Interactions between Behavioral Thermoregulation and Color Change in Pipevine Swallowtail Caterpillars (*Battus philenor*)

Matthew Nielsen and Daniel Papaj

Department of Ecology and Evolutionary Biology, University of Arizona

Introduction

Temperature is a critical and highly variable factor in any organism's environment. With global climate change increasing both temperature and its variability, adjusting to this variation is increasingly important. One of the main ways organisms deal with environmental change is phenotypic plasticity, altering their phenotype to better suit their current environment. Many traits can change plastically in response to temperature change, including physiology, morphology, and behavior.[1] Although these responses are usually studied independently, they can all be available to the same organism. This raises the question:

How do different thermoregulatory mechanisms affect each other?

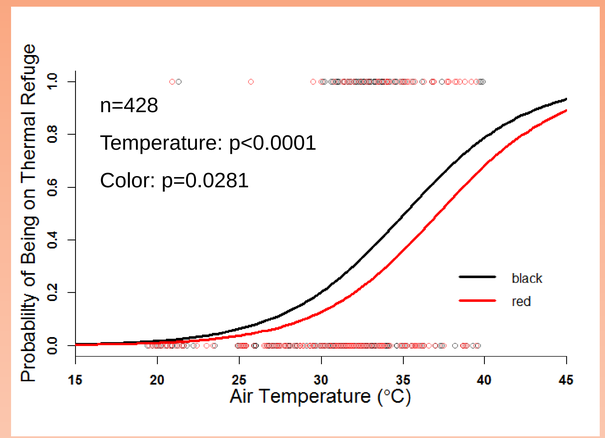
In the Southwest US, temperatures on *Aristolochia watsonii*, the low-growing host plant of *Battus philenor* (Pipevine Swallowtail), can reach over 50°C. One way caterpillars survive such extreme temperatures is by seeking a thermal refuge in taller, non-host vegetation.[2] They can also change color between a warmer black and cooler red form.[2] Both changes cool the caterpillar, but in different ways. How they interact is unknown.

Parameter	Color Change	Thermal Refuge-Seeking
Type of plasticity	Developmental	Behavioral
Response time	Slow (one instar)[2]	Fast (a few minutes)
Degree of effect	Small (about 3°C)[2]	Large (up to 10°C)
Costs	Small, possible immune cost but few parasitoids	Large, cannot eat while on refuge and leaving host risks not relocating it

Color and Refuge Seeking's Effect on Live Caterpillars

Methods:

- Santa Rita Experimental Range
  - Aug.-Sept. 2013
- Open-top enclosures
  - With or without wooden dowels as refuges
- 4th instar caterpillars
  - Black or red
- Record refuge use, survival, and temperature
  - Over one day
  - FLIR thermal imaging camera



Color's effect on refuge seeking: Black caterpillars seek refuges at lower temperatures than red ones. Because of this, black caterpillars were on refuges slightly more often than red ones (0.28 vs 0.22, p=0.082).

Mortality of Caterpillars over 24h by Refuge Availability, Color, and Date

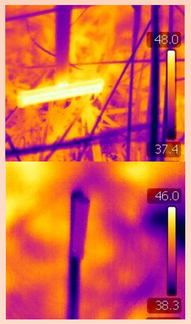
Date	Dead/ Total	Refuge	No Refuge
Aug. 17	Red	3/10	3/8
	Black	6/10	7/8
Sept. 2	Red	0/9	0/10
	Black	0/10	0/9
Sept. 16	Red	1/5	0/1
	Black	1/13	2/13
Sept. 30	Red	0/8	0/7
	Black	0/7	6/8

Combined effect on survival: The effects of color and refuge availability on survival varied across days. On cooler days (Sept.2 and Sept. 16) few caterpillars died of heat. On the hottest day (Aug. 17), caterpillars died under all conditions, although a red color reduced death. On an intermediate day (Sept. 30), either red color or a refuge were sufficient to prevent death, both were not needed.

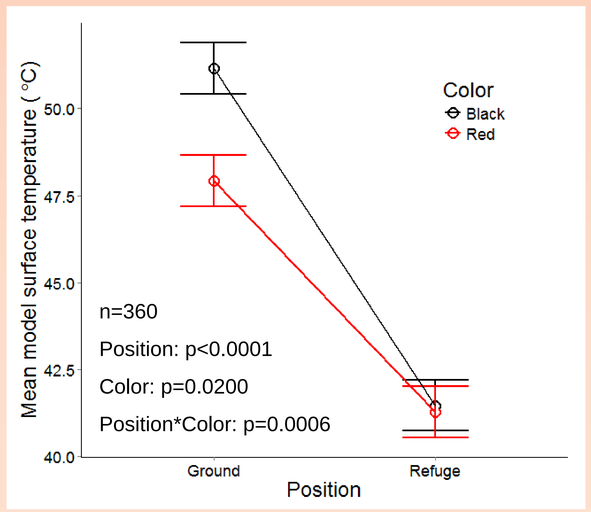
Position and Color's Effect on Caterpillar Models

Methods:

- Santa Rita Experimental Range
  - July 2013
- Aluminum model caterpillars
  - Painted red or black
  - Varied size (no effect on these results)
- Fixed height on wooden dowels
  - Host plant (1cm, horizontal)
  - Refuge (25.8 cm, vertical)
- Record temperature repeatedly
  - FLIR thermal imaging camera



Results: Both a position on a refuge and a red color cooled models; however, the red color only had a cooling effect on models positioned on the host plant.



Conclusions

Black caterpillars seek thermal refugees at lower air temperatures.

For caterpillar models, color only affects temperature on the host plant, not on a refuge.

Under moderate thermal stress, color change and refuge seeking are each independently sufficent to prevent overheating.

The redundancy of color change and refuge seeking in their effects on temperature will limit the ability of caterpillars to avoid extreme high temperatures. Under these conditions refuge seeking should be more important for caterpillar survival because of with its greater effect on temperature. Red coloration may still be beneficial under these conditions, however, because it allows caterpillars to remain on their host until higher environmental temperatures and thus spend more time eating.

Future Directions

How do the patterns observed here vary with season?

-*Battus philenor* is active April to October, and thus is exposed to an even wider range of environmental temperatures than studied so far.

Does refuge availability affect the color of caterpillars?

-If having a refuge reduces the maximum temperature a caterpillar experiences, they might remain black at higher temperatures during their next instar.

Does shade affect the interaction between position and color in determining caterpillar temperature?

-The effect of color on temperature depends on light absorption, so shading models may alter this interaction.

How do color change and refuge seeking vary across *Battus philenor*'s range?

-*B. philenor* can be found as far north as Maryland, and only the black form is reported in most other locations.

Acknowledgements

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References

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[3]Rausher, M.D. 1979. Egg recognition: its advantages to a butterfly. *Animal Behavior* 27: 1034-1040.