this colour is weak and variable. Iridescent hairs are flattened and have highly reduced cuticular scales, providing a broad and smooth surface for light reflection. These scales form multiple layers of light and dark materials of consistent thickness, strikingly similar to those in the elytra of iridescent beetles. Optical modelling suggests that the multi-layers produce colour through thin-film interference, and that the sensitivity of this mechanism to slight changes in layer thickness and number explains colour variability. While coloured integumentary structures are typically thought to evolve as sexual ornaments, the blindness of golden moles suggests that the colour may be an epiphenomenon resulting from evolution via other selective factors, including the ability to move and keep clean in dirt and sand.

Keywords: structural colour; biophotonics; hair
and composed, as in most hairs, of three distinctive layers—moving inward from the outer surface: a darkly stained cuticle, a more lightly stained cortex containing low densities of melanosomes, and an air-filled medulla (figure 1b,c). The cuticle contains discrete, alternating thin layers of dark (electron-dense) and light (electron-lucent) materials (figure 1c). The light layers were several times thicker than the dark layers and the thickness and numbers of layers varied between species (table 1). By contrast, non-iridescent golden mole hairs were uniformly thin, tubular, had large protruding cuticular scales (figure 1d), and did not contain multi-layers (figure 1e).

Reflectance curves of hairs were uniformly low, but considerably variable between and within species (electronic supplementary material, figure S1). The optimization procedure estimated the RI of the dark layer to be between 1.51 and 1.54, and thus a value of 1.53 was used in all models. Both materials were also estimated to have low absorbance, with values between 0.02 and 0.05 for light layers and 0.01 and 0.03 for dark layers. Low extinction coefficients are predicted because multiple oscillating secondary peaks observed in the measured spectra (electronic supplementary material, figure S1) result from light resonating within the interfaces of the layers (i.e. Fabry–Perot interference [1]). We therefore used values of 0.04 and 0.02 for the light and dark layers, respectively. Variation in measured spectral curves (electronic supplementary material, figure S1) complicated comparison (as in [10]), and is consistent with slight variations in the thickness (position of the main peak) or number (position and number of secondary resonating peaks) of layers (table 1). Nonetheless, in all cases, more than half matched reasonably well in shape and peak reflectance with the predicted curves (figure 2).

Table 1. Mean (± 1 s.d.) values of layer thickness from measurements of TEM images of each species.

<table>
<thead>
<tr>
<th>species</th>
<th>MVZ catalogue no.</th>
<th>light layer (nm)</th>
<th>dark layer (nm)</th>
<th>number of layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amblysomus hottentotus</td>
<td>183 373</td>
<td>121.7 (15.3)</td>
<td>27.8 (6.7)</td>
<td>08 (0.7)</td>
</tr>
<tr>
<td>Amblysomus septentrionalis</td>
<td>81 568</td>
<td>237.4 (31.7)</td>
<td>34.3 (8.7)</td>
<td>03 (0.5)</td>
</tr>
<tr>
<td>Chrysochloris asiatica</td>
<td>117 920</td>
<td>108.6 (15.2)</td>
<td>30.7 (2.4)</td>
<td>19 (3.4)</td>
</tr>
<tr>
<td>Eremitalpa granti</td>
<td>117 919</td>
<td>145.8 (21.5)</td>
<td>20.9 (3.9)</td>
<td>06 (1.1)</td>
</tr>
</tbody>
</table>

(figure 1b) and composed, as in most hairs, of three distinctive layers—moving inward from the outer surface: a darkly stained cuticle, a more lightly stained cortex containing low densities of melanosomes, and an air-filled medulla (figure 1b,c). The cuticle contains discrete, alternating thin layers of dark (electron-dense) and light (electron-lucent) materials (figure 1c). The light layers were several times thicker than the dark layers and the thickness and numbers of layers varied between species (table 1). By contrast, non-iridescent golden mole hairs were uniformly thin, tubular, had large protruding cuticular scales (figure 1d) and did not contain multi-layers (figure 1e).
Figure 2. (a) TEM images, (b) best-fitting measured (solid line) and predicted (using optical modelling; dashed line) reflectance curves for hairs of four species of golden moles. The TEM images show dark and light layers in the cuticle of each species.
4. DISCUSSION
To our knowledge, this is the first report of the nanostructural basis of iridescent colours produced in mammal hairs. Several key morphological features contribute to this coloration. First, their flattened paddle-like shape increases the surface area available for reflection. Second, the compressed cuticular scales provide a smooth reflective surface that enhances specular reflectance. Third, the layers of light and dark materials in the cuticle act as multi-layer reflectors that produce reflectance. Finally, the low friction of the scales and hairs may streamline the profile and create a less turbulent flow, thereby easing movement through a highly viscous medium (in this case, dirt and sand). These hypotheses should be tested through future comparative and experimental work. While typically considered as functional in their own right, iridescent colours may also be byproducts of selection on mechanical or other functions.

We thank S. M. Doucet for the use of microspectrophotometer, Museum of Vertebrate Zoology for specimen use, and Tim Caro and three anonymous reviewers for their helpful comments and suggestions. This work was supported by AFOSR grant FA9550-09-1-0139.