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DROUGHT STRESS ALTERS THE CONCENTRATION OF WOOD TERPENOIDS IN SCOTS PINE AND NORWAY SPRUCE SEEDLINGS

SATU TURTOLA,[1,2,*] ANNE-MARJA MANNINEN,[1] RISTO RIKALA,[3] and PIRJO KAINULAINEN[1]

[1]*Department of Ecology and Environmental Science*
University of Kuopio, P.O. Box 1627
FIN-70211 Kuopio, Finland

[2]*Department of Biology*
Natural Product Research Laboratory
University of Joensuu, P.O. Box 111
FIN-80101 Joensuu, Finland

[3]*Finnish Forest Research Institute*
Suonenjoki Research Station
FIN-77600 Suonenjoki, Finland

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Abstract—Drought is known to have an impact on the resistance of conifers to various pests, for example, by affecting resin flow in trees. Little is known, however, about the quantitative and qualitative changes in resin when trees are growing in low moisture conditions. We exposed Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) seedlings to medium and severe drought stress for two growing seasons and analyzed the monoterpenes and resin acids in the main stem wood after two years of treatment. In addition to secondary chemistry, we measured the level of nutrients in the needles and the growth response of seedlings. After the first year of treatment, drought stress did not affect the growth of seedlings, but in the second year, shoot growth was retarded, especially in Scots pine. In both conifer species, severe drought increased the concentrations of several individual monoterpenes and resin acids. Total monoterpenes and resin acids were 39 and 32% higher in severe drought-treated Scots pine seedlings than in the controls, and 35 and 45% higher in Norway spruce seedlings. In Scots pine needles, the concentrations of nitrogen and phosphorus increased, while magnesium and calcium decreased compared to controls. In Norway spruce needles, nutrient concentrations were not affected. The results suggest that drought stress substantially affects both the growth of

* To whom correspondence should be addressed. E-mail: satu.turtola@joensuu.fi

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conifers and the chemical quality of the wood. We discuss the potential trade-off in growth and defense of small conifer seedlings.

Key Words—Drought stress, monoterpenes, resin acids, wood, seedlings, *Pinus sylvestris* L., *Picea abies* (L.) Karst, conifers.

INTRODUCTION

The secretion of oleoresin, a complex mixture of terpenes, is an important part of the defensive mechanism of coniferous trees against phytophagous insects, fungi, and microbes (e.g., Croteau and Johnson, 1985; Eberhardt et al., 1994; Micales et al., 1994; Phillips and Croteau, 1999). Oleoresin accumulates in woody tissues as a result of normal physiological processes, or as a response to wounding (Croteau and Johnson, 1985). In most pine and spruce species, the main components of oleoresin are diterpenes (resin acids), but also minor amounts of volatile monoterpenes and sesquiterpenes (Croteau and Johnson, 1985).

Drought stress limits photosynthesis in plants, alters carbon allocation between roots and shoots (Teskey et al., 1987), and changes nutrient uptake ratios and nutrient circulation (Schulze, 1991). It also changes the levels of soluble sugars, inorganic ions, amino acids, and other osmolytes (Mattson and Haack, 1987). The susceptibility of host trees to attack by pathogens and herbivorous insects may be influenced by stress factors, such as adverse weather conditions and competition from limited resources (Lindberg and Johansson, 1992). The ability of trees to resist attack by bark beetles and their associated fungi is linked to overall vigor and to the amount of carbohydrates that can be used for defense reactions (e.g., Christiansen et al., 1987). Therefore, any environmental factor (e.g., drought stress) that restricts the size of the canopy or its photosynthetic efficiency can weaken the resistance of the tree (Christiansen et al., 1987).

Only a few studies have been published about the effects of drought stress on the quality of oleoresin in conifer wood. The changes detected in the wood of loblolly pine (*Pinus taeda* L.) have been an increase in concentration of all individual monoterpenes (Hodges and Lorio, 1975). In contrast, in the same tree species, Gilmore (1977) observed an increased concentration of α-pinene followed by a decrease in the β-pinene, myrcene, and limonene concentrations. In the needles, drought stress increased the concentration of monoterpenes in Norway spruce (*P. abies* (L.) Karst.) (Kainulainen et al., 1992), Sitka spruce (*Picea sitchensis* (Bong.) Carr.) (Major, 1990), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) (Johnson et al., 1997), and several Mediterranean woody plants, e.g., Aleppo pine (*Pinus halepensis* Mill.) (Llusia and Penuelas, 1998).

In many areas of the world, a trend toward warming of the climate has been observed in this century. According to climate-change scenarios, in Finland the average temperature is expected to increase and lead to changes in precipitation during