Thirsty work

Maintaining a global food supply in the face of climate change will require the development of new crops that can thrive at higher temperatures. And that means using water more efficiently.

In late June of this year, western Canada and the northwestern United States experienced a period of unusually high temperatures. In Lytton, British Columbia, the temperature reached 49.6 °C on 29 June; before 2021, the temperature in Canada had never exceeded 45 °C. This heatwave has forced power cuts in Washington state due to excessive demand from air-conditioning units, and has likely resulted in several hundred premature deaths in the area. The immediate atmospheric cause of this event is a vast, high-pressure 'dome' of hot air sitting nearly stationary over an area stretching from the Arctic down to California. Like any 'freak' weather incident the creation of this dome cannot be directly attributed to climate change, but it is certainly an example of the phenomena that are predicted to become less uncommon as average global temperatures rise.

Basic biochemistry classes teach the 'Q10' rule, whereby enzyme-catalysed reactions approximately double in speed with a 10 °C temperature increase. With this logic, even a 5 °C increase — as is being endured in Canada — would increase reactions by 40%. But reaction speeds, binding affinities and denaturation rates are not all affected by precisely the same amount. Temperature changes threaten the delicate biochemical balance on which life depends, and must therefore be guarded against.

This issue of *Nature Plants* features an Article examining a mechanism to guard against changes in development at elevated temperatures. The study is performed in barley and finds that HvMADS1, a MADS-box protein which is homologous to SEPALLATA, has a role in maintaining an unbranched spike architecture. Loss-of-function mutants have wild-type inflorescence phenotypes when grown in temperature regimes varying between 15 °C during the day and 10 °C at night, but under heat-stressed conditions (28 °C day/23 °C night) a branched inflorescence architecture emerges. The suppression of the heat-stress phenotype is achieved by increased binding of HvMADS1 to nucleic acid sequences prone to conformational changes with temperature. Stabilizing such sequences in the promoters of genes associated with inflorescence differentiation and phytohormone signalling suppresses the abnormal development. Understanding such

thermoprotective mechanisms could help in breeding crops better suited to a warming climate. This would be especially beneficial to breeding cereals, where there is generally an unhelpful trade-off between high yields and heat tolerance.

Arguably the biggest threat associated with raised temperatures, however, comes from its indirect effect on water availability. Plants rely on constant transpiration from their leaves and other aerial parts to maintain transport of material from where it is produced to where it is used. A good supply of water is also needed to maintain a turgor pressure within individual cells which provides plant tissues with mechanical support. Higher temperatures increase transpiration rates, and if this exceeds the amount of water that the roots can supply the plant wilts and ceases functioning. Plants can of course regulate their transpiration rates by opening or closing stomata, but stomata are also the route by which carbon dioxide and oxygen enter and leave the organism, and without the exchange of those gases photosynthesis stalls.

In one way, the developments and innovations that are seen in photosynthesis through its evolution can be considered responses to the trade-off between transpiration and gas exchange. In most environments, sunlight is not a scarce commodity so increasing the efficiency of its capture is not particularly advantageous to many plants. In fact, plants face more danger from collecting more light than they can use, especially under conditions of fluctuating light, and so have evolved systems such as non-photochemical quenching to harmlessly dissipate excess energy when their photosynthetic machineries are overwhelmed. Water, on the other hand, is frequently limiting.

To put it simply, by compartmentalizing the light-capturing and biochemical processes in different tissues — separating the 'photo' from the 'synthesis' as it were — C4 plants are able to keep oxygen produced in the light reactions away from the key synthetic enzyme RUBISCO, which oxygen inhibits. The resultant lower demand for gas exchange means that C4 plants can function with less open stomata than more straightforward C3 plants, and therefore have a lower transpiration rate and higher water-use efficiency. Plants employing

crassulacean acid metabolism (CAM) go one better, by compartmentalizing photosynthetic processes temporally, only opening stomata at night when temperatures (and thus transpiration rates) are lower, and storing the carbon dioxide collected as malate to be used during the day — an extremely water-efficient approach.

Unfortunately, the majority of crops grown are the more water-inefficient C3 plants. Although plants such as maize, sugarcane, sorghum and millet employ C4 photosynthesis, pineapple and agave are essentially the only food crops to use CAM. This is the motivation for efforts to engineer crops with more efficient water (and nitrogen) usage through incorporating aspects of C4 photosynthesis. Prominent among these is the [Realizing Increased Photosynthetic Efficiency](#) (RIPE) project led by Professor Steve Long of the University of Illinois.

Another way to satisfy our crops' thirst for water could be to use (or make) plants more tolerant to salt. These crops could be irrigated with brackish or sea water, and so open up estuarine lands to agriculture. Only last month we published a study (*Nat. Plants* 7, 787–799; 2021) looking in detail at the gene regulatory networks involved in salt stress responses (albeit in *Arabidopsis* and *Marchantia*, neither of which can be considered crop plants). These networks are generally conserved across the plant kingdom, so employing this knowledge to crop development is entirely plausible.

Of course, there is no shortage of water in the sea, but marine agriculture is not widespread. Seaweed has long been a feature of Asian cuisine, and laverbread, made from *Porphyra umbilicalis*, is a traditional dish in Wales. Over the last decade kelp farming has been developing around the coasts of North America, and while it has not proved to be 'the new kale' as it was once touted, it is fast growing and highly sustainable.

Water is a precious commodity, as essential for plant growth as for all other forms of life. Finding ways to improve water usage must therefore be a priority for plant research. □

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