Title: Climate associated selection produces non-linear patterns of local adaptation in physiological trade-offs.

Abstract

Author Details

Keywords

Introduction

Climate gradients provide good test cases for how species are able to cope with stress

Climate may be an agent of selection , but identifying which ones are critical for understanding the types

Species may respond to these multi-faceted stressors, but the evolution of stress resistance or tolerance may be constrained if stress responses are correlated.

Moth paragrap

What makes this moth to be a major agricultural pest and worldwide distribution was because of: 1. It can do both the facultative diapause and migration to escape the stress condition, 2. high levels of polyphagy, 3. high fecundity. How it coordinates the trade-offs between the growth and stress hardiness could also be important for local adaptation and make it so widely distributed.

In this study, we determined the correlated stress responses across a latitudinal climate gradient in china under common garden conditions. We measured heat and cold tolerance, desiccation, and starvation tolerance.

Materials and methods

Study species

The cotton ballworm, Helicoverpa armigera is widespread in China. The north edge of successful overwinter is around N’43. Dozens of fully grown larvae were collected from 7 geographic regions across N17 to N43 with ~ every 5 degrees. Larvae were individually kept in 21 well rearing trays (Length: 2.5cm; Width: 2.5cm; Height: 2.5cm) with artificial diet until pupation. The pupae were taken out from the tray and placed in a cage cages (40 × 25 × 18 cm) for adult eclosion and mating. The adults were fed with 10% sucrose solution. A removable gauze cloth was placed on the top of each cage for egg collection. Eggs were collected on days 4, 5 and 6 after eclosion.

After hatching, every 3–5 newly hatched larvae were reared together in 24-well cell culture plates (for each well: diameter: 1.5 cm; height: 2 cm) by an artificial diet until the 3rd instar. Third instar larvae were individually transferred a new 21 wells tray with fresh diet until pupation. The third lab-reared generation was used for the experiment. All the experiments were carried out in incubators (LRH-250-GS, Guangdong Medical Instrument Manufacturer, Guangdong, China) equipped with six fluorescent 30W tubes. The light intensity during photophase was approximately 2.0W/m2 and variation of temperatures was ±1°C.

Experimental design

For each population, newly hatched larvae from three different days were treated as three independent blocks. Larvae from each block were randomly separated to five groups for life history traits, desiccation tolerance, starvation tolerance, cold tolerance and heat tolerance.

Life history traits

For life history traits, we recorded the larval development time from hatching to pupation and pupal development time from the day of pupation to adult eclosion. Together these measurements give the total development time. All pupae were weighed within 24 h after pupation by using an electric balance (AUY120 produced by SHIMADZU Corporation, Japan). A measure of growth rate was calculated for each individual according to the equation: Growth rate =ln (pupal weight)/ larval development time ([Gotthard et al. 1994](#_ENREF_16)). Weight loss during pupal development was also calculated for each individual according to the equation: Weight loss rate = ln (pupal weight - adult weight)/pupal time.

Cold and heat tolerance

The cold tolerance was determined by the chill comma recover time in the adult, and heat tolerance were evaluated by the heat knock down time. Newly emerged adults were individually kept in 40ml jars and feed with honey water for 3 days and then used for the experiments.

For the cold tolerance, we kept the adults in -6°C with a cold incubator for 80 min and the adult will enter the chill comma state. Then, we move the adults to room temperature and individually placed in a jar with upside down position. Chill comma recover time was calculated from move out the freezer to adult stand up.

For the heat tolerance, we kept the adults in a jar and submarined the jar into a 44°C water bath. The heat knock down time was calculated from submarining the jar to the adult lost the physical balance.

Desiccation and starvation tolerance

Newly emerged adults were individually placed in 40ml bottle and feed with honey water after eclosion. The desiccation and starvation tolerance was measured with the three-day-old virgin adult and at least 60 adults from three different cohorts were measured for each population. To measure desiccation resistance, adult from each bottle were transferred to a new bottle covered with cotton mesh secured with an elastic band. Desiccation bottles were kept at 25 \_C under LD 16:8 and the relative humidity was controlled as 10%-15%. We observed for the number of dead adult every 8 h since the adults were originally transferred.

starvation tolerance

Newly emerged adults were individually placed in 40ml bottle and feed with honey water after eclosion. The starvation resistant was measured with the three-day-old virgin adult and at least 60 adults from three different cohorts were measured for each population. To measure starvation resistance, adult from each bottle were transferred to a new bottle covered with cotton mesh secured with an elastic band, a cotton ball with water was placed inside the jar and water was added as needed. Desiccation bottles were kept at 25 \_C under LD 16:8 and the relative humidity was controlled as 75%-80%. We observed for the number of dead adult every 8 h since the adults were originally transferred.

Results

*Axes of variation in physiological traits of organism*

*Independent axes of trade-offs in organism*

We found three independent axes of trade-offs in the organism using a principal component analysis that altogether, represents 85.36% of the total variation in physiological traits . PC1, which accounts for 47.9% of the variation, shows the negative correlation (opposite loading patterns) between overall stress hardiness ( starvation, desiccation, heat knock down, and chill comma recovery time) growth rate,indicating trade-off between overall stress hardiness and growth rate. PC2 accounts for 22.25% of the variation and shows a negative correlation between heat knock time and chill coma recovery time, indicating a trade-off between upper and lower thermal limits. Lastly, PC3 accounts for 15.21% of the variation and desiccation/starvation had opposite loading patterns than thermal hardiness, indicating a trade-off between the two.

Axes of variation in climate across latitude

Patterns of climate across latitude

We found two main axes of variation in climate accounting for 87.5% of the variation. PC1 accounts for 70% of the variation in climate had opposite loading patterns between mean climate and climate variation (temperature and precipitation). PC2 accounts for 17.5% of the variation, and represents the difference in climate relating to precipitation and temperature. The aseasonal-seasonal climate PC1 was negatively (β = 2.08 ± 0.16) associated with latitude, whereas the precipitation-temperature PC2 (β = -0.88 ± 0.25) was unrelated to latitude.

Physiological trade-offs are linear and non-linear with climate

Altogether, the axes of different physiological trade-offs varied with climate PCs, but to different degrees. For the growth rate – hardiness PC, there was a significant quadratic relationship with the asesasonal-seasonal Climate PC and a negative relationship with the overall precipitation PC. The thermal limits trade-off was positively associated with the aseasonal-seasonal climate PC. Lastly, the desiccation/starvation – thermal limits trade off PC was highest in the center and decreased at the edges with the aseasonal-seasonal climate PC. Conversely, the desiccation/starvation – thermal limits trade off PC3 was lowest in the center and higher at the extreme ends of the overall precipitation PC2.

Discussion

Summary paragraph: talk about the trade offs identified

Talk about heat and cold tolerance trade offs

Talk about

Conclusion paragraph

Authors’ Contributions

Acknowledgements

Data Accessibility

Where do we intend to archive data ?

References

Figures and Tables



Figure 1



Figure 2



Figure 3



Figure 4

Tables:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  | | --- | --- | --- | --- | | Trait | PC1 (47.9%) | PC2 (22.3%) | PC3 (15.2%) | | Starvation hardiness | -0.49 | 0.34 | -0.28 | | Desiccation hardiness | -0.54 | -0.14 | -0.53 | | Heat knock down | -0.38 | -0.45 | 0.65 | | Chill coma recovery time | -0.23 | 0.79 | 0.44 | | Growth Rate | 0.53 | 0.20 | -0.14 | |  |  |  |
|  |  |  |  |
|  |  |  |  |
| |  |  |  | | --- | --- | --- | |  | PC1 (70%) | PC2 (17.5%) | | bio1 | 0.27 | -0.11 | | bio2 | -0.26 | -0.08 | | bio3 | 0.15 | -0.42 | | bio4 | -0.25 | 0.19 | | bio5 | 0.21 | 0.27 | | bio6 | 0.26 | -0.10 | | bio7 | -0.26 | 0.16 | | bio8 | 0.22 | 0.07 | | bio9 | 0.26 | -0.11 | | bio10 | 0.26 | 0.09 | | bio11 | 0.26 | -0.14 | | bio12 | 0.26 | -0.01 | | bio13 | 0.20 | -0.26 | | bio14 | 0.19 | 0.38 | | bio15 | -0.19 | -0.33 | | bio16 | 0.23 | -0.22 | | bio17 | 0.19 | 0.38 | | bio18 | 0.19 | -0.05 | | bio19 | 0.21 | 0.32 | |  |  |  |
|  |  |  |  |
|  |  |  |  |