Developing climate adapted varieties for future cotton productivity

By Dr Robert Sharwood[1] and Dr Michael Bange[2]

AT A GLANCE…

- Climate change is a serious threat to future cotton productivity associated with the rise in CO_2 emissions.
- New strategies to improve cotton productivity are being considered through improving leaf photosynthesis – the process critical to maintaining plant growth.
- Manipulating the key CO_2 fixing enzyme Rubisco in the leaf may provide some new help in mitigating future climate change impacts on cotton growth.

THE future productivity of Australia's cotton industry is challenged by seasonal conditions that are progressively more unpredictable, with increased heatwave and drought events. Anthropogenic CO_2 emissions across the globe are continuing to rise. The Mauna Loa Laboratory in Hawaii recently recorded the global atmospheric CO_2 concentration at 415 ppm – up from 410 ppm in 2017 (*https://www.esrl.noaa.gov/*).

The continued increase in atmospheric CO_2 has already led to an increase in the average temperature across Australia of 1°C (*www.bom.gov.au*). Climate modelling published from the Intergovernmental Panel on Climate Change (*https://www.ipcc.ch/*) is predicting a future of potentially up to 4°C increase in the mean surface area temperature across the globe by 2050. Without doubt, curbing CO_2 emissions is a significant global challenge, so there is a need to fortify cotton crops (including the development of resilient varieties) to cope with these changes. Future varieties need to respond to higher CO_2 and withstand higher temperature and more extreme drought events.

They also need to be more nitrogen and water use efficient. Other research is being undertaken to investigate management strategies to reduce these impacts.

Researchers Demi Gamble and Robert Sharwood.

One strategy to reduce the impacts of climate change and to improve the resilience of cotton varieties is to consider improvements in leaf level photosynthesis. Photosynthesis is key to crop productivity through enabling utilisation of light to power the process of CO_2 assimilation to produce carbohydrates, which the crop ultimately uses for growth (including seed and lint yield). Photosynthesis is linked to water use efficiency (WUE) as for every CO_2 molecule that enters the leaf, 500–1000 water molecules are transpired into the atmosphere. So improvements in WUE can be addressed through improving CO_2 assimilation within the leaf and the whole canopy.

To address this challenge for cotton, a collaborative cross-institutional initiative is being undertaken to consider solutions for improving photosynthesis from the molecular level (DNA) to the leaf and ultimately to the crop in the field. The institutions involved are the Australian National University (ARC Centre of Excellence for Translational Photosynthesis), the CSIRO, Western Sydney University and the United States Department of Agriculture.

Rubisco is an important enzyme in the photosynthesis process. Under the right conditions, it initiates the carboxylation reaction which assimilates CO_2 within the leaf to build carbohydrates. But in some circumstances, such as drought conditions or high temperatures, Rubisco uses oxygen instead, in a very inefficient oxygenation reaction.

Rubisco can also confuse CO_2 with O_2 and promote oxygenation reactions, which decrease yield potential. Another limitation of Rubisco is that it relies heavily on its regulatory partner, Rubisco activase, to maintain its own activity (Figure 1).

In the carboxylation reaction, Rubisco converts RuBP into 3-phosphoglycerate (3-PGA) that is cycled through the Calvin cycle for the generation of carbohydrate building blocks.

So the first aim of the research is to increase Rubisco carboxylation reactions and suppress the oxygenation reaction. This means the plant takes more advantage of the CO_2 present in the leaf and responds less to the oxygen. This is important as the oxygenation process is increased under drought and elevated temperatures.

Furthermore, oxygenation produces a toxic molecule that needs to be recycled through photorespiration (Figure 1). This results in a loss of assimilated carbon and means more energy is used to produce carbohydrates.

The second aim of the research is to improve the heat tolerance of Rubisco activase in cotton. Rubisco activase regulates the activity of Rubisco, but under higher temperatures this enzyme falls apart, which renders Rubisco inactive and CO_2 assimilation becomes severely limited.

In crops like cotton the imperfections of Rubisco described above have been combatted by leaves producing large amounts of the enzyme in the leaf (up to 50 per cent of the leaf soluble protein) to ensure appreciable rates of CO_2 assimilation. This

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makes Rubisco one of the most abundant enzymes on the planet. It also makes it a huge nitrogen sink for the plant and is a significant reason for needing heavy rates of N in high yielding cropping systems.

Strategies to improve photosynthesis under future climates?

The first strategy is to screen for natural diversity across different species and/or cultivars of cotton for their Rubisco performance. This will provide insight into the evolution of cotton Rubisco and the key determinants for Rubisco carboxylation.

Recently, new technology has become available to express plant Rubisco in bacteria which will increase the capability of screening for enzyme performance. With this knowledge, we can either directly engineer changes into the enzyme via gene editing or directly transplant new versions into varieties by utilising plant transformation technology.

The second target is to alter the heat tolerance of Rubisco activase. Versions of activase exist in nature that offer improved rates of Rubisco activation at elevated temperatures. Examples now exist in plants such as *Agave tequiliana* (plant used to make tequila), which have a Rubisco activase that operates under substantially higher temperatures.

In either case, it will take time to incorporate these changes through pre-breeding germplasm development and the subsequent incorporation into breeding programs. The need for improving resilience of cotton productivity to future climates is on our doorstep and new technologies will be required to facilitate incorporation of these favourable traits.

We recognise that it is possible under future climate scenarios that there may be challenges associated with increasing photosynthesis, especially in cotton systems which are considered high input. While field studies conducted under elevated CO_2 and temperature have observed increased leaf level photosynthesis, these studies have also identified challenges associated with these environments, including increased vegetative biomass and water use.

Reduced water use efficiency

Crops that have excessive vegetative growth with large leaf areas significantly increase transpiration, resulting in a reduction in water use efficiency. Further reductions of water use efficiency were observed under high temperatures. Finally, excessive vegetative growth also resulted in excessive canopy shading due to increased leaf area, leading to fruit shedding.

This, in turn, continued to exacerbate the excessive vegetative growth and the loss of fruit because there was little fruit load to restrict vegetative growth. So practices restricting early vegetative growth to limit water use early in the season may be necessary if vegetative growth is greatly increased due to the fertilisation effect of elevated CO_2 or manipulations in leaf physiology to increase photosynthesis.

Management to restrict early vegetative growth (resulting in season long reductions in transpiration) may include the use of growth regulators or cultivars that develop fruit early to act as a sink, restricting vegetative growth. As part of the overall research effort we are building the appropriate research capacity to ensure that these investments deliver the changes needed and fit appropriately in cotton systems of the future.

1. ARC Centre of Excellence for Translational Photosynthesis, Australian National University.
2. CSIRO Agriculture and Food.

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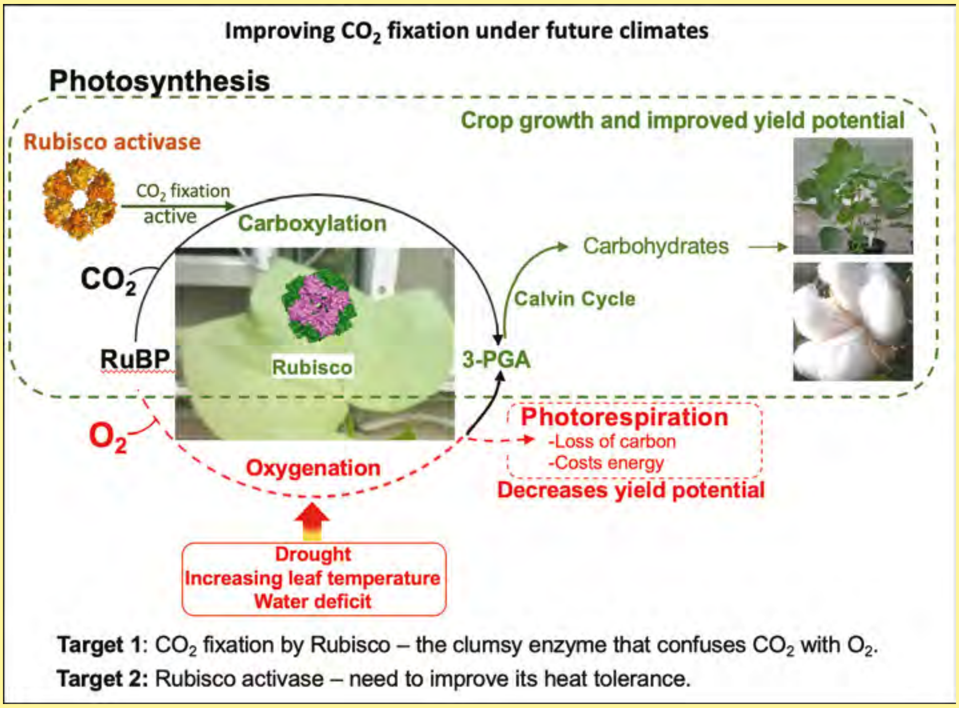
FIGURE 1: Overview of photosynthesis and the key components for assimilating carbon for productive plant growth and yield



Rubisco (RuBP) is an imperfect enzyme that confuses CO_2 with O_2. The carbon assimilation pathway of Rubisco (carboxylation) involves the CO_2 fixation that produces 3-phosphoglycerate (3-PGA) that is cycled through the Calvin cycle that ultimately produces carbohydrates that maintain growth and facilitate fibre yield. Oxygenation decreases yield potential through the loss of carbon and energy costs of photorespiration. Photorespiration is increased as the propensity of oxygenation increases under conditions of drought and elevated ambient air temperature.