



Differences in dehydration rate and ability to rehydrate in contrasting needle abscission resistant balsam fir genotypes



Rajasekaran R. Lada*, Mason T. MacDonald

Christmas Tree Research Center, Faculty of Agriculture, Dalhousie University, Truro, NS, B6L 2R2, Canada

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ABSTRACT

Postharvest needle abscission is a major challenge in balsam fir with respect to postharvest Christmas tree quality. It is hypothesized that differences in dehydration rate or ability to rehydrate may contribute to observed differences in needle abscission resistance (NAR). Branches were collected from low and high NAR genotypes and dehydrated for 0, 1, 2, 5, 7, 14, or 21 d before being provided water and evaluated for water content, xylem pressure potential, stomatal conductance, and needle abscission. Fresh branches were 57% water content at -0.5 MPa and rapidly declined over 21 d without water to approximately 28% water content at -7.0 MPa. The ability to rehydrate was different between low and high NAR genotypes; low NAR genotypes could only successfully rehydrate within 2 d of dehydration (51% water content, -2.8 MPa) while high NAR genotypes were able to rehydrate within 7 d of dehydration (36% water content, -4.9 MPa). There was no significant difference in postharvest abscission of contrasting NAR genotypes when dehydrated for up to 2 d, but high NAR genotypes had significantly lower abscission when water was withheld for 5 or 7 d. When dehydrated for 14 or 21 d, no branches were able to recover and abscission occurred rapidly. It was concluded that low NAR genotypes were unable to recover from a similar water content as high NAR genotypes, which contributes to genotypic differences in postharvest abscission rates.

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1. Introduction

Balsam fir is an important horticultural species in Canada, preferred by the Christmas tree and greenery industries for its unique color, architecture, and fragrance. Christmas trees are grown on approximately 130,000 acres and worth \$56 million annually (Statistics Canada, 2014). However, a combination of warmer autumn temperatures and early harvest practices has resulted in postharvest needle abscission negatively impacting the industry (Lada and MacDonald, 2015). A variety of factors influence postharvest needle abscission characteristics in balsam fir, such as cold acclimation (Chastagner and Riley, 2007; Thiagarajan et al., 2012; MacDonald et al., 2014a,b), ethylene evolution (MacDonald et al., 2010), volatile terpene compounds (Korankye, 2013), abscisic acid concentration (Thiagarajan et al., 2012), or certain biophysical factors, such as water uptake, XPP, membrane injury, relative water content, or capacitance (MacDonald and Lada, 2014). In this context some factors, such as cold acclimation, tend to be associated with delayed needle abscission (Chastagner and

Riley, 2007), especially in low needle abscission resistant clones (MacDonald et al., 2014a,b). Other factors, such as increased concentrations of endogenous ethylene, tend to promote needle abscission (MacDonald et al., 2010).

The initial impetus for postharvest abscission is typically considered to be water deficit or dehydration. Species closely related to balsam fir, such as Nordman fir and Fraser fir, experienced increased needle loss when water was withheld postharvest, but minimal needle loss when provided water or rehydrated before reaching a critical water potential (Mitcham-Butler et al., 1987; Chastagner and Riley, 2003). Similar observations have been noted in Douglas fir, which reached a critical water potential within 12 d of harvest resulting in significant needle loss (Montano, 1985). Provision of water, greenhouse storage under humid conditions, or use of antitranspirants had various levels of success maintaining favorable water potential and, consequently, reducing needle abscission. Dehydration has also been linked to postharvest abscission in balsam fir where a 5-fold decrease in xylem pressure potential (XPP) and 20% decrease in relative water content occurred concurrently with accelerated abscission rates (MacDonald and Lada, 2014). When balsam fir branches were provided water and subjected to low vapor pressure deficit (VPD), then water status was maintained and needle retention increased approximately 5-fold compared to

* Corresponding author.

E-mail address: raj.lada@dal.ca (R.R. Lada).

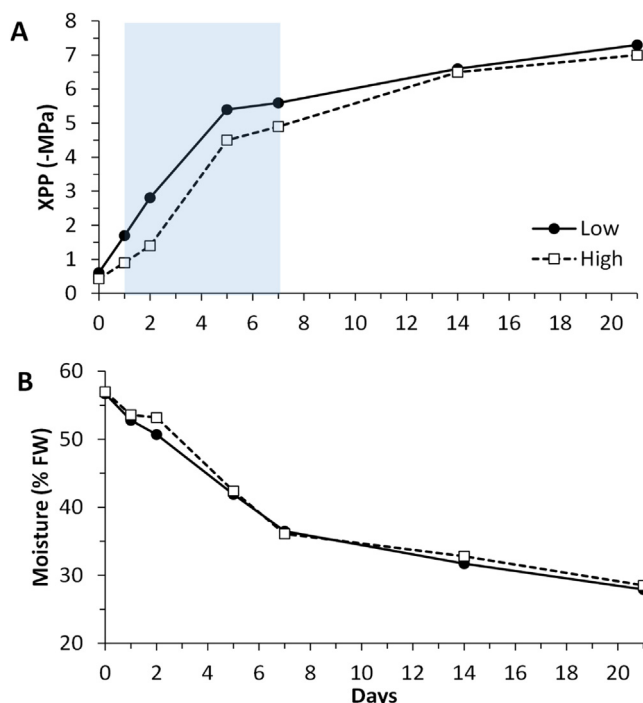


Fig. 1. Xylem pressure potential (XPP) of low and high needle abscission resistant (NAR) clones over 21 d without water. Significant differences ($P \leq 0.05$) in XPP of the two genotypes were found from days 1 to 7, which is indicated by gray shading. All means were calculated from 12 replicates.

branches subjected to a higher vapor deficit (MacDonald et al., 2012a). Dehydration may be an initial signal, which may also be linked to physiological changes in ethylene and abscisic acid, as water deficit has increased ethylene and abscisic acid in other species (Taylor and Whitelaw, 2001; McAdam et al., 2011).

There is a high degree of variability among clones in postharvest needle abscission patterns in balsam fir where complete abscission may occur within 6 to 60 d from harvest. However, abscission patterns in branches from the same tree are much more consistent, which led to the development of a genotype classification system based on needle retention. Genotypes were labelled as having low needle abscission resistance (NAR) if they completed abscission in under 20 d, moderate NAR if they completed abscission between 20 and 40 d, and high NAR if they completed abscission in over 60 d (MacDonald, 2010; MacDonald et al., 2014a,b). In addition to having lower postharvest needle retention, low NAR genotypes were found to have denser needles (MacDonald et al., 2014a), higher ethylene sensitivity (MacDonald et al., 2012b), evolve ethylene at higher rates (MacDonald et al., 2012b), and benefit more from cold acclimation (MacDonald et al., 2014a,b).

As noted above, dehydration is considered one of the major biophysical triggers for postharvest needle abscission, but it has not yet been studied with respect to differences in NAR genotypes. It is hypothesized that low NAR genotypes may dehydrate faster, perhaps owing to increased needle density (MacDonald et al., 2014a), or may be more sensitive to dehydration. The objective of this study is to (1) determine postharvest dehydration dynamics in low and high NAR genotypes and (2) determine the point at which low and high NAR genotypes can no longer successfully be able to rehydrate.

2. Materials and methods

2.1. Experimental design

The experiment followed a completely randomized design with two factors: NAR genotype and duration of dehydration. Genotypes

were classified as either low or high NAR. Duration of dehydration was the length of time after harvest until water was provided to a branch, which was either 0 (control, provided water immediately upon harvest), 1 d, 2 d, 5 d, 7 d, 14 d, or 21 d. The experiment was considered a 2×7 factorial and was replicated 12 times, which required 168 branches.

2.2. Sample collection and branch display

Balsam fir branches were collected from an orchard in Debert, Nova Scotia, Canada ($45^{\circ}25'N$, $63^{\circ}28'W$). A description of the orchard may be found in MacDonald et al. (2010). Each branch was cut from the most recent 2-years growth and was visually screened for absence of disease and nutrient deficiencies. Control branches were provided reverse osmosis water immediately upon harvest, thus the control treatment low and high NAR branches placed in containers for transport with cut ends submerged in water. All other branches were transported in similar containers but no water was provided.

The protocols for branch preparation and display were based on work by MacDonald et al. (2010). The growth room was maintained at a temperature of $20^{\circ}C$, 40% humidity, and provided fluorescent lights. Lighting intensity was $80 \mu\text{mol m}^{-2} \text{s}^{-1}$ and provided for 16 h each day. Branches were placed in darkness for the remaining 8 h. All branches were initially weighed and then placed in a 100 mL amber bottle. The neck of each bottle was sealed with cotton gauze to reduce evaporation and add stability to a branch. As above, control branches were immediately provided with water while all other branches were submitted to same display protocol, but without water being added immediately. Water was added to remaining treatments after water was withheld for the corresponding number of days. All branches were given a fresh cut approximately 2 cm from the base of the branch before being provided water. The small fresh cut stems were then used XPP measurements, as described in Section 2.5.

2.3. Postharvest needle abscission

Needle abscission was measured by collecting the number of needles that would fall after a 'finger run' test each day. The mass of those needles was measured fresh and after oven drying. The experiment was run until all needles had abscised (16 weeks). Percent needle loss was calculated as the cumulative dry mass of needles that had fallen divided by the total dry mass of needles. Further, two points of needle loss were evaluated as response variables. The first was the length of time until 5% of needles had abscised, which is an approximate indicator of when abscission began. The second was the length of time until 100% of needles had abscised, which is an indicator that abscission had concluded.

2.4. Water content

The water content of each treatment was calculated at the point water was provided. The difference in fresh and dry mass of the needles was used to calculate water content and expressed on a fresh mass basis as below, where M_f is the fresh mass of the branch and fallen needles and M_d is the dried mass of the branch and fallen needles:

$$\% \text{Moisture} = \frac{M_f - M_d}{M_f} \times 100$$

2.5. Xylem pressure potential

The XPP of the branches was measured immediately after making a fresh cut using a Plant Moisture System Pressure Bomb (PMS

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