L’apparition et la perte subséquente de la diversité de ploïdie durant l’évolution expérimentale chez *Saccharomyces cerevisiae* 

The appearance and subsequent loss of ploidy diversity in experimental evolution with *Saccharomyces cerevisiae*
Transitions in form over evolutionary time

What are the selective forces?
Hard to test hypotheses through the fossil record
We use batch culture evolution to track the fossil record.

Ancestral (generation 0) - Evolved

Diagram showing the process of evolution from ancestors to evolved forms.
Ploidy varies between species

Haploid (N)

Diploid(s) (2N)

Polyploid (4N)
Ploidy varies between species

- **Haploid (N)**
- **Diploid(s) (2N)**
- **Polyploid (4N)**
and across a phylogeny

Wendel lab
Ploidy can also vary within species

- **Haploid** – Male honey bee
- **Haploid** – *Mastocarpus papillatus* (gametophyte)
- **Diploid** – Female honey bee
- **Diploid** – *Mastocarpus papillatus* (sporophyte)
- **Haploid/Diploid** – *Ulva lactuca*
Yeast Ploidy in Nature!

Ezov et al. (2006) Genetics
Yeast Ploidy

Ezov et al. (2006) Genetics
Ploidy can directly affect evolution

• Mutation rate

• Mutation effect size (s vs. sh)

• Rate of adaptation
Convergence toward diploidy in 1800 generations

![Graph showing convergence towards diploidy over 1800 generations. The graph is divided into two panels: Unstressed and Salt-stressed. Each panel shows the change in genome size (FL1 intensity) over time (generations). The initial ploidy is indicated by different colors and symbols: haploid (red), diploid (blue), and tetraploid (black).]
Convergence toward diploidy in 1800 generations (not in nature)
Convergence toward diploidy in 1800 generations
What is different between haploid and diploid yeast?

Haploid Ancestral

64 ± 3 µm³

Diploid Ancestral

90 ± 4 µm³

17 genes differ in expression (Galitski, 1999)

2.7% of the proteome changes more than 50% in abundance (de Godoy, 2008)
Batch culture growth

- **Lag phase**
- **Exponential growth**
- **Stationary phase**

Graph showing the growth phases over time.
Batch culture growth

Stationary phase

Lag phase

Exponential growth
Batch culture growth

\[ \log(\text{Optical density}) \]

- **t** (lag phase)
- **K** (biomass production)
- **r** (growth rate)
Hypothèse # 1 – Les diploïdes se multiplient mieux dans une culture discontinue (rendement de biomasse plus élevé, croissance exponentielle plus rapide, et/ou temps de latence plus courts).

Hypothesis # 1 – Diploids are better at growth during batch culture (higher biomass yield, faster exponential growth, and/or shorter lag phase).
Directly compare haploids and diploids isolated throughout the fossil record
Biomass production through the fossil record

![Graph showing biomass production over time for haploid and diploid organisms.](image-url)
Variation in biomass production

Biomass production (OD at 24 hours)

1100 generation colonies

1400 generation colonies

Biomass Production:
- haploid
- diploid

Colony number

Variation in biomass production

Time (generations): 0 500 1000 1500 2000

Biomass production: 0.0 0.2 0.4 0.6 0.8 1.0 1.2

Colony number

Graphs showing variation in biomass production over colony number for 1100 generation colonies and 1400 generation colonies, with data points indicating biomass production at different colony numbers and time points.
Growth rate through the fossil record

Time (generations)

0 500 1000 1500 2000

Growth rate (/hour)

0.00 0.05 0.10 0.15 0.20 0.25

d haploid
d diploid

Generations

1000 1500 2000

0 0.2 0.4 0.6 0.8

haploid
diploid
Growth rate through the fossil record

Time (generations)

Growth rate (/hour)

haploid
diploid

### Chart Details

- **Y-axis**: Growth rate (hour)
- **X-axis**: Time (generations)
- **Legend**:
  - Red dots: haploid
  - Blue dots: diploid

The chart illustrates the growth rate over time for haploid and diploid organisms, as indicated by the scatter plots in red and blue, respectively.
Variation in growth rate

1100 generation colonies

1400 generation colonies

Growth rate

Colony number

Time (generations)

Biomass Production

haploid
diploid
Lag phase - glucose utilization

![Graph showing glucose utilization over time with separate markers for haploid and diploid strains.](attachment:graph.png)
**Lag phase - glucose utilization & ethanol production**

![Graph showing glucose and ethanol levels over time with red and blue dots representing haploid and diploid strains, respectively.](image-url)
Conclusion # 1 – Diploids do not produce biomass more efficiently, grow faster, or have a shorter lag phase than haploids.
Conclusion # 1 – Les diploïdes ne produisent pas de biomasse plus élevée, ne montre pas de croissance exponentielle plus rapide, et n’ont pas de temps de latence plus courts.

Hypothèse # 2 – Les diploïdes sont plus compétitifs que les haploïdes.

Conclusion # 1– Diploids do not produce biomass more efficiently, grow faster, or have a shorter lag phase than haploids.

Hypothesis # 2 – Diploids are more competitively fit than haploids.
Competitive fitness

Day 0

Day 2

Day 4
Competitive fitness ($s$)

\[
p_0 e^{st} \over 1 - p_0 + p_0 e^{st}
\]
Competitive fitness
(to a common competitor)
Competitive fitness
(to a common competitor)
Competitive fitness
(to a common competitor)
Competitive fitness
(to a common competitor)
Conclusion # 2 – Diploïdes sont les plus compétitifs que les haploïdes.

Conclusion # 2 – Diploïdes are not more competitively fit against a common competitor.
Qu’est-ce qui rend les diploïdes meilleurs?

**Conclusion # 2** – Les diploïdes ne sont pas plus compétitifs que les haploïdes.

**Hypothèse # 3** – J’ai besoin d’une nouvelle hypothèse.

**Conclusion # 2** – Diploids are not more competitively fit against a common competitor.

**Hypothesis # 3** – I need a new hypothesis.
Directly compete haploids and diploids

Haploid

Diploid
Directly compete haploids and diploids

Day 0

Day 14 (100 generations)
Directly compete haploids and diploids

Day 0

Day 14 (100 generations)
Directly compete haploids and diploids

Haploid

Diploid

Day 0

Day 14 (100 generations)
Directly compare (this time for sure!) haploids and diploids
1400 generation diploid colonies against haploid population
1400 generation diploid colonies against haploid population
1400 generation diploid colonies against haploid population
N population vs. 2N population at 1400 generations

Change in diploid frequency

N pop: 2N pop proportions

haploid
diploid
Negative frequency dependent selection is common

beginning and end of the experiment as described by

\[ p(t) = \frac{N(t)}{N_0} \]

where \( N(t) \) is the final bacterial density and \( N_0 \) is the initial bacterial density. The proportion of genotype \( L \) was defined as the ratio of the number of \( L \) bacteria to the total number of bacteria present in the sample.

Results

Acanthamoeba actinomycetemcomitans is a major cause of root surface infections, particularly in children and adults. The growth rate of \( A. actinomycetemcomitans \) is affected by both nutrient availability and the presence of other bacteria. The fitness of \( A. actinomycetemcomitans \) relative to its competitor, \( E. coli \), was measured using a competitive exclusion assay. The fitness of \( A. actinomycetemcomitans \) was greater than that of \( E. coli \) for all initial frequencies of \( A. actinomycetemcomitans \), indicating a positive frequency-dependent selection advantage for \( A. actinomycetemcomitans \).
Qu’est-ce qui rend les diploïdes meilleurs?

**Conclusion # 3** – les diploïdes de génération 1400 ne remplace pas les haploïdes de génération 1400; mais les diploïdes de génération 1600 peuvent.

**Conclusion # 4** – La sélection négative relative à la fréquence maintient les polymorphismes dans le système.

**Conclusion # 3** – 1400 generations diploids do not outcompete the 1400 generation haploid population; though generation 1600 diploids can.

**Conclusion # 4** – Negative frequency dependent selection may act to maintain polymorphism in the system.
Ma perspective moléculaire sur la biodiversité

- Même dans les environnements simples, les polymorphismes peuvent être maintenus pour des centaines de générations
- La métaphore des paysages adaptatifs ne s’applique pas ici – ce n’est pas une mutation peu avantageuse essayant de grimper une colline

- Even in simple environments, polymorphism can be maintained for hundreds of generations
- Adaptive landscape metaphor doesn’t work here – not a simple hill climbing low s mutation
Ma perspective moléculaire sur la biodiversité

• Il n’est pas trivial d’expliquer pourquoi la diversité se maintient ou est éventuellement perdue
• Les forces stochastiques & déterministiques sont probablement présentes pour maintenir et pour réduire la diversité ploïdique

• Not trivial to explain why diversity is either maintained, or eventually lost
• Stochastic & deterministic forces likely present to both maintain and remove diversity
Ploidy can directly affect evolution

- Mutation rate ?
- Mutation effect size (s vs. sh) ?
- Mutational neighbourhood ?
The Next Generation

- Sequence!
- What mutations are fixed at 1600 generations?
- How many appear in only a diploid background?
- How rapidly did they sweep?
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Restart evolution at 1400 generations