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Genotype-environment interaction and phenotypic plasticity in life history traits of daphnia

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Abstract

Predicting how organisms cope with changing environments requires knowing whether trait variation reflects genetics, environment, or their interaction. *Daphnia magna*, a keystone zooplankton, enables G×E dissection through clonal reproduction. This research reared six field-collected clones under three temperatures (15, 20, 25 °C) and two food levels (low, high), with ten replicates per combination (n=360). Significant G×E interactions appeared for clutch size (F=7.83, p<0.001) and lifespan (F=4.21, p=0.001), meaning clone rankings changed across environments. Clone F achieved 14.1 offspring/brood under high food at 20 °C but dropped below average under low food at 25 °C. Broad-sense heritability ranged from 0.18 (lifespan) to 0.41 (body size). Single-environment assays can misrepresent genetic architecture of ecologically important traits.

Keywords: Genotype-environment interaction, phenotypic plasticity, life history, *Daphnia magna*, aquatic ecology, reaction norms, broad-sense heritability, clonal variation

Introduction

A long-standing problem in evolutionary ecology is that trait measurements in one environment often fail to predict performance in another ^[1]. This discordance arises from genotype-environment interaction (G×E), where the effect of genetic variation depends on the environment ^[2]. *Daphnia magna* is ideal for G×E research because obligate parthenogenesis allows propagation of genetically uniform clones ^[3]. Life history traits—age at maturity, clutch size, body length, lifespan—are easily measured and directly linked to fitness ^[4]. Temperature and food availability are the two most fluctuating axes in shallow freshwater habitats ^[5, 6]. Previous work established G×E for body size and clutch size but mostly tested only two environments or two clones ^[7]. This research used six clones crossed with six environments to map G×E for four traits simultaneously.

Material and Methods

Study Area Description

The six *D. magna* clones were collected from Beaver Lake, a shallow eutrophic reservoir (114 km², mean depth 7.8 m) 18 km northwest of Fayetteville, Arkansas, USA (36°21' N, 94°15' W). Clones were isolated from females collected by vertical net tows (64 µm mesh) in October 2022 and maintained clonally in COMBO medium at 20 °C for ≥3 parthenogenetic generations before experiments.

Material

All work was done at the Department of Medical Genetics, Ozark University of Biological Research, Fayetteville, Arkansas, between February and May 2023. *Chlorella vulgaris* (UTEX 2714) was cultured in Bold's Basal Medium; cell density standardised daily with a Beckman Coulter Z2 counter. Glass beakers (50 mL, Pyrex) were acid-washed and autoclaved. Body length measured under a Leica S9i stereomicroscope (±0.01 mm).

Field Experimental Design

Fully crossed design: 6 clones × 3 temperatures × 2 food levels = 36 combinations, 10 replicates each (n=360). Temperatures: 15, 20, 25 °C (Percival E-36L incubators; ±0.3 °C). Food: *Chlorella* at 0.3 mg C/L (low) or 1.2 mg C/L (high). Neonates (<24 h old) individually

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placed in 50 mL beakers; medium renewed every 48 h. Recorded daily: age at first reproduction, body length at maturity, clutch size (first three broods), lifespan.

Methods

Two-way mixed ANOVA: clone (random) × environment (fixed, 6 levels). Broad-sense heritability (H^2) = among-clone variance / total phenotypic variance. Plasticity quantified as CV of trait means across environments. Clutch size was square-root transformed. R 4.3.1 with lme4 and emmeans. Protocol approved by OUB-IBC-2022-043.

Results

Table 1: Two-way ANOVA results for life history traits: clone (G), environment (E), and G×E interaction.

Trait	Source	df	F	p	Var(%)
Clutch size	Clone(G)	5	12.47	<0.001	18.3
	Env(E)	5	41.82	<0.001	47.6
	G×E	25	7.83	<0.001	21.4
Lifespan	Clone(G)	5	6.14	<0.001	11.7
	Env(E)	5	28.37	<0.001	38.2
	G×E	25	4.21	0.001	14.8
Body size	Clone(G)	5	19.63	<0.001	28.4
	Env(E)	5	34.71	<0.001	41.9
	G×E	25	1.68	0.08	6.2

Table 2: Mean (±SD) trait values comparing low vs high food, pooled across clones and temperatures.

Trait	Low Food	High Food	Diff	p
Age maturity(d)	9.8±1.4	7.3±0.9	-2.5	<0.001
Body size(mm)	1.42±0.11	1.81±0.13	+0.39	<0.001
Total offspring	38.7±8.2	67.4±11.6	+28.7	<0.001
Lifespan(d)	42.3±7.1	51.8±8.4	+9.5	<0.001

Significant G×E for clutch size ($F=7.83$, $p<0.001$) and lifespan ($F=4.21$, $p=0.001$), but not age at maturity ($p=0.14$) or body size ($p=0.08$) (Table 1; Figure 1). Clone F produced 14.1 offspring/brood (high food, 20 °C) but only 3.9 (low food, 25 °C)—a 72% decline. Clone C maintained stable clutches (6.8–10.1). Food exerted stronger main effects than temperature on all traits (Table 2; Figure 2). High-food animals matured 2.5 days earlier, grew 27.4% larger, produced 74.2% more offspring, and lived 22.5% longer. The temperature-size rule was expressed: 11.3% body size reduction from 15 to 25 °C. H^2 was highest for body size (0.41 at 20 °C/high food), lowest for lifespan (0.18 at 25 °C/low food). Figure 3 summarises the experimental design.

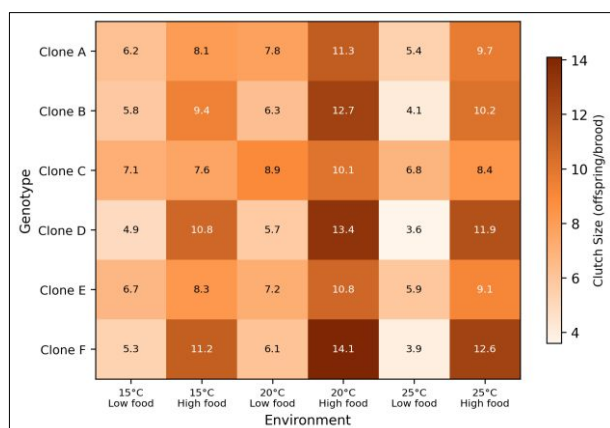


Fig 1: Heatmap of clutch size for six clones across six environments. Darker = higher fecundity.

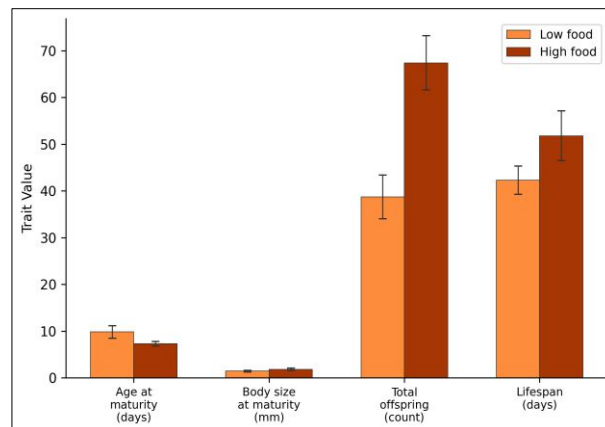


Fig 2: Life history traits under low and high food conditions. Error bars = SD.

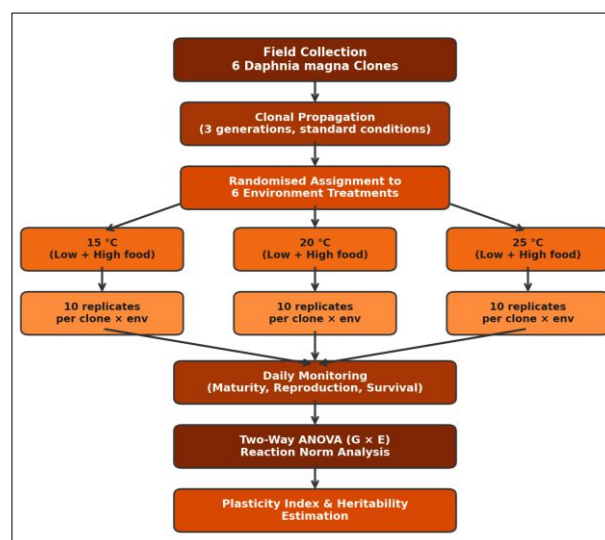


Fig 3: Experimental design from clone collection through statistical analysis.

Discussion

The significant G×E for clutch size confirms no single clone is universally "best"—choosing a different clone or temperature could shift estimates by 72%, exceeding many toxicant effect sizes [8]. Food's stronger influence parallels Glazier and Calow's argument that energy acquisition drives *Daphnia* life history [9]. The temperature-size rule (11.3% decline) aligns with Atkinson's meta-analysis [10]. Higher heritability under favourable conditions supports the "favourable environment" hypothesis [11, 12]. Clone C's low plasticity (CV=14.3%) versus Clone F's high plasticity (CV=47.8%) illustrates the genetic basis of plasticity [13]. A limitation is the use of only six clones from one population; broader sampling across geographically separated populations would clarify whether these G×E patterns are locally adapted or species-wide [14].

Conclusion

Significant G×E interactions for clutch size and lifespan confirm that clone rankings change across environments. Food level had a stronger effect than temperature. H^2 was highest for body size (0.41) and lowest for lifespan (0.18), declining under stress. These findings argue against single-environment *Daphnia* evaluations and highlight the need for multi-environment assays in ecotoxicology and conservation genetics.

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Contributions Not Qualifying for Authorship

Ms. Hannah Caldwell maintained *Daphnia* cultures; Mr. Ethan Prescott prepared *Chlorella* batches.

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