Plant thermal tolerance: a global synthesis for future research

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Extreme temperature events are increasing in frequency and intensity across the globe. These extremes, rather than averages, drive species evolution and determine survival by profoundly changing the structure and fluidity of cell membranes, altering enzyme function, and denaturing proteins. Given not only our dependence on agricultural crops and natural vegetation, but also the role of photosynthetic processes within the carbon and hydrological cycles, it is imperative to assess the state of our understanding of the potential impacts of extreme events on plants. Scaling responses from the molecular and organ level to ecosystem function is not without challenge however. There is vast literature on plant thermal tolerance research, but the body of literature is so large, the approaches so disparate and often siloed among disciplines, that research in this field risks floundering at a critical time. We conducted a systematic review of more than 21,500 studies spanning over 100 years of research that yielded almost 1,700 included studies on the tolerance of cultivated and wild land plants to both heat and cold. Our review indicates that most studies on thermal tolerance focus on the cold tolerance of cultivated species (52%) and only a trivial percentage of studies have considered both heat and cold tolerance of any given species (~5%). Combined heat and cold tolerance are important in areas where plants are exposed to extremes of both or may be in the future. This review illustrates the global distribution and concentrations of thermal tolerance studies and the diversity of thermal tolerance methods, ranging from molecular to biochemical, physiological and physical examinations, from transgenic model plants to agricultural and horticultural crops, to natural forest trees, shrubs, and grassland herbs. Critically, it also demonstrates that methods and metrics for assessing thermal tolerance are far from standardised, such that our potential to achieve mechanistic insight and compare across species and biomes is compromised. Without reconciling these issues, the scope for incorporating this critical ecological information into vegetation elements of land surface models may be limited. To aid this, we identify priorities for achieving efficient, reliable, and repeatable research across the spectrum of plant thermal tolerance. These priorities, including meta-analytical approaches and comparative experimental work, will not only further fundamental plant science, but will prove essential next steps if we are to integrate such diverse data on a critical plant functional trait into a usable metric within biogeochemical models.