Complex Influences on Plant Development: the Interaction of Genotype, Environment, and Parent Environment

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Introduction

Until recently, biologists considered the traits of an individual organism to be determined entirely by its genotype and its environment. However, new findings for both plants and animals have shown that the parents' environment can also influence an organism's development via inherited regulatory factors. Little is known, however, about the impact and interaction of these three factors throughout an organism's life cycle as sources of variation for individual fitness.

Using multiple inbred genotypes of the common annual plant *Polygonum persicaria,* our controlled greenhouse experiment investigates the effects of genotype, current environment, and parent environment on offspring phenotype and gene expression throughout the life cycle. Light availability is our environmental variable. We ask the following questions: a) do genotype, environment, and parental environment individually impact key traits? b) do these factors interact in influencing key traits? c) how does the impact and interaction of these factors change throughout the plants' life cycles? d) how do these factors influence gene expression throughout plant development? As this is an ongoing experiment, the data presented here—seedling emergence day and plant height at days 17 and 28—is only a subset of the complete dataset to be collected this summer.

A *P. persicaria* plant in the full sun treatment (left) and moderate shade treatment (right)

Methods

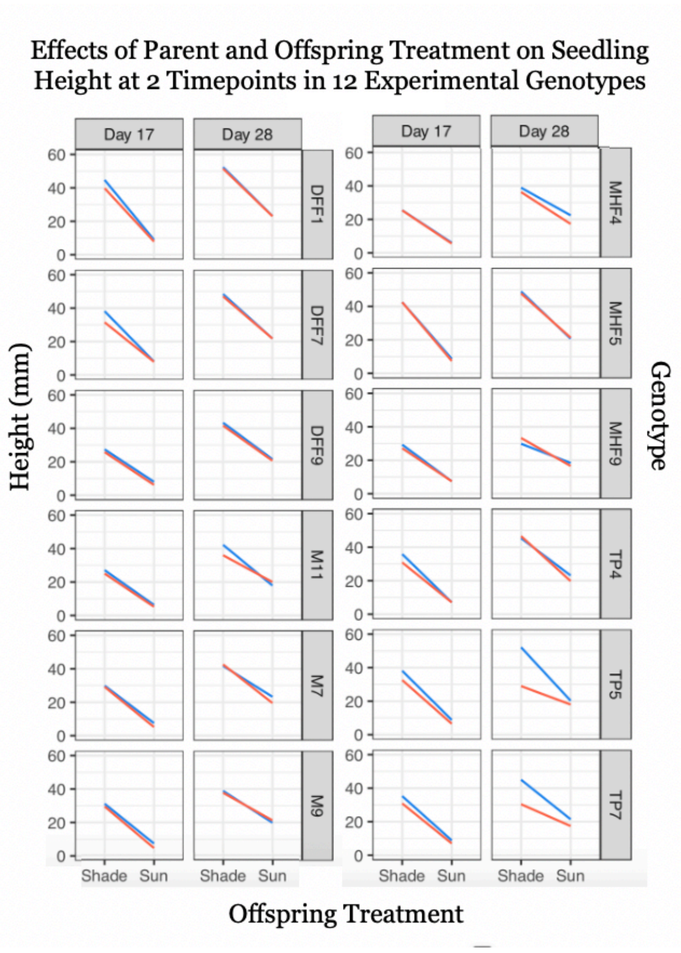
- 12 inbred field-collected genotypes of *P. persicaria*
- 2 parental greenhouse treatments: full sun and moderate shade.
- 2 offspring greenhouse treatments: full sun and moderate shade.
- All 768 plants maintained at field capacity soil moisture with full nutrients, in 1L clay pots
- Early life cycle measurements: day of seedling emergence recorded for first 8 days after sowing; seedling aboveground biomass at day 17
- Repeated measurements taken at 1-2 week intervals throughout life cycle: plant height, leaf number, whole-plant canopy area (based on digitized photos; see related poster by Jolie Villegas)
- Final adult traits measured at harvest: biomass allocation, leaf size, Specific Leaf Area, total estimated leaf area, reproductive output (fitness)
- At 3 points throughout plant life cycle - harvest plants for RNA extraction and sequencing

Full sun treatment (left) vs. moderate shade treatment (right)

Undergraduate Charlotte Babbin measuring the height of a plant in the sun treatment

Undergraduate Andy Tan taking photos to be analyzed using ImageJ program to determine canopy area

Results



Day 17:	
Genotype	p<0.0001***
Parent Treatment	p=0.0055**
Offspring Treatment	p<0.0001***
OT x PT	NS
Gen x PT.	p=0.0012**
Gen x OT	p=0.0001***
Gen x OT x PT	p=0.0052**
Day 28:	
Genotype	p<0.0001***
Parent Treatment	p<0.0001***
Offspring Treatment	p<0.0001***
OT x PT	NS
Gen x PT.	p=0.0002***
Gen x OT	p=0.014*
Gen x OT x PT	p=0.0044**

Seedling Emergence Timing

Genotype	p=0.001***
Parent Treatment.	p=0.001***
Offspring Treatment.	p=0.001***
OT x PT	p=0.001***
Gen x PT	p=0.001***
Gen x OT	NS
Gen x OT x PT	NS

Each main factor (Genotype, Parent Treatment, and Offspring Treatment), the Offspring Treatment by Parent Treatment interaction, and the Genotype by Parent Treatment interaction significantly affected seedling emergence timing—the number of days from sowing until the seedling emerges from the soil.

Photograph: A flat containing seedlings on day 15

Discussion

Plant height at both time points was significantly affected by each main factor—Genotype, Offspring Treatment, and Parent Treatment. The Genotype by Offspring Treatment interaction was significant, indicating that the effect of current light environment on plant height varies from one genotype to another. The Genotype by Parent Treatment interaction was also significant at both time points, showing that the effect of the parents' light environment on offspring height also depends on the plant's genotype. Furthermore, the Genotype by Offspring Treatment by Parent Treatment interaction was significant, indicating that the different expression of the parental effects in the two offspring environments varies between genotypes.

The seedling emergence data was also significantly affected by each main factor. The Offspring Treatment by Parent Treatment interaction was significant as well, indicating that the effect of the parents' light environment on plant height differed in the sun and the shade. The Genotype by Parent Treatment interaction was significant, whereas the Genotype by Offspring Treatment interaction was not. This likely occurred because seedling emergence timing is largely determined by germination time, which is mostly parentally determined. The amount of provisioning to the offspring by the parents may also have a role in emergence timing.

The differences between the time points of the height data can provide some insight into the changing roles of an individual's genotype, environment, and parental environment throughout its life cycle. Interestingly, no single pattern was shared by all genotypes. For genotypes TP4 and DFF7, the impact of the parent environment diminished from day 17 to day 28, whereas for genotypes MHF4, TP5, TP7, DFF1, DFF9, MHF5, and M11, the impact of the parent environment on plant height was larger at the second time point. Whether the impact of parental environment on plant height (and possibly other traits) increases, decreases, or remains the same across the life cycle is therefore genotype-dependent. This suggests that plant genotypes differently integrate current and parental environmental influences throughout development.

Genetic variation therefore exists for the effect of parental environment and the interaction of parental and offspring environment on height and seedling emergence—ecologically important phenotypic traits that can influence fitness. Because genetic variation provides potential for adaptive change, this is evidence that the phenotypic impact of parental environment can evolve. This idea can reshape the way we view evolution, as organisms can evolve in their use of information from their parents' environments, as well as their own environments, rather than simply evolving to have a specific phenotype.

Future Directions

The height and emergence data presented here are part of an ongoing large-scale experiment. As we measure height, canopy area, leaf count, and aboveground biomass at further time points, we will gain a clearer picture of the changing role of genotype, environment, and parental environment throughout organismal development. We are also extracting RNA from the plants at three time points throughout the summer, which will be sequenced using RNA seq. This will provide key insight into the impact of genotype, environment, and parent environment on gene expression throughout the plants' life cycle.

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Photographs taken by Andy Tan