生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	反射率造成白粉蝶的白色 (Reflectance Causes White Color)
生物系統 LIVING SYSTEM	白粉蝶 (Cabbage white butterfly)
功能類別 FUNCTIONS	#傳遞在可見光譜上的光訊號 #調整光/顏色 #Send Light Signals in the Visible Spectrum #Modify Light/Color
作用機制標題	由於縱向的脊線和佈滿卵珠的交叉肋骨使白粉蝶的翅膀為白色 (The wings of the cabbage butterfly are white due to longitudinal ridges and cross-ribs studded with ovoid beads.)
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	  https://asknature.org/strategy/reflectance-causes-white-color/

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)
白粉蝶提供了一個關於翅膀著色生物學有趣的例子，這種蝴蝶的兩種性別，除了在翅膀鱗片上和有黑色素的小區域的黑色斑點有些許不同外，對於人類而言相當單調。白色的產生是由於翅膀鱗片中強烈散射光線的結構所致。其反射率只有在 450 奈米以上時才會很高，在 400 奈米以下時則很小，原因是因為雄性的白粉蝶含有大量吸收紫外光的黃色素。 “The small white, P. [Pieris] rapae, offers an interesting example of the biology of wing coloration. Both sexes of this butterfly species are rather featureless for human eyes, except for slight differences in the black spots, small wing areas where the wing scales contain melanin. The white color is caused by strongly scattering structures in the wing scales (Stavenga et al., 2004). The reflectance is only high above 450 nm, but it is minor below 400 nm, because the scales of male P. rapae crucivora contain a substantial amount of UV-absorbing pteridins.” (Stavenga and Arikawa 2006:314)

文獻引用 (REFERENCES)
夜間飛蛾的色彩通常相當不明顯，當有明顯的色彩圖案時，它們往往是具有破壞性的，這樣可以使飛蛾在視覺上躲避掠食者。然而，許多黃昏活動的飛蛾，尤其是白天活動的飛蛾和蝴蝶，以它們鮮豔的色彩而聞名。翅膀色彩的演化，無論是用於展示還是偽裝，都可能已經影響了視覺色彩辨識的演化，這取決於動物的行為和其棲息地。 這為蝴蝶創造了獨特的色彩，因為它們有能力檢測紫外光。雌性十字花的白粉蝶翅膀幾乎不含有吸收色素，因此它們對蝴蝶的視覺來說是白色的。正如上文所述，十字花的雄性和雌性的眼睛在短波長受體方面有所不同。這種差異是由雄性眼睛中的一種吸收紫羅蘭色素引起的，可以通過其螢光在體內觀察到。短波長受體可能參與藍色和（超）紫外波長範圍的顏色辨識，因為雄性專門在陰涼處尋找雌性，在那裡紫外對比最強烈。 歐洲亞種十字花的雌雄異色現象不像日本小白蝶那樣明顯。小白蝶的雌雄異色現象似乎在全球各地逐漸變化，但推動這種全球梯度的進化力量需要進一步研究。 性異色是硫蝶的一個常見特徵，它與白蝶一起構成了粉蝶科。硫蝶具有顯著的黃色或橙色色彩，因為吸收紫外光和藍光的葉酸抑制了短波長範圍的散射。然而，大多數硫蝶物種雄性的翅膀在紫外光下並不是黑色的，這是因為上側的鱗片高度折疊，形成了多層結構，在紫外光下強烈反射。紫外線的彩虹光澤結合了黃色/橙色的散射，至少在蝴蝶看來，形成了一種紫色。人們在珂粉蝶雄蝶的尖端也觀察到了紫色，那裡藍色的彩虹光澤與紅色的散射相結合。後者是由於存在一種色素，在除了紅色以外的所有波長吸收。 粉蝶亞科和黃粉蝶亞科的色彩方法和性異色現象完全相反。至少是雄性的白粉蝶的翅膀反射紫外光的能力通常很低，在 450 納米以上的波長上反射能力較高。硫蝶雄性的翅膀在紫外光中反射能力很高，在藍光中很低，在黃光中（550 納米以上）反射能力較高。許多 Colotis 物種的雄性似乎採用了兩種策略的混合。背翅的尖端與黃粉蝶亞科相似，即短波長的彩虹光澤結合了較長波長的散射。背翅的其餘部分則更像是白粉蝶的翅膀，即紫外光下的低反射率結合了 450 納米以上的高散射率。由於黃粉蝶亞科是粉蝶亞科的祖先，可以推測 Colotis 群體在硫蝶和白粉蝶進化過程中形成了一個中間階段。 感光細胞的光譜特性很可能與翅膀的著色共同演化。至少，目前的證據雖然有限，但對許多昆蟲物種的研究支持這樣一種觀點，即感光細胞的光譜敏感性被調整到了同種個體的體色。然而，即使未來的研究僅顯示出白粉蝶和硫蝶的視網膜感光細胞之間存在微小差異，

也可以預期，處理光譜信息的視神經節的神經系統已經演化成這樣一種形式，即通過色彩來區分同種個體的能力被最佳化。

The coloration of nocturnal moths is generally rather inconspicuous, and when there are clear color patterns they tend to be disruptive, so that they serve to camouflage the moths from predators. Many crepuscular moths and especially the diurnal moths and butterflies are famous for their bright colors, however. The evolution of wing colors, for display and/or camouflage, will presumably have influenced the evolution of visual color discrimination, depending on the animal's behavior and its habitat.

This creates a distinct coloration for the butterflies, because of their capacity to detect UV light. The wings of female P. rapae crucivora hardly contain absorbing pigment, so that they are whitish, even for butterfly vision. As was described above, the eyes of male and female P. rapae crucivora differ in the short-wavelength receptors . The difference is caused by a violet-absorbing pigment in the eyes of the males, which can be observed in vivo via its fluorescence. Presumably the short-wavelength receptors are involved in color discrimination in the blue and (ultra)violet wavelength ranges, as the males search for females specifically in the shade where UV contrast is strongest.

The European subspecies P. rapae rapae does not feature the distinct sexual dichroism of the Japanese small white . The sexual dichroism of the small white appears to change gradually along the globe, but the evolutionary forces that have driven this global gradient need further study.

Sexual dichroism is a common feature of the sulphurs , the subfamily that together with the whites constitutes the Pieridae. The sulphurs have a dominant yellow or orange coloration, because ultraviolet- and blue-absorbing pteridins suppress the scattering in the short-wavelength range. The wings of the males of most sulphur species are not black in the ultraviolet, however, because the scales at the upper side are highly folded, thus forming multilayers that strongly reflect in the ultraviolet . The UV iridescence combined with the yellow/orange scattering creates a purplish color, at least as seen by the butterflies. A purple color is indeed also observed by humans in the tips of the male Colotis regina, where a blue iridescence is combined with red scattering. The latter results from the presence of a pigment that absorbs at all wavelengths except in the red.

The coloration methods and sexual dichroism of the Pierinae and Coliadinae are quite opposite. The wing reflectance of the whites, at least the males, is generally low in the UV and high at wavelengths above 450 nm. The wing reflectance of the male sulphurs is high in the UV, low in the blue and high in the yellow (above 550 nm). A mixture of both strategies appears to be employed by males of many Colotis species . The tips of the dorsal wings are like that of Coliadinae, that is, a short-wavelength iridescence is combined with scattering at longer wavelengths. The remaining parts of the dorsal wings are rather like the wings of the whites, that is a low reflectance in the UV is combined with a high scattering above 450 nm. Because the Coliadinae are ancestral to the Pierinae , it may be speculated that the Colotis group forms an intermediate stage in the evolution of the sulphurs and the whites.

The spectral properties of the photoreceptors have presumably co-evolved with the wing coloration . At least, the present evidence, although scanty, gained for a number of insect species favors the view that the spectral sensitivity of the photoreceptors is tuned to the body coloration

of the conspecifics. Nevertheless, even if future research will reveal only minor differences between the retinal photoreceptors of the whites and sulphurs, it may be expected that the neural systems of the optical ganglia that process spectral information have evolved in such a way that the discrimination of conspecifics by their colors is optimized.
參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**
Stavenga, D. G., & Arikawa, K. (2006). Evolution of color and vision of butterflies. Arthropod Structure & Development, 35(4), 307-318. (https://doi.org/10.1016/j.asd.2006.08.011)
延伸閱讀: Harvard 或 APA 格式（取自 AskNature 原文；若為翻譯者補充，請註明）
生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
https://asknature.org/?s=&p=0&hFR%5Bpost_type_label%5D%5B0%5D=Biological%20Strategies&hFR%5Btaxonomies_hierarchical.system.lvl0%5D%5B0%5D=Animals%20%3E%20Arthropods%20%28Insects%2C%20Spiders%2C%20Crustaceans%29%20%3E%20Insects%20%3E%20Butterflies%20and%20moths%20%3E%20Cabbage%20white%20butterfly
撰寫/翻譯/編修者與日期
戴霖翻譯 (2024/03/22)；陳柏宇編修 (2024/11/30)
AskNature 原文連結
https://asknature.org/strategy/reflectance-causes-white-color/

更多補充的圖片 (1. 確認版權、註明出處 2. 品質: 盡量 72dpi 或 300K)