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ORIGINAL PAPER

Effect of frost nights and day and night temperature during dormancy induction on frost hardiness, tolerance to cold storage and bud burst in seedlings of Norway spruce

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Abstract For trees, the ability to obtain and maintain sufficient levels of frost hardiness in late autumn, winter and spring is crucial. We report that temperatures during dormancy induction influence bud set, frost hardiness, tolerance to cold storage, timing of bud burst and spring frost hardiness in seedlings of Norway spruce (*Picea abies* (L.) Karst.). Bud set occurred later in 12°C than in 21°C, and later in cool nights (7°C) than in constant temperature. One weekly frost night (−2.5°C) improved frost hardiness. Cool nights reduced frost hardiness early, but improved hardiness later during cold acclimation. Buds and stems were slightly hardier in 21°C than in 12°C, while needles were clearly hardier in 12°C. Cold daytime temperature, cool nights and one weekly frost night improved cold storability (0.7°C). Seedlings receiving high daytime temperatures burst buds later, and were less injured by light frost some days after bud burst.

Keywords Cool night · Day temperature · Dormancy · Norway spruce · Storage injury

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Introduction

A decrease in day length, followed by a decrease in temperature, and finally occurrence of subzero temperatures are the natural conditions for frost hardening in boreal tree species. It is a generally accepted tenet that low temperature exposure is necessary for development of maximal frost hardiness (Weiser 1970; Levitt 1980). In accordance with this, cool night treatments have been used to enhance the development of hardiness in several conifer species, including Norway spruce (*Picea abies* (L.) Karst.), although this practice has not been studied explicitly (van den Driessche 1970; Aronsson 1975; Jonsson et al. 1981; Johnsen 1989a). Occurrence of frost nights during the dormancy induction period has been shown to induce deeper hardiness in both angiosperms (Junttila and Kaurin 1990) and conifers (Timmis and Worral 1975; Greer and Warrington 1982; Hawkins 1993; Silim and Lavender 1994). The impact of frost nights as they might occur in nature during early autumn has, to our knowledge, not been studied experimentally using controlled freezing chambers in Norway spruce.

The majority of studies on frost hardiness in conifers have focused solely on one tissue, usually needles or stem. In a few studies on Norway spruce that included several tissues, markedly less hardiness was observed in buds than in stem and needles (Dormling 1993; Qamaruddin et al. 1993; Beuker et al. 1998; Kohmann and Johnsen 2007; Luoranen et al. 2008). Beuker et al. (1998) observed that low hardiness in buds was especially pronounced in a season with an unusually mild autumn and winter. This suggests that exposure to frost is more crucial for the development of deep hardiness in buds than in other tissues.

Hardening conditions in autumn may influence the seedlings tolerance to cold storage (Colombo 1990; Lindström