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ORIGINAL PAPER

Predicting spring frost sensitivity by bud development and temperature sum in Norway spruce seedlings

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Abstract Nurseries would benefit greatly if frost hardiness (FH) of seedlings could be predicted by some environmental variable or by bud development in spring. We investigated the FH of 1-year-old Norway spruce (*Picea abies* (L.) Karst.) seedlings of local origin. The seedlings were stored frozen until incubated in the growth chamber at six different temperature sums (TSs) (0, 55, 88, 142, 185 and 240 d.d., >5°C) from mid-February to mid-March. FH of the buds, stems and previous year needles was assessed on three occasions. When the TS was 88 d.d. or less, buds exhibited only microscopic signs of development, even when seedlings tolerated temperatures below −10°C. As TS increased, primordial needles and primordial stems of buds grew while FH weakened, especially in previous year needles. When the TS was at least 142 d.d., all plant parts were frost hardy to approximately −6°C. Monitoring TS and bud development can help predict FH of Norway spruce seedlings in spring. However, more studies with seedlings of different ages and from multiple locations are necessary to appreciate the generality of our results.

Keywords Bud phenology · Frost hardiness · *Picea abies* · Stereomicroscopy

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Introduction

In Fennoscandia, springtime frosts are common even in May when conifer buds are developing. In southern Finland, every second year spring frost occurs in late May after the accumulated temperature sum (TS) is more than 100 d.d. and buds are vulnerable to frost damage (Leikola and Rikala 1983). As such, nursery seedlings stored outdoors must be protected against frost and most nurseries rely on irrigation (Rose and Haase 1996). This approach is effective but because root plugs become waterlogged and nutrients are washed out of the growth media, alternative solutions have been sought and a greater understanding of seedling frost hardiness (FH) is necessary to provide better protection and only when it is needed. Traditional methods used to determine seedling FH are slow and expensive. An improved method would estimate the level of FH based on bud phenological stage and/or by monitoring environmental conditions.

Lester et al. (1977), Bigras and Hébert (1996) and Bigras et al. (2004) showed that FH of seedling buds and shoots was dependent on phenological stage of bud development in 10-month-old white spruce (*Picea glauca* (Moench) Voss), 8–9-month-old black spruce (*Picea marina* (Mill.) B.S.P.) and 3-year-old balsam fir (*Abies balsamea* (L.) Mill.), respectively. Bigras et al. (2004) suggested that frost tolerance at a given phenological stage is variable among species. Furthermore, frost sensitivity within a plant varies depending on tissue type and age (Sutinen et al. 1992; Taschler et al. 2004).

Springtime bud burst takes place when the TSs exceed a species- and provenance-specific threshold (Campbell and Sugano 1975; Cannell and Smith 1983; Hannerz 1994; Sarvas 1972). Among different threshold values, TS +5°C has been considered to predict the onset of bud burst