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Embolism: How Changes in Xylem Sap Surface Tension Affect the Resistance against Hydraulic Failure

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Abstract : In vascular plants, water flows from roots to leaves in a metastable state, and even a small perturbation of the system can lead a sudden transition from the liquid to the vapor phase, resulting in xylem embolism (cavitation). Xylem embolism, induced by drought stress and/or freezing stress is caused by the aspiration of gaseous bubbles into xylem conduits from adjacent gas-filled compartments through pit membrane pores ('air seeding'). At water potentials less negative than the threshold for air seeding, the surface tension (γ) stabilizes the air-water interface and thus prevents air from passing the pit pores. This hold is probably also true for conifers, where this effect occurs at the edge of the sealed torus. Accordingly, it was experimentally demonstrated that γ influences air seeding, but information on the relevance of this effect under field conditions is missing. In this study, we analyzed seasonal changes in γ of the xylem sap in two conifers growing at the alpine timberline (Picea abies and Pinus mugo). In addition, cut branches were perfused (40 min perfusion at 0.004 MPa) with different γ solutions (i.e. distilled and degassed water, 2, 5 and 15% (v/v) ethanol-water solution corresponding to a γ of 74, 65, 55 and 45 mN m-1, respectively) and their vulnerability to drought-induced embolism analyzed via the centrifuge technique (Cavitron). In both species, xylem sap γ changed considerably (ca. 53-67 and ca. 50-68 mN m-1 in P. abies and P. cembra, respectively) over the season. Branches perfused with low γ solutions showed reduced resistance against drought-induced embolism in both species. A significant linear relationship ($P < 0.001$) between P12, P50 and P88 (i.e. water potential at 12, 50 and 88% of the loss of conductivity) and xylem sap γ was found. Based on this correlation, a variation in P50 between -3.10 and -3.83 MPa (P. abies) and between -3.21 and -4.11 MPa (P. mugo) over the season could be estimated. Results demonstrate that changes in γ of the xylem sap can considerably influence a tree´s resistance to drought-induced embolism. They indicate that vulnerability analyses, normally conducted at a γ near that of pure water, might often underestimate vulnerabilities under field conditions. For studied timberline conifers, seasonal changes in γ might be especially relevant in winter, when frost drought and freezing stress can lead to an excessive embolism.

Keywords : conifers, Picea abies, Pinus mugo, timberline
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