Wax Blooms Prevent Sunstroke in Black Namib Desert Beetles

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Reversible colours brought about by wax blooms are not normally found in Arthropods. However, many beetles in the Namib desert are covered with reversible pastel wax blooms. These desert beetles are day active, and moreover, substrate dependent as they cannot fly. Do the wax blooms confer a means of off-loading radiant energy thus allowing beetles access to otherwise hostile conditions? We assessed the colour qualities and reflectance properties of these various wax blooms. This was carried out over the visible spectrum which covers some 50% of solar radiation. All the wax bloom colours found on beetles were of low purity and saturation. These colour properties contributed to the flat reflectance curve obtained over a wide range of wavelengths comprising the visible spectrum. Up to one half of the visible sunlight can be reflected by the beetles wearing a wax bloom. This probably accounts for their ability to be active on the sand surface during times of the day which would be deleterious for their black counterparts.

Colours and reflective properties of desert Arthropods has been the subject of much controversy. If highly reflective, the surface of desert Arthropods is thought to be of little thermal value due to the amount of radiant energy in the environment. Also the paradox of so many species living in deserts being black has led people to believe that black coloration must not add significantly to their heat load.[1] The small size and surface to volume ratios of Arthropods would further prevent protection by surface color. However, evidence is accumulating which indicates that surface colours and their reflective properties are important in the thermal strategy of desert Arthropods.[2-5]

Reflectance measured in the field for a number of insect species indicates that increased reflectance of the surface correlates with habitats having increased irradiance levels[6]. Therefore, might the colour and the reflective properties of wax blooms of Namib desert beetles enhance their diurnal activity? In the Namib Desert, Namibia, there are a number of Tenebrionid beetles which have a black cuticle covered with a wax bloom. Wax blooms on the Namib desert species are either localized or widespread over the surface of the beetle. The ventral surface is always white while the dorsal surface is coloured. These wax blooms are yellow, white, red or pink. The number of beetle species having a wax bloom increases from the cool coastal fog desert (few) to the hot dry inland desert (many)[7]. We collected tenebrionid beetles belonging to the tribes Adesmiini and Zophosini throughout the central Namib desert and transported them to CSIR in Pretoria, South Africa where colour and reflective properties were measured in the visible region of the spectrum (380 nm to 750 nm). The apparatus used to measure reflectance of the surface colours was modified from equipment originally designed to measure colorimetric properties of small diamonds[8]. The trichromatic components, X, Y, Z, derived from the spectral measurements, which define a colour, were plotted on a

C.I.E. (Comm. Int. de l' Eclairage) 2° Chromaticity diagram (Photo Research, Burbank, California). The purity and dominant wavelength for each coloured wax bloom was obtained from this diagram. In addition, the total spectral power which could be reflected by the beetle's integument in sunlight was calculated for the visible wavelength region. The solar radiation of these wavelengths represents about 50% of the total solar radiation which reaches the earth. For these calculations the spectral irradiance values of total daylight as measured in Pretoria, South Africa were used[9].

The wax bloom colours were all unsaturated (Table 1). This is advantageous for these substrate dependent diurnal beetles. If the colours of the wax blooms were saturated there would be a reduction in light reflection over a wide spectral region[10]. The light reflection over a wide spectral range is also advantageous in reducing heat gain from sunlight for these diurnal beetles. Indeed, if the wax bloom was removed from Zophosis testudinaria (pink) and the cuticle temperature monitored under desert conditions, the black surface soon reached a lethal level of 44°C, but never rose above 38°C in bloomed individuals (unpublished data). The wax blooms enhance the effect of behavioural thermoregulation as the cuticle surface slowly accumulates solar energy while beetles are out on the surface shuttling between small grass clumps across open patches of sand.Cuticle colours of much higher saturation (narrow reflectance) as in the metallic colours of tiger beetles proved ineffective in reducing heat gain from solar radiation[11].

In all species of diurnal tenebrionid beetles examined the wax bloom increased the reflectance of the cuticle surface. Furthermore a fairly flat reflectance curve throughout the visible spectrum was obtained. *Zophosis mniszechi* with and without the pink wax bloom is seen in Figure 1 a,b. The spectral daylight reflected power of the wax bloom of the same beetle is seen in Figure 2 a,b. The total amount of daylight which can be reflected by the surface wax of *Z. mniszechi* represents over one half of the radiation in the visible spectrum (Table 2). Species with a whitish or bluish wax bloom appeared to reflect only about half this amount. This was partially due to the fragile nature of the waxy material which abrades easily. If field measurements could be done on these beetles without handling them the total amount of solar energy reflected in would be greater.

The waxy material found on beetles has a very rapid rate of renewal. Under field conditions of the Namib, wax blooms can be renewed in 4 to 8 hours. This is much more rapid than the 7 to 10 days required for renewal of the wax bloom for a Sonoran desert beetle, *Cryptoglossa verrucosa*[12]. Certainly this rapid rate of renewal is a unique adaptation for life in the Namib, where humidity is low and sand surface temperatures are often above 70°C. *Onymacris plana*, a Namib beetle extending across the entire climatic gradient is an indicator of this aridity, where along the coast in the cool fog desert it has little or no wax bloom but is completely covered with it in the hot inland portion of the desert[13] . Another Namib species Cauricara phalangium is a seasonal beetle which emerges with a white bloom. Water loss rates measured on field collected beetles after emergence were much less than those measured at the end of the season when the glands responsible for the wax bloom secretion were inoperative[14]. Field reflectivity measurements of this beetle confirmed the increased reflectance of the white wax bloom[15]. For all these Namib beetles the wax blooms play a role in water balance by lowering the transpiration rate and in their thermal balance by retarding the rate at which radiant energy is accumulated. For example, two species, Zophosis meniszechi (pink) and Zophosis moralesi (black) which are found in the same Namib desert habitat were observed for several days to determine their activity rhythms. It was found that the beetles which produced the wax bloom over the black cuticle were surface active for longer periods of time than the black species which produces no surface bloom (unpublished data). These beetles stayed out longer in the heat of the day and reemerged earlier in the afternoon when air temperatures still exceeded 40°C and sand surface temperatures were 68°C. In addition these wax blooms also act as camouflage as the same species living in very different habitats will have a wax bloom matching the colour of each of the substrates[16].

The advantage therefore, that the wax blooms confer, enables beetles to stay on the surface for longer periods of time for foraging and mating while being protected against high radiant energy.

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FIGURE LEGENDS

Figure 1. Reflectance of the dorsal surface of *Zophosis mniszechi* with the pink wax bloom (a) and without (b). The spectrophotometric measurements were made in the visible region of the spectrum between 38Ø nm and 75Ø nm in steps of 1Ønm. Sixty readings were taken at each wavelength and averaged by computer in order to set high measurement precision. A quartz halogen projector lamp with compact filament was used as a light source. It was placed inside a cylindical housing in order to reduce unwanted stray light. One condensor lens focused the image of the lamp filament on a small aperture of an iris diaphragm of which the size could be varied. The second condensor lens focused the image of the diaphragm aperture at an 8 mm diameter aperture at the front and back of the 1ØØ mm intergrating sphere, whose inside was painted with high reflecting barium sulphate paint. The dorsal surface of the beetle was mounted onto the back of the hole in the intergrating sphere and adfixed with matt black tape. Integrated light from the sphere passed through a third aperture into a 1ØØ mm focal length double monochromator which had a photomultiplier tube as detector, powered by a stabilized high voltage supply. The signal from the photomultiplier was amplified by an operational amplifier, measured by a digital voltmeter and recorded by a desk top computer (HP 86B). The computer also controlled the stepmotor which selected the appropriate wavelength on the exit

of the monochromotor. Since glass lenses were used it was not possible to extend measurements to shorter wavelengths as the lenses absorbed most of the ultraviolet radiation. Care was taken in handling the beetles as the wax bloom was easily abraded.

Figure 2. The spectral daylight reflected powers ($mW/m^2/nm$) for Zophosis mniszechi with the pink bloom (a) and without (b). For these calculations the spectral irradiance values of the total daylight as measured in Pretoria, South Africa were used[9].

Table 1. Colour characteristics of wax blooms of selected Namib Desert Beetles. The field collected beetles were killed in ethyl acetate. They were mounted onto the back of the integrating sphere, exposing a 2 mm surface area centered in the light beam. Care was taken not to abrade off the wax bloom by handling the insects with forceps. From the spectral reflectance measurements the trichromate components X, Y, Z which define a colour were plotted on a C.I.E. 2° Chromaticity diagram in order to obtain the purity and dominant wavelength of each coloured wax bloom.

Table 2. Total amount of solar energy reflected by Namib Desert Beetles with and without the surface wax.

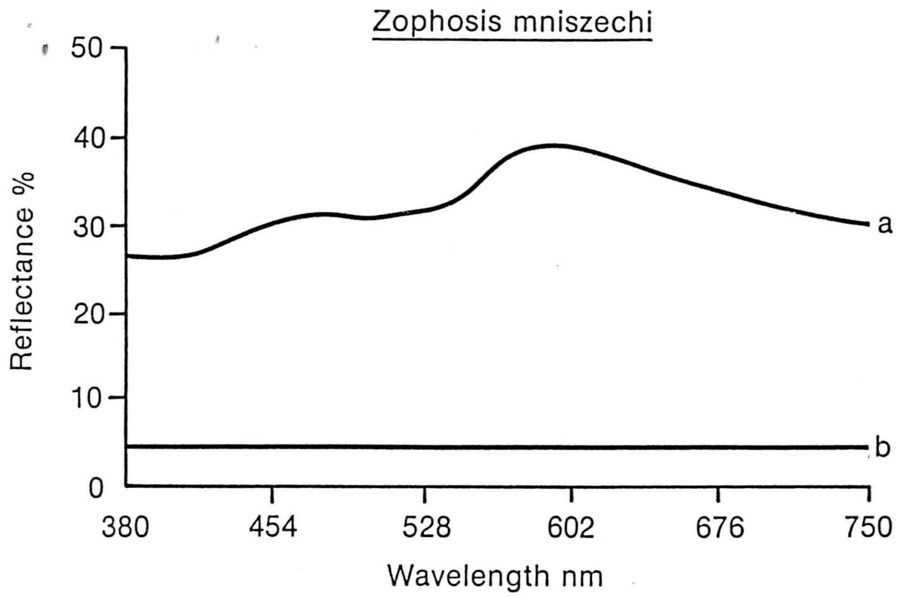
Table 1. Colour characteristics of wax blooms of selected Namib Desert Beetles

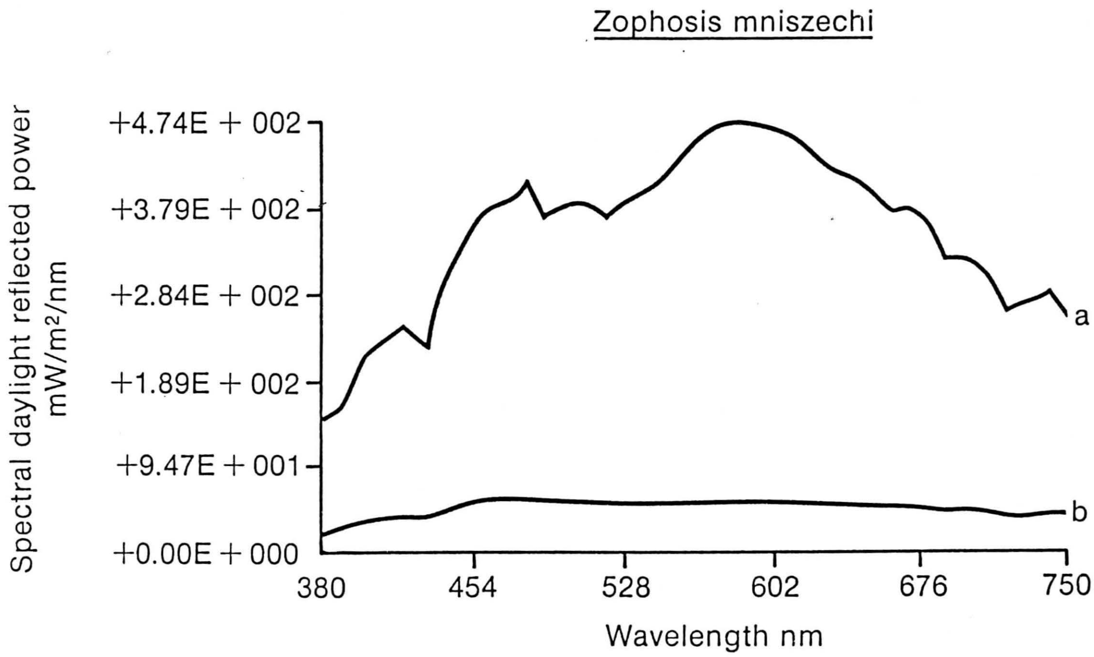
Name	Field perceived colour	Trichromatic components X	Trichromatic components Y	Dominant wavelength	Purity	Colour from C.I.E. 2° diagram
Onymacris plana	Bluish-white	.312	.328	489	0.08	Blue-green
Onymacris rugatipennis albotessallata	White	.352	.358	573	0.12	Green-yellow
Epiphysa arenicola	Blue	.324	.345	506	0.03	Black
Zophosis orbicularis	Blue	.317	.335	494	0.05	Black
Zophosis mniszechi	Pink	.372	.373	578	0.22	Yellow-orange
Zophosis testudinaria	Pink	.397	.372	585	0.30	Yellow-orange
Zophosis omnigena	Red	.402	.369	587	0.31	Yellow-orange
Zophosis fairmairei	Yellow	.395	.413	573	0.42	Yellow

Table 2. Total amount of solar energy reflected by Namib Desert Beetles with and without the surface wax*

Name	mW/cm^2 no bloom	% daylight reflected	mW/cm^2 with bloom	% daylight reflected
Onymacris plana	1.5	3.0	5.7	11.4
Zophosis fairmairei	4.1	8.2	10.0	20.0
Zophosis testudinaria	1.8	3.6	10.4	20.8
Zophosis mniszechi	1.8	3.6	13.2	26.4
Onymacris rugatipennis albotessallata	2.0	4.0	5.9	11.4

*These figures were calculated from total daylight radiation of Pretoria, South Africa between 380nm and 370nm. This was found to be $40mW/cm^2$ and is about 50% of the total radiation.


Zophosis mniszechi
Reflectance %
50
40
30
20
10
0
380
454
528
602
676
750
Wavelength nm
a
b


Zophosis mniszechi
Spectral daylight reflected power mW/m²/nm
+4.74E + 002
+3.79E + 002
+2.84E + 002
+1.89E + 002
+9.47E + 001
+0.00E + 000
380
454
528
602
676
750
Wavelength nm
a
b