Genetic Resources and the Challenge of Climate Change

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Abstract

Adaptation to climate change is an urgent plant breeding priority. Selection for combined heat and drought tolerance is underway for wheat in Mexico and India, and for maize in South Africa. Landrace germplasm can be prioritized for tolerance screening by application of historic weather data for; temperature stresses and variability, low rainfall and frost frequency, at different crop growth stages. This methodology is being used to screen pea landraces from China.

Very little is known of genetic variance in growth or yield either between or within crop species for responsiveness to increased levels of CO_2, which has recently increased from 280 ppm to 380 ppm and will continue to rise. Free Air CO_2 Enrichment experiments have shown large genotypic yield differences to elevated CO_2 in both wheat and field peas. In 2010 and 2011 peas showed respective yield responses to CO2 at 550ppm of 27% and 14%, with differences between varieties. Recent studies have found that older cultivars of wheat are more responsive to elevated CO_2 than more recent post “green revolution” types. There are also known interactions between water and nitrogen dynamics and elevated CO_2. Screening of germplasm for CO_2 responsiveness and tolerances of (and interactions with) abiotic stresses is feasible with suitable screening environments, and marker assisted selection.

Key words. Landrace, climate change, genetic variation, abiotic, tolerance.

Introduction

World climate change and plant breeding initiatives

The Intergovernmental Panel for Climate Change (IPCC) is continually updating the principal drivers for climate change, the unprecedented recent rise in the levels of CO_2 and of highly damaging pollutants such as methane, which trap back radiation of solar energy from earth to create a warming blanket effect around earth. This effect is super-imposed on a complex weather system to result in short term volatility overlaying a consistent long term trend for an increase in temperature globally of 2 – 4°C between corresponding optimistic and pessimistic scenarios (Singh et al., 2011).

Further consequences of these changes could include an arctic ice melt interference with the flow of the gulf stream from the Caribbean to warm northern Europe, increased inroads of deserts into west Africa, a drier central Africa and drier and hotter conditions in northern India (Lotze-Campden 2011, Singh et al., 2011, Battisti and Naylor 2009). Southern Australia is also expected to be hotter and drier with increased frost frequencies, while northern Australia may be wetter with more irregular rainfall increasing the frequency of floods (O’Leary et al., 2011, Howden and Crimp 2011).

A global rises in mean temperature will be accompanied by extreme temperature spikes to levels rarely experienced by crops, and by more severe in-crop droughts in temperate cropping regions (Battisti and Naylor 2009). These major abiotic stresses may be partly mitigated by the fertilization effect of increased CO_2 concentration. However on balance crop production is expected to be negatively affected in the temperate zone, positively affected in high latitudes in the northern hemisphere by warmer and longer growing seasons and similarly for crops at high altitudes, while effects in the tropics are likely to vary by crop and regional climates (Lafarge et al., 2011).

In anticipation of these challenges, international crop research institutes and national breeding programs are striving to select for adaptation to the expected climatic stresses. At CIMMYT, late sowing of wheat screening nurseries in northern Mexico have placed the vulnerable reproductive phase into high summer temperatures, while irrigation is withheld in other nurseries to screen for drought tolerance (Trethowan and Mahmood 2011). Selections from these programs supplement national wheat breeding in northern India, aiming for new combinations of drought plus heat tolerance.

In southern Africa, CIMMYT and Monsanto are collaborating to select maize with both heat and drought tolerances, with multi-location testing both in the target cropping zone and in high stress test environments (Redden et al., 2011).

World population and food security

The world population is rising to unprecedented levels from 7 billion now to over 9 billion by 2050, when the majority will be urbanized. Mega-cities will occupy previously productive farm land and compete with agriculture for access to water. This is the context in which a 70% increase in world food production needs to be achieved, to ensure sufficiency for all (Lotze-Campden 2100, Redden et al., 2011). There will be many complexities to resolve, but overall crop productivity will need to be increased in a far more challenging environment,

Genetic diversity for adaptation to climate change.

There has been no selection for responsiveness to high levels of CO_2 which have been below 280 ppm over the last 10,000 years since crop domestication. Genetic variation for this trait, if it exists, may be found in the wild relatives of crops which may retain residual genes for responsiveness dating back to high CO_2 levels during the ancient evolution of higher plants. We are only now researching crop responses to increased CO_2 levels over the current 380 ppm and up to 750 ppm, in both controlled environments and in Free Air CO_2 Enrichment (FACE) studies in open fields. The screening for potential diversity for CO_2 responsiveness has barely begun.

FACE experiments have shown large genotypic yield differences (from negative to over 30% stimulation) to elevated CO_2 in oats, soybean, rice and wheat (see review by Tausz et al., in press). These experiments are typically performed on small sets of well-developed modern cultivars, making it difficult to generalize on species' responses. Little to no information exists on the response of wild relatives to elevated CO_2. However, some recent studies suggest that older cultivars of wheat may be more responsive to elevated CO_2 than more recent post "green revolution" types (Ziska et al., 2004), while others show contrasting responses, depending on their early vigour status (pers. comm. Palta). There are also known interactions between water and nitrogen dynamics and elevated CO_2. Screening of germplasm for CO_2 responsiveness and tolerances of (and interactions with) abiotic stresses is feasible with suitable screening environments, and marker assisted selection once contrasting parents are identified and recombinant inbred populations established.

In cowpea, Hall (2011) found two rare landraces from the west African Sahel with tolerance of temperatures over 40°C during reproduction, and one vegetable cowpea from India had similar tolerance. The Asian Vegetable crops Research and Development Centre exploits major genes for pollen production under heat stress tolerance in tomato and in cabbage in breeding for heat stress (33°C) tolerance (de la Pena 2011). Recently, selection for heat tolerance in chickpea has become a breeding priority for ICRISAT. High temperature field screening of the reference mini-core collection (n=280) identified 18 stable genotypes that were tolerant in both north and south India, suggesting that this adaptation is relatively common in chickpea. In addition to increasing seasonal temperature, heat shock events are likely to become more common under future climates. Heat shock around flowering can have severe impacts on yield in many crops, but tolerance can be a difficult factor to screen for (Fischer 2011). Knowledge of whether elevated CO_2 ameliorates or exacerbates heat shock effects on crops, and the interactions with timing and duration of these events, has received little attention experimentally. Nonetheless, simulation modeling shows that altering the time of flowering or developing more heat tolerant lines is likely to reduce the impacts on yield (Gouachea et al., 2012).

The CIMMYT wheat program has screened advanced lines for drought and for heat stresses, with measurement of physiological parameters, which explained 34% of their yield variation in trials across heat and drought stress locations. Opportunities were identified for combining heat and drought adaptive traits into one genotype (Lopes et al., 2012). 'Stay Green' another drought related trait in wheat, as measured by spectral reflectance as the 'normalised difference vegetation index' in combination with canopy temperature at grain filling accounted for 30% of yield variability in another CIMMYT trial (Lopes and Reynolds, 2012).

Techniques such as these have been applied also in the CIMMYT maize program in multi-location testing across drought stress sites in southern Africa (Redden et al., 2011).

Methods.

At Horsham 8 large FACE rings of 16M diameter fed CO2 to field plots of wheat and of pea varieties to achieve 550 ppm CO2, with 8 more rings as controls. Half of each treatment was irrigated and half was rainfed. In 2010 and 2011 different varieties of each were compared over the whole growing season for growth traits and yield.

Pea landrace collection sites in China were analysed with world climate databases.

Results

(Results will be fully reported and presented at the Agronomy conference)
- CO2 stimulated yield by 20% across two years of data (p=0.035 in 2010, no stats yet for 2011)
- There were no irrigation by CO2 effects
- No CO2 effects were detected using heat chambers on the wheat plots
- There was a wide range of yield stimulation response for pea (see table 1) but no consistent trends across the two years. The data suggests wide cultivar variation in response to eCO2 but the cause of these differences is unclear. The yield component that was more highly significant in 2010 was seeds/m2 (p=0.012). This is similar for cereals where grains/m2 was the principal yield determinant.

Table 1. Grain yield responses of pea cultivars to enhanced levels of CO2, in the FACE trial, Horsham, in 2010 and 2011.

Pea cultivar	% increase	
	2010	2011
Bohatyr	--	2
Kaspa	18	37
OZP0902	50	9
Twighlight	33	0
Sturt	19	25
Mean	27	14
Canola	--	-8

Germplasm collection site climate

Li Ling et al., (2012) characterized the locations where pea landraces were collected in China for long term climatic data, to identify sites with heat, drought and frost stresses in the reproductive phase, and even with tolerance to combined stresses. Landraces from these selected sites have been prioritized for validation of these putative stress tolerances at Waite Campus University of Adelaide. If validated, this approach indicates a potentially useful means of targeting genetic resources for specific traits from both the domestic and wild relative gene pools.

Table 2. Summary of candidate stress tolerant pea landrace accessions from climatic stress collection sites in China.

Tolerance	Number	Source province	Habit
Frost and drought	23	Yunnan	Winter
Heat	10	Ningxia, Xingjiang	Spring
Heat and drought	23	Inner Mongolia, Xingjiang, Hebei	Spring
Frost	5	Gansu, Qinghai	Spring

Conclusion

There is genetic variation for heat and for drought tolerances in the germplasm of many crops, with scope for further exploration in the related wild relatives. There are also opportunities to search for such abiotic tolerances using ecogeographical analyses of origins of land races and of wild relatives. Major international breeding programs have well developed assessment procedures that can applied in breeding programs, and with evidence of selection gains for heat and drought stress related traits. However more research is required to assess genetic variability both between crop species and within crop germplasm for responsiveness to increased levels of $CO_{2,}$ which will be increasingly important as both economic development and population growth increase this century and magnify the carbon footprint of humanity.

If plant breeding programs are better targeted now to address both the challenges and opportunities of climate change, there is hope that agriculture will be capable of coping with predicted more intense drought, high temperature and frost stresses in southern Australia, and high temperature stress in northern Australia, especially as the worst case scenario of mean world temperature increasing over 2°C beyond 2050 appears more likely.

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