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Down-to-earth drought resistance

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Drought is a serious threat to global food security. In upstream research, crop drought-tolerant traits are often studied under extreme drought conditions, which can seem irrelevant in the eyes of breeders.

Although wildfire may have positive ecological function (as we discussed in our February editorial[1]), drought — its related, but seemingly lesser, stressor — is harmful or even devastating, particularly to agricultural ecosystems. Drought develops gradually and its start or end can be difficult to identify, but its effects are often long-term and catastrophic. Climate change is predicted to lead to more frequent and severe droughts in many parts of the world. Last year was one of the hottest and driest in historical record, and people in the Horn of Africa suffered particularly badly[2]; a record that is likely to be surpassed all too soon. Breeding drought-resilient crops is often proposed as a solution for mitigating the negative outcomes of drought and has become an important and urgent goal for global research communities. But this endeavour is impeded by the gap between basic research and breeding practice.

A Comment published in *Nature*[3] in September 2023 highlighted that many previous publications have oversold the effects of their reported genes in yield gain. Out of 1,671 reported yield-increasing genes, only one showed constant yield benefits in maize across years and locations in a large-scale field trial. Without close collaborations between molecular biologists (or geneticists) and breeders, unrealistic field trials have overestimated the agronomic effects of tested genes. The authors proposed five criteria for evaluating yield gain in field trials, including standardized definitions of yield, and multiple-location and multiyear experiments.

Drought resistance is also a complex trait that is defined differently under different scenarios, and is greatly affected by the environment. This complexity causes a similar disconnect between genetic studies and the breeding of drought resistance. Multiple breeding programmes have been undertaken worldwide by large research units such as the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT) in pursuit of drought-resistant crops. At the same time, molecular biologists and geneticists continue to report the cloning of genes with drought resistance or tolerance traits, but these genes are rarely beneficial to crop breeders. As drought resistance expert Lijun Luo said at a recent conference in Sanya last month, “out of the over 300 rice functional genes claimed to increase drought resistance, none of them has been successfully applied in breeding!”

The main problem, according to Luo, is that these molecular studies focus on ‘drought tolerance traits’ rather than ‘yield under drought’. There is a well-established trade-off between stress tolerance and the productivity of plants; many wild relatives of crops exhibit strong stress tolerance but poor yield potentials. Conversely, upland rice varieties, such as IRAT109, that display stable yield under drought tend to have very poor drought tolerance (according to Luo). Improving the drought tolerance of crops without considering yield in the field is shooting at the wrong target.

If IRAT109 is not drought tolerant, then the question arises of what guarantees its yield stability under drought. The answer is its elite drought avoidance. It has long been realized that drought resistance can be achieved by multiple traits that are broadly classifiable into three main types: drought escape (by short life duration), drought avoidance (by deeper root distribution) and drought tolerance[4]. Scientists who use model plants such as *Arabidopsis* and rice to study drought resistance mechanism often focus on drought tolerance traits — such as the ability of plants to survive drought when dehydration has already occurred in the plant tissues — using water deprivation or polyethylene glycol treatment to screen for resistance. The resultant phenotypes often bestow a higher survival rate of the plants under drought or a higher recovery rate during rehydration, but not necessarily a higher yield. Without deciding beforehand the specific drought-resistant trait that is needed to improve the productivity of the specific crops in the target environment, laboratory-based studies can become aimless and futile.

Knowledge about environments is also important. According to the levels of yield loss (from 85% to 40%) under drought, Kumar et al. classified drought stresses as very severe, severe, moderate and mild[5]. Henry and Torres in the IRRI tested the performance of several rice varieties and found that the varieties that are adapted to mild and moderate drought with stable yield are different from the varieties adapted to more severe drought stress[6]. As mild drought stress affects a large proportion of drought-prone rice-growing areas in the world, a laboratory experiment that applies severe stress treatment can hardly be expected to identify genes that are useful in most drought-affected areas. In addition, droughts can be of different durations (short or long), different frequencies (continuous, intermittent or once per season) or occur at different growth periods of the crop. Crops use different drought-resistant traits or mechanisms to adapt to these types of droughts. Purely laboratory-based research can oversimplify drought stress treatments and so fail to understand the severity or types of droughts that are agriculturally relevant[7].

In a paper published in 2021, Xiong et al.[8] reported that climate change has increased the ranking changes of wheat varieties in breeding trials over the past four decades. In other words, the relative performance of crop varieties is becoming less easy for breeders to predict. However, breeding trials targeted to drought or heat stress environments have not been affected. Breeding trials would also benefit from precisely targeted agronomically relevant stress environments.

To better cope with future droughts, drought-related crop research needs precision. Molecular biologists must cooperate with — or at least consult — agronomists to better understand their needs. It is certainly informative to study a drought avoidance trait such root architectures or a drought tolerance trait such leaf rolling[9], but it is also crucial to monitor yield under drought. Moreover, high-yielding and widely planted varieties make a more appropriate genetic background than poor-yielding model genotypes when testing for drought resistance in the real world.

The natural variations of crops held in their wild relatives or in adapted landraces (such as upland rice) provide a valuable genetic resource to help to balance yield and drought resistance. The increasing availability of their genomes provide opportunities for researchers to identify the genes or quantitative trait loci that are most likely to complement the current breeding pool for drought resistance. Better evaluation of these materials, followed by their utilization in precision drought research, will hasten the development of resilient crops.

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