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Novel perspectives for the engineering of abiotic stress tolerance in plants

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Adverse environmental conditions pose serious limitations to agricultural production. Classical biotechnological approaches towards increasing abiotic stress tolerance focus on boosting plant endogenous defence mechanisms. However, overexpression of regulatory elements or effectors is usually accompanied by growth handicap and yield penalties due to crosstalk between developmental and stress-response networks. Herein we offer an overview on novel strategies with the potential to overcome these limitations based on the engineering of regulatory systems involved in the fine-tuning of the plant response to environmental hardships, including post-translational modifications, small RNAs, epigenetic control of gene expression and hormonal networks. The development and application of plant synthetic biology tools and approaches will add new functionalities and perspectives to genetic engineering programs for enhancing abiotic stress tolerance.

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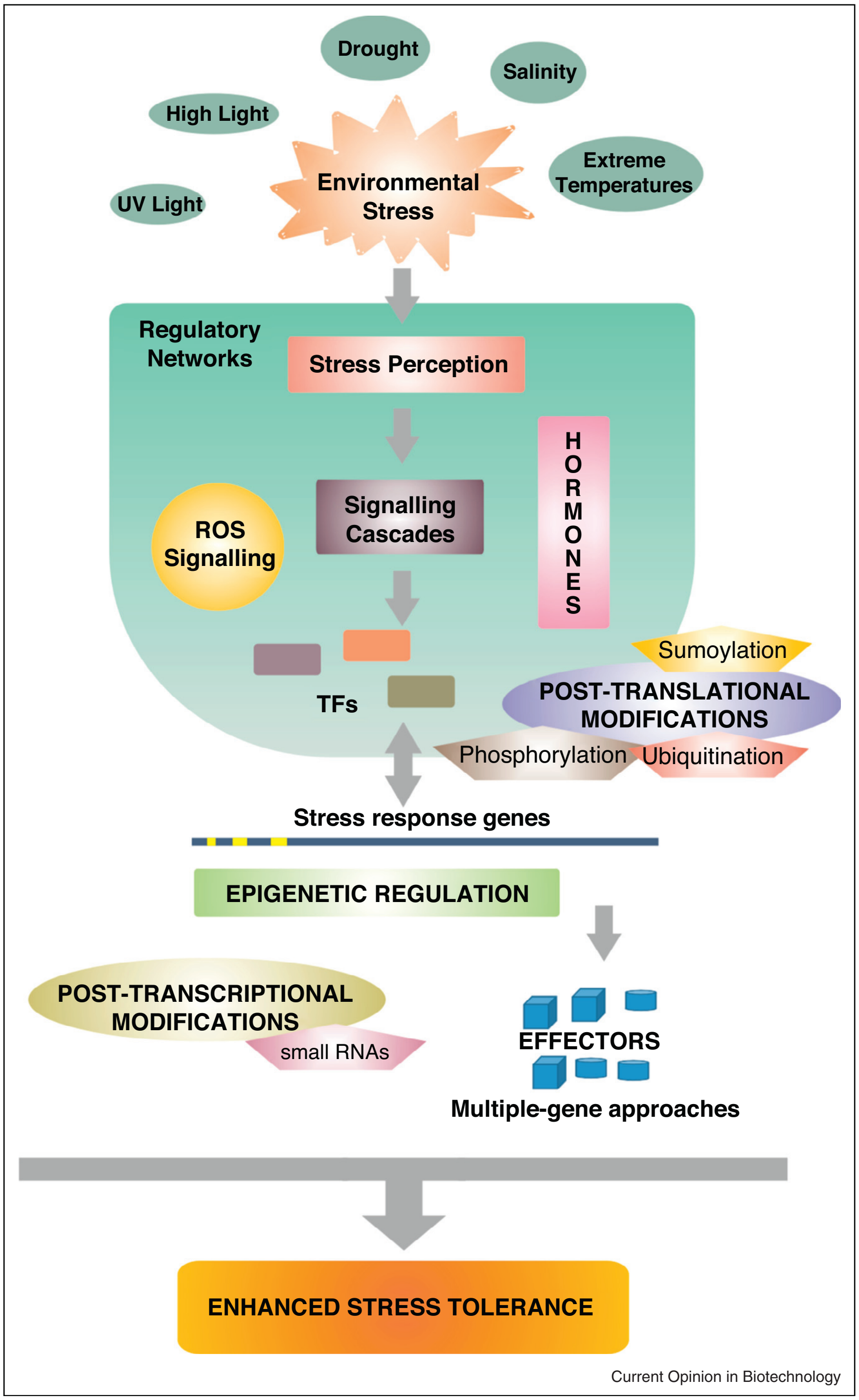
Introduction

One of the most active fields of research in plant science focuses on the understanding of plant molecular, physiological and genetic responses to environmental stress conditions, and the development of approaches towards improving tolerance and acclimation. Drought, salinity, extreme temperatures and high irradiation among a plethora of sources of abiotic stress, are perceived by sensor systems leading to the activation of complex regulatory networks controlling the expression of effector genes to counteract the detrimental effects and re-establish cellular homeostasis [1,2•].

The classical approach to engineer plants for enhanced tolerance to abiotic stress consists in strengthening the endogenous systems by intervening at different levels of the response, from sensors and signalling/regulatory elements (e.g. kinases, transcription factors), to direct-action genes or effectors (e.g. antioxidant enzymes, heat-shock proteins, enzymes for the synthesis of osmo-protectants) [2•,3,4]. Even though this strategy shows relative levels of success with an ever-increasing number of tolerant plants being reported [5••], it is not exempt of downsides. In the first place, there is considerable cross-talk between several regulatory, metabolic and developmental pathways. Therefore, while intervening upstream in the signalling network could lead to increased tolerance towards different sources of stress, there is a higher probability of producing undesired pleiotropic effects like growth handicap and developmental alterations. On the contrary, up-regulation of the expression or activity of direct-action genes normally provides enhanced performance only against individual sources of stress [3]. These aspects are particularly relevant as plants growing in natural environments are often simultaneously challenged by a combination of stresses, for example, drought and heat, which lead to synergistic, neutral or even antagonistic effects [6]. A better and more comprehensive knowledge of the complex mechanisms involved in the stress responses provided by the various 'omics' platforms has allowed to identify novel points of intervention, dealing in particular with a new layer of control or fine tuning of the main response scheme. Manipulation of processes like post-translational modification of signalling components, regulatory systems based on small RNAs, epigenetic control of gene expression and the intertwined effects of several hormones within these networks, among others, provide ways of achieving a more generalized stress tolerance while keeping a tighter control on the response [2•,4,7].

We describe herein recent reports of successful approaches to obtain enhanced tolerance to environmental stress, especially focusing on further perspectives provided by engineering the above-mentioned novel regulatory targets (Figure 1). We also analyse the limitations and challenges encountered when translating these

Figure 1



Plant abiotic stress response and intervention points for genetic engineering strategies. Environmental stress conditions, such as drought, salinity, extreme temperatures and high irradiation induce the activation of complex regulatory networks leading to the establishment of a defence response. Sensor systems trigger downstream signalling and transcriptional control cascades, involving numerous families of transcription factors (TF), which results in extensive changes in cellular gene-expression programs. In this context hormonal responses integrate plant development and physiology with environmental cues. Reactive oxygen species (ROS) operate as powerful signalling molecules within the regulatory networks. Stress-induced genes encode for regulatory components and effector proteins that activate stress-responsive mechanisms to re-establish cellular homeostasis, eliminate toxic compounds and protect and repair damaged proteins and membranes. Fine-tuning of the response is supported by post-translational modifications to proteins, for example, ubiquitination, sumoylation and phosphorylation, as well as by epigenetic control of gene expression. Post-transcriptional regulation by stress-induced small RNAs (miRNAs and siRNAs) constitutes an alternative regulatory layer amenable for genetic engineering approaches.