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Research Article

THE THERMOREGULATORY ADVANTAGES OF HEAT STORAGE AND MIMICRY BEHAVIOUR OF KATYDIDS IN THAR DESERT

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ABSTRACT
Desert katydid (family Tettigoniidae) like *Microcentrum rhombifolium* is able to survive the harsh hot climate because of the specialized anatomical, physiological and behavioural adaptations such as coloration and mimicry. Heat transfer theory predicts that metabolic heat loss in this species mostly depend on the ability to radiate heat. To examine this, thermal imaging of desert katydids was reported at (27°51'5.80" N & 75°16'25.82" E) Seth G B Podar College, Nawalgarh. During different climatic conditions, most of the outer surfaces of the body were warmer than the surrounding high temperature zone. In such conditions, the wings were camouflaged as leaf like structures with vein and sub-vein surface. However, owing to the thermal conductivity of insect surface any heat transfer to the skin surface will be negligible. Future thermal imaging studies are likely to add to the knowledge of adaptations of this species in the harsh climate of desert.

Keywords: *Heat Sensitivity, Katydids, Coloration & Mimicry*

INTRODUCTION
Some predators identify prey by a relative difference in temperature of prey and its environment. Leaf feeding insects are green and have extremely flattened, leafy wings, and legs; they are usually about 5-6 cm long. Their wings often have venation similar to that of the leaves on which they live. The eggs of leaf insects are found scattered on the ground and hatch in the spring. The young resembles the adults except for their smaller size and reddish color; shortly after they begin feeding on leaves they turn green. The walking sticks of tropical and temperate climates are members of the same order. Leaf insects belong to the phylum Arthropoda, class Insecta, order Orthoptera, suborder Ensifera, super-family *Tettigonioidea*, and family *Tettigoniidea*. Insects in the family Tettigoniidae are commonly know katydids or bush crickets. Part of the suborder *Ensifera, Tettigoniidae* is the only family in the super-family Tettigonioidea. These are primarily nocturnal in habit, with strident mating calls, many katydids' exhibit mimicry and camouflage, commonly with shapes and colors similar to leaves in feeding and protecting time. The diet of *tettigoniids* includes leaves, flowers and seeds, but many species are exclusively predatory, feeding on other insects, snails, or even small vertebrates such as snakes and lizards. Some are also considered pests by commercial crop growers and are sprayed to limit growth, but population densities are usually low, so a large economic impact is rare.

Defense mechanisms of *tettigoniids* include going to rest during the day time; they go into a diurnal roosting posture to maximize their cryptic qualities. This position fools predators into thinking that either the katydid is dead or just a leaf on the plant. By flicking their wings open when disturbed they use the coloration to fool predators into thinking as if the spots are eyes. This in combination with their coloration, mimicking leaves which allows them to blend in with their surroundings. This also makes predators unsure about distinguishing front and back side of the insect (Castner and David, 2004).

Due to the exothermic nature of insects, metabolic rate is extremely dependent upon environmental temperature. Optimal growth and development of insects falls within a fairly broad range of temperatures. For example, for codling moth (*Cydia pomonella*) the range is between 10 and 30°C (Rock and Shaffer, 1983). Acute changes in temperature, as experienced in post harvest quarantine treatments, can elicit a range of metabolic responses. Some insects may increase anaerobic metabolism, as in non feeding larvae of *Cochliomyia macellaria*, which results in an increase in polyols and polyphosphates (Meyer, 1978). One of the most important effects of temperature change is on enzymes. Changes in temperature may affect the binding of a substrate to the enzyme, causing a shift in the Michaelis constant Km, thereby effecting immediate metabolic compensation (Hochachka and Sommero, 1984). Elevated temperatures may also influence the rate of enzymatically catalyzed reactions by determining the proportion of molecules in a given population that possess sufficient energy (energy of activation, Ea; enthalpy of activation, DH) to react and form an activated complex. The temperature dependence of the barrier free energy of activation is proposed as a possible molecular basis for spontaneous temperature compensation observed by Hoffman, (1984).

Diapause is not restricted to insects from temperate and Polar Regions and it's not always limited to the winter season. Diapause is well documented in the summer in temperate zones. In these situations diapauses occur in the apparent absence of cold hardening (Figure 1.). In many insects, the ability to enter diapause has contributed greatly to their evolutionary success. Through diapause, insects are able to survive adverse climatic conditions (Chippendale, 1982). Diapause as a process is divided into four eco-physiological phases: pre-diapause, diapause, post-diapause quiescence, and post-diapause development (Koštál, 2006). Insect diapause is centrally mediated at specific developmental stages, either in response to key stimuli from the environment (facultative diapause) or as a fixed component of ontogeny (obligatory diapause) (Denlinger, 2002; Koštál *et al.*, 2008).

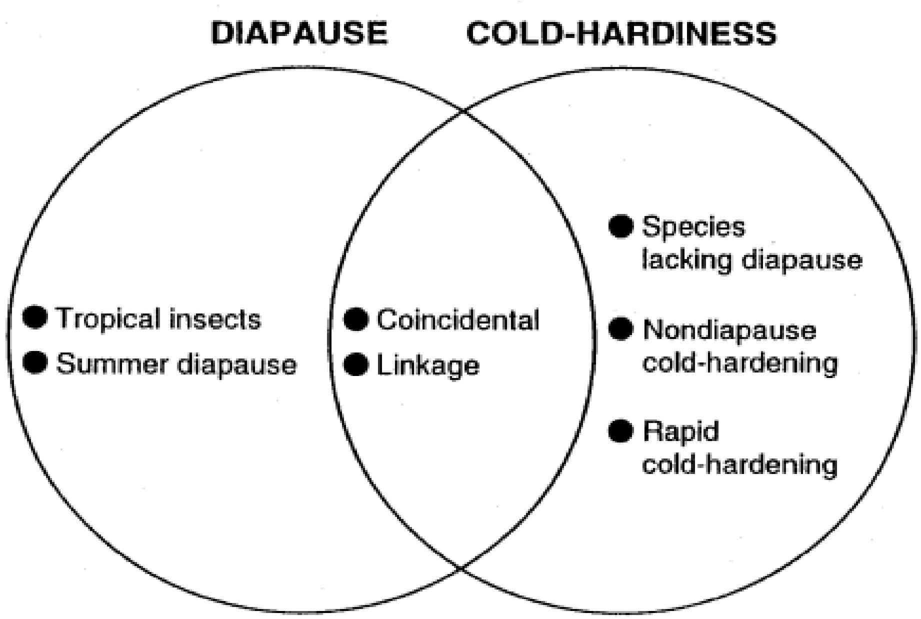

Figure 1: Diapauses and Cold Hardening

Defense in Insects

According to Gillott (1995) insects have a wide variety of predators, including birds, reptiles, amphibians, mammals, carnivorous plants, and other arthropods. The great majority (80–99.99%) of individuals born do not survive to reproductive age, with perhaps 50% of this mortality rate attributed to predation. In order to deal with this ongoing escapist battle, insects have evolved a wide range of defense mechanisms. The only restraint on these adaptations is that their cost, in terms of time and energy, does not exceed the benefit that they provide to the organism in question. The further that a feature tips the balance towards beneficial, the more likely that selection will act upon the trait, passing it down to further generations. The opposite also holds true; defenses that are too costly will have a slim to zero chance of being passed down.

Examples of defenses those have withstood the test of time include hiding, escaping by flight or running, firmly holding ground to fight, producing chemicals and strong social bonds. All these help prevent predation.

One of the best known modern examples of the role that evolution has played in insect defenses is the link between melanism and the peppered moth (*Biston betularia*). Peppered moth evolution over the past two centuries in England has taken place, with darker morphs becoming more prevalent over lighter morphs so as to reduce the risk of predation (Gullan and Cranston, 2005).

MATERIALS AND METHODS

Insects are known to live in a wide range of thermal climates, but there is very little variability in the maximum temperature (40–50°C) which they can survive (Heinrich, 1981). Post harvest heat treatments to disinfest fresh and stored products have been used for more than 60 years (Jones, 1940). The successful application of these treatments relies on a delicate balance between commodity tolerance and insect intolerance.

In desert ecosystem, during extreme summer between March and June, a highest diurnal temperature change is seen. Observations were recorded on March 11, 2016 from Nawalgarh, Jhunjhunu, Rajasthan (27° 51' 5.80" N & 75° 16' 25.82" E) in Seth G B Podar College, Nawalgarh. For collection and comparison of body part temperature FLIR C2 compact Thermal Imaging System was used.

The FLIR C2 is pocket-sized thermal camera designed for hidden heat patterns of the body signal energy waste and structural defects. The C2's must-have features including MSX® real time image enhancement, high sensitivity with fully radiometric imagery. The mechanism of temperature perception is not known and there is no indication of an "intermediate substance" being involved between the sensory receptor cell and the heat waves.

Anatomically the thermal sense organs have simple sensory cells and are usually localized by observation of the reactions of insects to temperature and the way their behaviour modifies on amputation of various parts of insect body.

Calculation of Heat Radiation

Thermal radiation is energy transfer by the emission of electromagnetic waves which carry energy away from the emitting object. During ordinary temperatures (less than red hot"), the radiation is in the infrared region of the electromagnetic spectrum. Formula was used for calculation of heat radiation by excretory thermal value of katydids. The relationship governing the net radiation from hot objects is shown by Stefan-Boltzmann equation:

$$P = e\sigma A(T^4 - T_C^4)$$

P= net radiated power, A=radiating area, σ= Stefan's constant (5.6703×10^{-8} watt/M^2K^4)
e= emissivity, T= Temperature of radiator, T_c= Temperature of surrounding
(*Source*: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/stefan.html#c2)

RESULTS AND DISCUSSION

Result

Thermal data were observed from different body parts including head, thorax and abdomen with helping FLIR C2 software with pointer. During day time external (Leaf) and body surface temperature difference was 4.4^0F observed (*Ar1*). Head, Thorax, Abdomen, Appendage end were important sites of heat exchange, as their radiative heat flux density were 9.80 W m^{-2} from head, 13.03 W m^{-2} to 14.65 W m^{-2} from eyes, 13.09 W m^{-2} to 17.90 W m^{-2} from thorax, 17.20 W m^{-2} from abdomen and lesser 5.67 W m^{-2} from appendage (Table 1).

Table 1: Thermal Data and Net Radiated Power of Different Body Parts of *M. rhombifolium*

S. No	Body Part Parameters	Aberration		Temp (⁰F)	Temp (⁰C)	Net Radiated Power (watt/$m^2k^4X10^{-4}$)
1.	Head	Sp 2		78.2	25.66	09.80
2.	Right eye	Sp 6		79.7	26.50	14.65
3.	Left eye	Sp 3		79.2	26.22	13.03
4.	Right thorax	Sp 1		80.7	27.06	17.91
5.	Left thorax	Sp 7		79.4	26.23	13.09
6.	Thorax appendage	Sp 4		76.9	24.94	05.67
7.	Abdomen end	Sp 5		80.5	26.94	17.20
8.	Abdomen (Insect Body)	**Ar1**	**Max**	**80.5**	**26.95**	13.05
9.	Leaf (External)		**Min**	**75.1**	**23.94**	Nil
			Average	**78.1**	**25.61**	09.51

* Emissivity 0.95 and Refl. temp. 68 °F

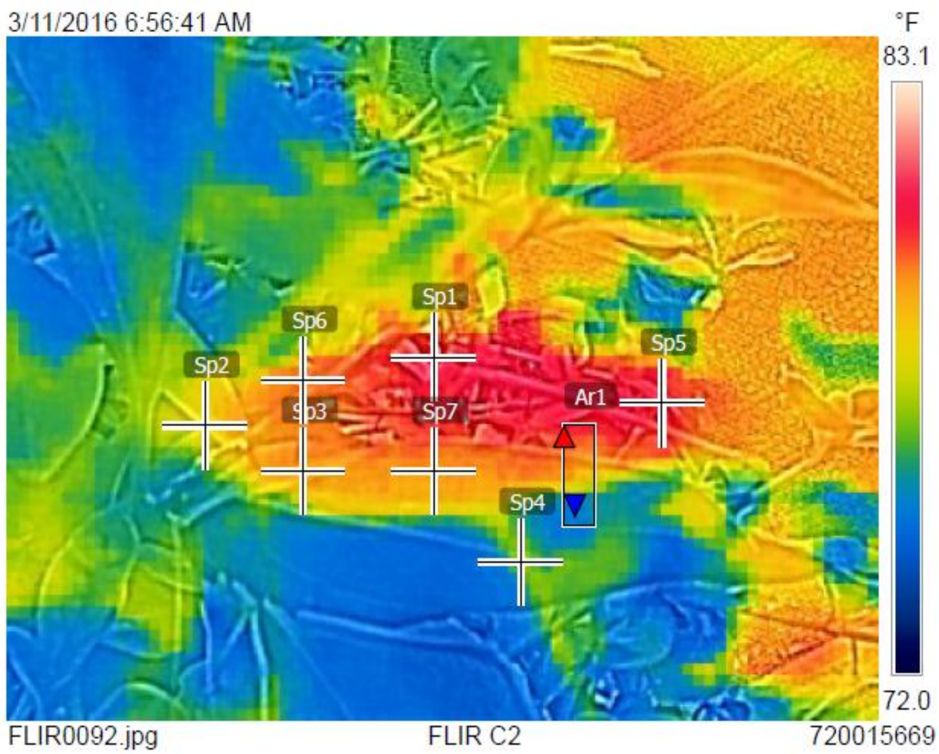

Figure 2: Thermal Imaging of *Microcentrum rhombifolium*

Discussion

Different regions of body surface showed temperature differences (ranging from 78.2⁰F to 80.7⁰F). Earlier Inter-individual variation in displacement patterns was limited to the head, neck and trunk segment and the lower limb segments, but marked in the segments of the upper limbs, particularly the lower arms and hands (Cross *et al.*, 2008). In compression to the body parts, thorax appendage showed huge temperature difference (76.9⁰F). Infrared thermography provided a remote and non-invasive temperature measurement well-suited to a species such as the emperor penguin (Frost *et al.*, 1975).

Figure 3: Normal view of *Microcentrum rhombifolium* with Coloration and Mimicry

Thick plumage has excellent insulation and only un-feathered regions (feet, eye and bill) and sparsely feathered flippers showed heat loss from the body interior. Heat loss in penguins is minimized by counter-current heat exchange systems through arterio-venous networks in the head, axillae and legs. In particular, the post-orbital rate mirabilis functions as a heat exchanger in the eye, nasal passages and jaw muscles. Emperor penguins have relatively small bills in proportion to their body size, and small beaks have been selected to minimize heat loss (Symonds and Tattersall, 2010; McCafferty *et al.,* 2013). Surface temperature of the pedal phalanges and webs was quite low. However, their thick scaly skin affords good protection from radioactive cooling and contact with ice. Previously tarsus temperature has been recorded to be a few degrees above 0°C (Goldsmith and Sladen, 1961; Prévost and Sapin-Jaloustre, 1964).

Insect mostly known as prey, protect themselves by changing cuticle coloration and other mimicry processes. According to this observation and data, predator, especially snake, need only 4.4^0 F changeable temperature (Figure 2 & Figure 3) to catch its prey.

Microcentrum rhombifolium showing body coloration with adaptation includes leaf vein and sub vein. Only predators which have obtained thermal sensitivity identified insect location as like FLIR C2. Measurements on sheep exposed to a clear night sky have shown the fleece to be at least 2.5°C below air temperature. Experiments on pigeons, Columba livia, have recorded temperature differences of 5°C (McArthur, 1991; Leger and Larochelle, 2006). On a clear night, a sheep's fleece can accumulate water (and release latent heat) by condensation when the fleece temperature drops below the dew point of air (McArthur, 1991; Lisa, 2000). In this study, the *Microcentrum rhombifolium* has shown an average temperature (26.94°C).

The temperature variation of coated regions was mostly explained by air temperature alone while wings and appendage temperatures were also dependent on wind speed. Our heat transfer model, therefore, provided a realistic estimate of metabolic heat loss, and showed that radiative heat loss dominated in clear and relatively calm conditions. *Microcentrum rhombifolium* cleverly managed the temperature of its different body parts (80.7^0 F to 78.2^0 F).

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Conclusion

In conclusion, thermal imaging clearly showed that the surface temperature and energy balance of *Tettigoniidae microcentrum* is dependent on spatial variation in their coloration, mimicry and its interaction within environmental conditions.

The predator, smartly identifies *Microcentrum rhombifolium* (Prey) via temperature variation (80.7^0 F to 78.2^0 F) between the body and leaf surface. First time we have unlocked the thermal capacity of prey and predator using manmade tools (FLIR C2).

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