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Trehalose: The Wonder Cryoprotectant

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1. Introduction

Trehalose is a natural alpha linked disaccharide formed by an α,α-1,1-glucoside bond between 2 glucose units. Wiggers in 1832 discovered Trehalose in ergot of rye but this name was assigned to this disaccharide by Berthelot in 1859 who isolated it from cocoons or trehala of desert beetles *Larinus nidificans*, *L.maculates*. These edible secretions were known as "trehala manna" by the native people. Trehalose is common sugar in both prokaryotes as well as eukaryotes such as bacteria, fungi and invertebrates (Crowe and Crowe 1984; Elbein et al. 2003) where it serves as an energy source or stress protectant (Muller et al. 1999). Mushrooms contain up to 10–25 % Trehalose by dry weight (Higashiyama 2002). With the notable exception of the desiccation-tolerant ''resurrection plants,'' including the ferns *Selaginella lepidophylla* ("rose of Jericho") (Adams et al. 1990), and *S. sartorii* (Iturriaga et al. 2009) Trehalose does not accumulate to detectable levels in most plants (Garg et al. 2002) and most of the plant species accumulate sucrose as major transport sugar (Wingler 2002). Although distinctly absent in most plants, Trehalose biosynthesis genes were discovered recently in higher plants (Paul et al. 2008; Schleupmann and Paul 2009).

2. Structure of Trehalose

Trehalose is structurally α-D-glucopyranosyl-[1,1]-α-D-glucopyranoside), a non-reducing disaccharide (Fig. 1) since it is formed by the bonding of two reducing groups thereby unable to reduce other compounds (Muller et al. 1999).

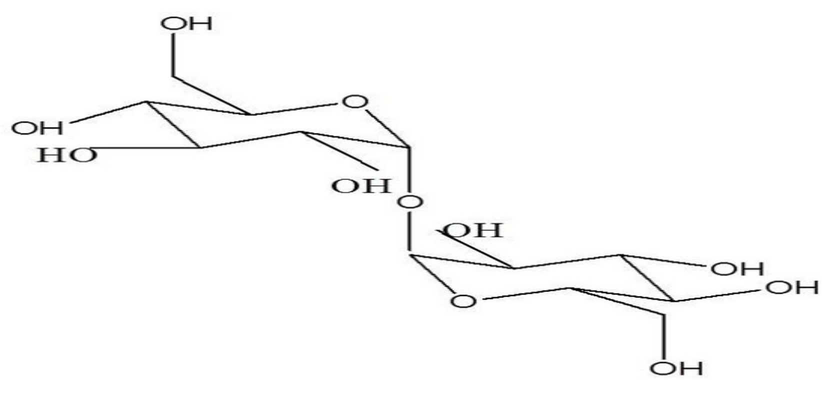

Fig. 1: Molecular structure of Trehalose (Bhandari and Nayyar, 2014)

3. Biosynthesis of Trehalose

Trehalose is synthesized in 2 steps (Avonce et al. 2005) from glucose-6-phosphate and uridine diphosphoglucose (UDP-Glucose).

STEP 1: Glucose-6-phosphate and UDP-Glucose in the presence of enzyme Trehalose phosphate synthase (TPS) react to form Trehalose-6-phosphate and UDP.

STEP 2: In this step, the products of step 1 in the presence of enzyme trehalose-6-phosphate phosphatase (TPP) react to form the ultimate product

Trehalose (UDP-Glucose + Glucose-6-P → UDP+ Trehalose-6-P→Trehalose + Pi)

4. Role of Trehalose in plants

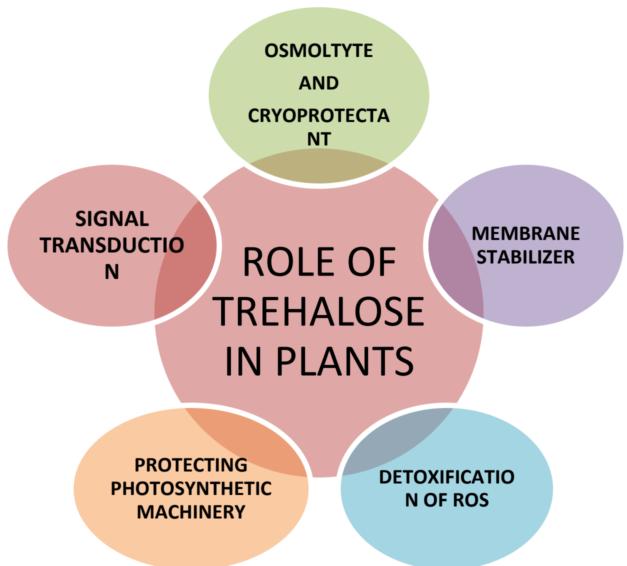

Fig. 2: Role of Trehalose in plants (Bhandari and Nayyar, 2014).

Trehalose protects organisms against various stresses (Fig. 2) such as drought (Yeo et al. 2000; Karim et al. 2007), freezing, salinity (Lopez et al. 2008) and osmopressure. In the case of resurrection plants, which can live in a dry state, when the water dries up, the plants dry up too. However, they can successfully revive when placed in water. The anhydrobiotic organisms are able to tolerate the lack of water owing to their ability to synthesize large quantities of Trehalose, and it plays a key role in stabilizing membranes and other macromolecular assemblies under extreme environmental conditions (Higashiyama 2002). Trehalose appears to play important role as a protectant under various abiotic stresses (Elbein et al. 2003) since Trehalose levels were found to be elevated in response to drought, and salt stress (Carolina and Caulinez-Macia, 2005) and cold (Mihaela and Ryozo, 2008). Transgenic plants producing Trehalose exhibited improved drought tolerance without any undesirable side effects (Karim et al. 2007). Activity of various Trehalose metabolizing enzymes also followed a regular trend whereby activity of trehalose-6-phosphate (TPS) showed increase (Kolbe et al. 2005) whereas that of trehalase decreased under stress. Increase in TPS activity was found to be parallel with Trehalose accumulation under stress (El-Bashiti et al. 2005). Pioneer experiments for obtaining transgenics over-expressing Trehalose were carried out on tobacco plants (Iturriaga et al. 2009) that corroborated its role in stress protection. Following is the list (Table 1) of some transgenics overexpressing Trehalose showing their response to abiotic stresses.

Table 1: Transgenic plants expressing trehalose biosynthetic genes.

Used gene	Origin	Transformed Plant	Morphological Alterations	Tolerance
TPS1	Yeast	Tobacco	Yes	Drought
Ots A[a]	E. coli	Tobacco	Yes	Drought
TPS1[b]	Yeast	Potato	Yes	Drought
TPS1	Yeast	Tomato	Yes	Drought, Salinity
TPS1	Arabidopsis	Arabidopsis	Flowering Delay	Drought
Ots A- Ots B[c]	E. coli	Rice	No	Drought, Salinity cold
TPS1- TPS2[e]	Yeast	Arabidopsis	No	Drought, salinity heat, freezing
TPS1- TPS2	Yeast	Alfalfa	Stunted	Drought, salinity heat, freezing

5. Conclusions

Thus, trehalose is a potent osmoprotectant and can be utilized as an effective cryoprotectant. Since trehalose doesn't accumulate in appreciable amounts in higher plants, it may be exogenously supplied to the plants or plants may be genetically modified. Transgenics over-expressing the trehalose synthesis genes were found to be tolerant to various abiotic stresses thereby further corroborating its role as a cryoprotectant.

6. Acknowledgements

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