Ecology and population genetics of wild system dynamics

Eric JB von Wettberg
University of Vermont
December 12, 2017
Today’s outline

• Key Terms
• Motivations: Re-assessing one of our central assumptions
• Water and phenology
• Fungal disease
• Suggestions for going forward
Ecology and Population Genetics

• Ecology:
• The study of distribution and abundance of organisms
• The movement of nutrients through ecosystems
Ecology and Population Genetics

- Evolutionary Ecology:
- Factors affecting changes in the distribution and abundance of organisms
- $\Delta Ecology$
Ecology and Population Genetics

- Population Genetics:
- Origin, maintenance, and loss of genetic diversity in populations
Loss of genetic diversity in agriculture

Domestication bottleneck

- Breeding a limited number of individuals
- Artificial selection on few anthropocentric traits

Doebley et al. 2006
Loss of genetic diversity in agriculture

Domestication bottleneck
- Breeding a limited number of individuals
- Artificial selection on few anthropocentric traits

Specificity of microbial symbiosis?
Seed dehiscence, phenology, seed size
The story of chickpea and its symbiont domestication includes drastic changes to distribution and abundance.
Post-domestication diversification of chickpea

In situ: MYA
Domestication: 10-12,000 years ago

Secondary diversification:
~6,000 years ago

Secondary diversification:
~3-4,000 years ago

Secondary diversification:
~3-4,000 years ago

Secondary diversification:
~100-500 years ago

Recent introduction:
Within last century
Ecology and Population Genetics

• Understanding what limits abundance and distribution of the crop remains critical
• Understanding these forces in the wild can provide insight in an agricultural setting
  – A roadmap for climate resilience

  – How to acknowledge and move forward from the challenges in the wild in Turkey
Understanding limits and controls on distributions

- What limits abundance and distribution of the crop and its wild relatives?

- Fundamental niche
  - Climatic range

- Realized niche
  - Biotic limitations
  - Dispersal limitation

- Genetic Variation
Species distribution models show suitable climatic space

Warmer (red) colors indicate grid cells predicted by Maxent (Maximum Entropy) to be more suitable for *Cicer reticulatum* and *C. echinospermum*

Von Wettberg et al., in review
Ethiopia’s drought

On the edge of disaster

The government’s achievements appear increasingly precarious

Feb 27th 2016 | ADIGRAT | From the print edition

“AHE animals die first” is a common refrain from many Ethiopians living in Tigray and Afar, two northern states, as the country experiences its worst drought in decades. Crop production in these regions has dropped by 50% or more in some areas, and failed completely in others. Hundreds of thousands of domestic animals are reckoned to have perished.

The rapidly changing skylines of Ethiopia’s modernising cities notwithstanding, about 80% of its population still live off the land. Yet despite the drought there are not yet scenes reminiscent of the famine of 1983-84 when as many as 1m people died.

That reprieve may not last. Those working for NGOs, which are now scrabbling to raise funds for relief, point out that in previous dry spells, hunger intensified from April onwards because by then people have eaten through their last food

Climate change will further ravish Ethiopia

All colored cells currently suitable for chickpea

Red cells are predicted loss by the year 2070

Yellow are stable

Green are gains

Korbu, Machovina, Garcia and von Wettberg in preparation

2070
CCMS4 8.5
65% net loss
Understanding limits and controls on distributions

- What limits abundance and distribution of the crop and its wild relatives?
  - Water
  - Temperature
  - Phenology
  - Nitrogen and soil fertility
- Fungal disease
- Insects and nematodes
- Genetic variation
- Suitable Habitat
- Dispersal opportunities
Wild Species
High diversity

Wild Species
lower diversity

Domestication

Rand Flora

Domestication

Spring Planting

Modern crops
Low diversity

Domestication

Phenology

Breeding
Why does wild Chickpea lack Diversity?

Rand Flora: Ancient loss of habitat

Pokorny et al 2015
Rand Flora: Ancient loss of habitat

The genus *Cicer*, to which chickpea belongs, has a Rand Flora distribution, with members along the fringe of what was once a much wetter African continent. Distantly related wild chickpeas can be found in the Canaries, Atlas Mountains, and Ethiopia, as well as Southwest Asia.
Demographic models show drastic bottleneck

\[ \theta = 1.1 \times 10^{-3} \]

\[ \theta = 8.3 \times 10^{-5} \]

\[ \theta = 9.0 \times 10^{-3} \]

\[ \theta = 1.1 \times 10^{-2} \]

\[ \theta = 1.4 \times 10^{-4} \]

Width of line corresponds to effective population size
Demographic models show drastic bottleneck

\[ \theta = 1.1 \times 10^{-3} \]

\[ \theta = 8.3 \times 10^{-5} \]

\[ \theta = 9.0 \times 10^{-3} \]

\[ \theta = 1.1 \times 10^{-2} \]

\[ \theta = 1.4 \times 10^{-4} \]

\[ \theta = 0.0005 \text{ (6X Cult.)} \]

\[ \theta = 0.011 \text{ (100X Cult.)} \]

\[ \theta = 0.00008 \]
Wild Species
High diversity

Rand Flora

Domestication

Wild Species
lower diversity

Domestication

Modern crops
Low diversity

Spring Planting

Phenology

Breeding
Phenology and drought

• A major project focus shared by many of us
Segregating Flowering time variation in reVIL F2 population. Sixteen wild lines were crossed into a common cultivated line (ICC 96029). Progeny segregate for an early flowering time locus from ICC 96029 which behaves in a partially dominant manner. Variation in the earliest flowering tail of the distribution reflects the background contribution of wild variation to early flowering imposed by the ICC 96029 allele.
Potential new drought tolerance traits

\[ y = 10.962x^4 - 19.481x^3 + 8.745x^2 + 0.9618x + 0.0653 \]
\[ R^2 = 0.9765 \]

von Wettberg et al., in revision
Potential new drought tolerance traits

\[ y = 1.6016x - 0.1803 \]

\[ R^2 = 0.22474 \]

von Wettberg et al., in revision
Shifts in nitrogen responsiveness

- Ongoing activities and analyses
- Root shape
- Leaf morphometrics
- Stable isotopes
- IRGA
Still much more work to do
Wild Species
High diversity

Wild Species
lower diversity

Domestication

Rand Flora

Domestication

Modern crops
Low diversity

Domestication

Spring Planting

Phenology

Breeding
A major QTL accounts for 70% of flowering time variation
Because 2 FT genes are next to each other on LG4 of chickpea, we don’t yet know which one or both confer flowering time and vernalization differences.

Image from Weller and Ortega, 2015, Front P Sci
Is Jens right about the phenology switch

- I don’t know
- The evidence at the FT locus is still incomplete
- We could use functional work; assess allelic variation in the new collection and assess phenotypes of different alleles in controlled light environments
- I suspect that climatic differences between natural populations or early landraces from coastal Aegean, Central Anatolian, and southern Fertile Crescent sites could have driven as much differentiation in early diversification
- More evidence to follow
Characterizing fungal associates and pathogens
Still much more work to do

- Molecular characterization of pathogens
- Next-Gen approaches to R genes
- Natural pathosystems that vary in climate and phenology
Diverse chickpea landraces

- VIR chickpea collection
- AARI – TK collection
- EBI – ET collection
- NARC – PK collection
- USDA and CG collections
- USAID FtF 2014 collection

Plekhanova et al, 2017; Abbas et al in press; Dinegde et al in prep
Chickpea landraces best described as 5 groups

~30,000 SNPs
Gene diversity barely varies over a century of collections

Allelic Patterns across historical collections

Dinegde et al., in preparation
An example derived allele where ancestral and Derived segregate within cultivated chickpea.
Understanding limits and controls on distributions

- What limits abundance and distribution of the crop and its wild relatives?
- Water
- Temperature
- Phenology
- Nitrogen and soil fertility
- Fungal disease
- Insects and nematodes
- Genetic variation
- Suitable Habitat
- Dispersal
Questions?
USA
UC Davis
Doug Cook
Varma Penmetsa
Alex Greenspan
Peter Chang
Noelia Carraquilla
Lisa Vance
Emily Bergmann
Bullo Mamo
Reyaz Mir
Florida International Univ.
Eric von Wettberg
Manny Dacosta-Calheiros
Emily Warschefsky
Chris Krieg
Edward Marques

USC
Sergey Nuzhdin
Nina Noujdina
Wendy Vu
Matilde Cordeiro
Vasantika Vasantika
Travis Longcore

USDA
Clare Coyne
George Vandemark

Ethiopia
EIAR
Asnake Fikre
Solomon Chanyalew
Lijalem Korbu
Dagnachew Bekele
Million Esthete
Ridwan Mohammed
et al

Addis Ababa Univ.
Fassil Assefa
Mashresha Fetene
Kassahun Tesfaye
Zahara Mohamed
Kassaye Dinegde
et al

Hawassa Univ.
Gashaw Sefara
et al

Pakistan
Quaid-i-Islam University
Syed Gul Abbas Sani

ICARDA
Sripada Udupa
Michel Ghanem

India
ICRISAT
Vincent Vadez
Jana Khalova
Hari Sharma
Pooran Gaur

IARI K. Annapurna
KAUST Reyaz Mir

Russia
St. Petersburg Polytechnic
Maria Samsonova
Elena Plekhanova

VIR
Margarita Vishnyakova

Canada
U. of Saskatchewan
Bunyamin Taran
Donna Lindsay

Australia
CSIRO Jens Berger
DAFF John Thompson
Murdoch U Graham Ohara
Wendy Vance

Turkey
Harran University
Adbullah Karhaman

Turkish GDAR
Abdulkadir Aydogan

Samsun University
Huseyin Ozcelik

Dicle University
Bekir Bukun
Fatma Basdemir

Antalya University
Cengiz Toker

FROM THE AMERICAN PEOPLE