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Reversible cellular and metabolic changes induced by dehydration in desiccation-tolerant wheat seedling shoots

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Wheat seedlings obtained after 2 or 3 days of seed germination in darkness at 20°C (i.e. with a 0.5–0.7 cm long coleoptile) were still viable after drying in darkness in ambient conditions which reduced the shoot moisture content to about 0.30 g H_2O g^{-1} dry mass (DM). Coleoptile and primary leaf growth resumed upon rehydration, but primary roots died and new roots regenerated. In the present work we have investigated whether desiccation tolerance of the shoot (coleoptile and primary leaf combined) was related to some reversible cellular or metabolic changes induced by dehydration. Non-dehydrated shoots were high in moisture content (4.0–5.0 g H_2O g^{-1} DM) and exhibited an active metabolism as indicated by a high energy charge (EC = 0.85) and cells with well developed mitochondria, endoplasmic reticulum, polysomes and Golgi bodies. Dehydration induced changes in cell membrane properties since it reduced in vivo capacity of the shoot to convert 1-aminocyclopropane 1-carboxylic acid (ACC) to ethylene (i.e. ACC oxidase activity). This effect was already observed at 4–5 h of dehydration, namely when shoot moisture content dropped down below about 3.0 g H_2O g^{-1} DM, and ACC-dependent ethylene production became almost nil when shoot moisture content reached 1.0 g H_2O g^{-1} DM. Dehydration also resulted in decreases in ATP and non-adenylic triphosphate nucleotide (NTP) contents down to 1–2% of their initial values, and in EC value to 0.20. Concomitant with water loss, sucrose content of the shoot increased and was maximal (about 330 mg g^{-1} DM, namely three-fold that of non-dehydrated organs) after 2 days of drying. Upon rehydration, shoots regained their original moisture content within 3 days, during which they progressively recovered apparent normal metabolism. Reversal of extensive dehydration-associated cell wall folding occurred between 2 and 3 days of rehydration, when the ultrastructure of coleoptile and primary leaf cells also provided evidence of intensive autophagic activity, indicative of the removal of damaged cell components. Concomitantly, apparently undamaged organelles and endomembranes persisted in the cytoplasm. Restoration of 60–70% of ACC oxidase activity and 80–90% of EC value occurred within 48 and 18 h, respectively. However, the values of the ATP/ADP and NTP/ATP ratios remained lower than in control non-dehydrated shoots, indicating that not all metabolic deterioration induced by dehydration was completely repaired. Differences in relationships between shoot moisture content and ACC-oxidase activity or energy metabolism during dehydration and upon rehydration, and cell ultrastruture analyses suggest that desiccation tolerance of wheat seedling shoot is related to mechanisms involved in the maintenance of cell structure during water loss and the cell capacity to repair the dehydration damage.

Introduction

During germination, orthodox seeds lose their tolerance to dehydration after radicle protrusion and elongation (Senaratna and McKersie 1983, Leprince et al. 1994, Lin et al. 1998, and references therein). However, the stage of development at which the germinated seeds become desiccation intolerant depends on the species. For example, desiccation occurring 36 h after the start of imbibition kills soybean seeds (Senaratna and McKersie 1983), whereas wheat seed-

Abbreviations – ADP, adenosine diphosphate; AMP, adenosine monophosphate; ATP, adenosine triphosphate; EC, energy charge; ACC, 1-aminocyclopropane 1-carboxylic acid; NTP, non-adenylic triphosphate nucleotides; Σ, adenylate pool