Tansley review

Seed dormancy and the control of germination

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Supplementary material

This section on applied aspects of the control of seed germination by dormancy is an additional part of the Tansley review and is available as supplementary material at the *New Phytologist* website (http://www.newphytologist.org/tansley.htm).

III. How is non-deep physiological dormancy regulated within the seed at the molecular level?

5. Applied aspects of the control of germination by seed dormancy

Seeds are the delivery systems for agricultural biotechnology, and high levels of "field" performance (seed quality) are essential for predictable seedling establishment. High seed quality and seedling establishment can be considered as cornerstones of profitable, efficient and sustainable crop production (Finch-Savage, 1995). Dormancy (usually low) is an important component of physiological seed quality and so plants with a long history of domestication and plant breeding generally have a lower seed dormancy than wild or more recently domesticated species (Li & Foley, 1997; Copeland & McDonald, 2001; Benech-Arnold, 2004). However, dormancy can increase when germination takes place under stress (i.e. poor field conditions). In practice, dormancy not only affects the number of seeds which germinate (high dormancy), but also their rate of germination (low dormancy) especially under sub-optimal conditions. A rapid germination rate is a widely accepted measure of seed vigour; a key component of seed quality that is little understood. Thus factors that determine both seed dormancy and vigour may overlap (Hilhorst & Toorop, 1997).

In cereal crops, a certain degree of dormancy at harvest is a desirable trait because it prevents viviparous germination of grains in the head following exposure to cool moist conditions (Benech-Arnold, 2004; Gubler *et al.*, 2005). This pre-harvest sprouting in many wheat cultivars, due to low harvest dormancy, has led to reduced grain quality at harvest and therefore serious economic losses. In contrast, high harvest dormancy of barley results in extra storage costs because the grain requires after-ripening to achieve the rapid and uniform germination required for the malting process. Thus, a defined level of seed dormancy is an essential component of seed quality. QTL analyses of cereal crop dormancy is one way to identify genes that underlie these physiological problems (Koornneef *et al.*, 2002; Gu *et al.*, 2004; Gubler *et al.*, 2005).

The horticultural and forestry industries also have a requirement for predictable seedling establishment, but many of the species used still retain wild characteristics, and so dormancy can be particularly problematic. Practical methods to release dormancy and induce germination include after-ripening, temperature treatment, hormone application (GA), scarification, and various technologies for seed enhancement like priming (Benech-Arnold, 2004; Halmer, 2004). However, while seed enhancements like priming may overcome dormancy to improve the percentage and uniformity of germination they can decrease seed storability and longevity.

Weed control is an integral part of efficient crop production that has benefited from developing new methods of dormancy release and from the increasing understanding of allelopathic interactions (Hilhorst & Toorop, 1997; Adkins & Peters, 2001; Gu *et al.*, 2004). Nevertheless a lack of knowledge concerning the annual dormancy cycle of buried weed seeds and an inability to predict their germination time limits the introduction, accurate targeting and success of many novel weed control methods (Benech-Arnold *et al.*, 2000 and references therein; Batlla *et al.*, 2004), and in particular those for low-input (non-chemical; sustainable) agricultural production.

The dormancy classes (e.g. PD or MPD), seed structure (e.g. covering layers), hormonal responses (e.g. to GA or ABA), and modelling of germination and seedling establishment (section IV) of domesticated species have been widely investigated. Indeed much of the earlier physiology and molecular research on seed dormancy has been in agricultural species.

For example, harvest dormancy of sunflower seeds is released by after-ripening and involves hormonal changes like decrease in ABA biosynthesis and sensitivity (Corbineau *et al.*, 1990; Le Page-Degivry & Garello, 1992; Le Page-Degivry *et al.*, 1996). Increasing knowledge of the molecular mechanisms of dormancy will reveal further ways to improve seed technologies and seed quality.

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