Applications from UV studies in plants for crop improvement

Rainer W. Hofmann[1] and Shirley N. Nichols[2]

1. Faculty of Agriculture and Life Sciences, Lincoln University, P.O. Box 85084, Lincoln 7647, New Zealand
2. AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton 3240, New Zealand

Abstract. Here we provide an update on our research on stress protection in pasture plants in New Zealand. This work was originally inspired by investigations of UV effects in plants and then moved from the interaction of UV radiation with other environmental factors – particularly drought – to crop improvement research. The role of UV-absorbing phenolic compounds emerged as a focal point in this journey. In addition to their functions as plant pigments, these compounds also fulfil other roles of relevance to plant stress protection. Compared to cultivars bred for pastures, plant material collected from the wild contained higher levels of phenolic compounds such as hydroxycinnamic acids and flavonols. When bringing together a wild clover species high in these compounds with the key pasture legume white clover (*Trifolium repens*), the resulting clover hybrid proved more stress-tolerant, exemplified here by its response to drought.

Introduction

In nature, plants are exposed to a plethora of environmental factors, including ultraviolet radiation. Frequently, these factors interact with each other. This includes situations where one stress can lead to a response that protects plants against another stress, e.g. via the accumulation of protective biochemical compounds. One group of such compounds are the plant phenolics, which have been crucial elements of plant evolution, providing numerous ecological and physiological functions such as energy-dissipation, UV-screening and antioxidant activity (Hofmann et al. 2000; Markham et al. 1998).

The importance of these compounds and their involvement in the interaction of UV and drought in plants has been highlighted in previous NIWA UV workshops. Work in our group has focussed on the key legume species of NZ pastures, white clover. We have demonstrated that exposure to drought can decrease UV sensitivity in this species (Hofmann et al. 2003a; Hofmann et al. 2011). UV-induced increases in the levels of phenolics in white clover leaves were synergistically enhanced by drought. These compounds included the flavonol quercetin and its precursor kaempferol (Hofmann et al. 2003b), which can act as sunscreens in the epidermal layers of the plant.

UV-absorbing phenolic compound accumulation was particularly pronounced in white clover ecotypes collected in the wild and was related to tolerance to UV and drought (Hofmann et al. 2003b). These findings highlighted that wild (un-bred) white clover germplasm was more stress-tolerant compared to white clover cultivars bred for productivity in pastures. This tradeoff between plant productivity and stress tolerance was further examined by using an intraspecific pair cross between a stress-tolerant and a productive population of white clover (Ballizany et al. 2012).

The purpose of this article is to extrapolate on these earlier findings, showing how they are now being utilised in the development of novel plant material for future pastures.

Results & Discussion

We examined white clover plants that were hybridised with another clover species, *T. uniflorum* (e.g. Nichols et al. 2014a). The latter species is of Mediterranean origin where it is frequently exposed to dry conditions. When subjecting the first backcross (BC1) generation of this white clover x *T. uniflorum* hybrid to drought in the field, it showed lesser reductions of shoot dry weight and of plant morphological attributes than its white clover parent (Nichols et al. 2014a). The white clover x *T. uniflorum* BC1 generation increased root growth under drought stress, showed lower levels of drought-induced leaf senescence, as well as maintenance of photosynthesis and transpiration compared to white clover (Nichols et al. 2014a; Nichols et al. 2015).

In contrast to parent plants, leaves of the BC1 family contained high constitutive and drought-induced levels of flavonols, especially kaempferol. This is exemplified here by a comparison of the common NZ white clover cultivar Grasslands Kopu II with its BC1 generation (Figure 1). Constitutive kaempferol glycoside accumulation was linked to reduced leaf senescence and to less pronounced reductions in shoot dry weight under drought (Nichols et al. 2014a).

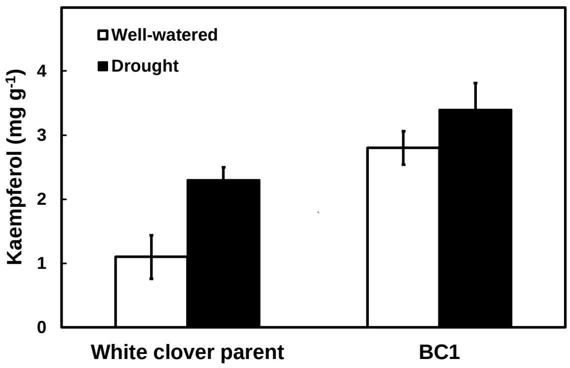

Figure 1. Mean levels of total kaempferol glycosides (±SE) in the white clover parent cultivar Kopu II and the first generation of a backcross (BC1) between Kopu II and a *T. repens* x *T. uniflorum* F1 hybrid, grown under well-watered and drought conditions in the field under an automated rain shelter at Lincoln, New Zealand (Nichols et al. 2015).

We also found higher drought-induced increases in the levels of hydroxycinnamic acid compounds in the leaves of the BC1 generation, when compared to its Kopu II white clover parent (Figure 2).

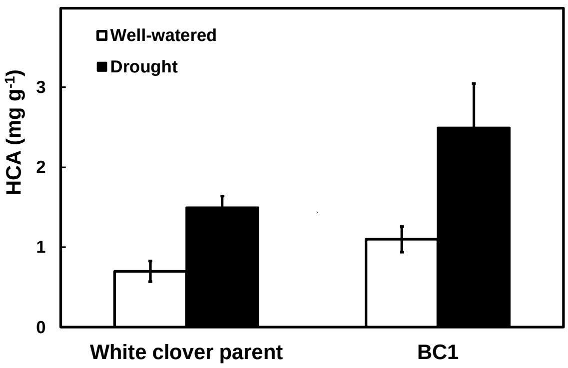

Figure 2. Mean levels of hydroxycinnamic acid (HCA) compounds (±SE) in the white clover parent cultivar Kopu II and the first generation of a backcross (BC1) between Kopu II and a *T. repens* x *T. uniflorum* F1 hybrid, grown under well-watered and drought conditions in the field under an automated rain shelter at Lincoln, New Zealand (Nichols et al. 2015).

In addition to screening UV (particularly UV-B), hydroxycinnamic acids also function as antioxidants, similar to the flavonols quercetin and kaempferol. However, in contrast to flavonols, hydroxycinnamic acids are simple phenolics that are distributed more ubiquitously and can perform antioxidant functions throughout the leaf. Thus, the leaves of the BC1 hybrid generation contained higher levels of stress-protective simple and more complex phenolic compounds that can all contribute to improved drought tolerance. Other findings also showed deeper root penetration of BC1 hybrids compared to white clover (Nichols et al. 2016) and tolerance of the BC1 hybrid to nutrient deficiency (Nichols et al. 2014b). This makes the white clover x *T. uniflorum* BC1 hybrid a promising candidate for plant breeding advances towards the development of cultivars for regions where climatic conditions are marginal for pasture production.

Conclusions

Ambient ultraviolet radiation is a regulatory factor for plants that interacts with drought and other stressors. There are key roles for UV-absorbing phenolic antioxidants in these interactions and this can be used for crop improvement. In particular, these findings provide opportunities for the development of improved water use and nutrient use efficiency in future pastures under a changing climate and where irrigation or the use of fertiliser are unsustainable, not practical or at a premium.

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