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Yield of stilbene glucosides from the bark of young and old Norway spruce stems

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ABSTRACT

Bioactive stilbene glucosides are the major constituents of the acetone extracts of the phloem and bark of Norway spruce (*Picea abies* (L.) Karst.) trees. We studied their variation patterns across phloem and bark within the stems of Norway spruce. The total yields of stilbene glucosides (astringin, isorhapontin, and piceid) from trees were estimated. Bark samples were collected from young (18 years-old) and older trees (37 years-old), representing age and size typical for energy wood harvesting and the first commercial thinning, respectively. Different bark layers of younger trees had 10%–63% lower average amount of stilbene glucosides than the bark layers of older trees. The inner bark had the highest mass fraction of stilbene glucosides (2.7%–4.8% of dry weight (d.w.)) and the outermost bark showed the lowest amount (0.4%–1.2% d.w.). Axially along the stem, the highest amount of stilbene glucosides was found at the stem base in the young trees (average over bark zones 2.1% d.w.) and at the breast height and the base of the living crown in the older trees (average over bark zones 3.6% d.w.). Astringin and isorhapontin yielded the highest amounts, while the share of piceid was the smallest. The total yield of stilbene glucosides was dependent on the bark biomass, and positively correlated with total wood and bark volume. The basal stem was the most valuable stilbene source in both younger and older trees. The bark of Norway spruce from the first commercial thinnings, especially of butt and middle logs, can provide feasible source for high-value extracts.

1. Introduction

Norway spruce (*Picea abies* (L.) Karst.) is one of the most abundant and economically important tree species in the boreal hemisphere, and it is mainly used for sawn timber and pulp. Regarding a growing interest in renewable sources of biomass for value-added bio-products and chemicals, Norway spruce bark has promising potential [1–3].

Spruce bark has high concentrations of several polyphenolic compounds, including stilbenes (mainly as stilbene glucosides and their aglycons), lignans, flavonoids and tannins. These phenolic metabolites have multiple biological activities, such as protection against environmental stresses, antifungal and antimicrobial functions, and antifeedant activity, all presumed to be vital for tree resistance [4–7]. In Norway spruce bark, hydroxylated stilbene glucosides *trans*-astringin and *trans*-isorhapontin have shown to be the major

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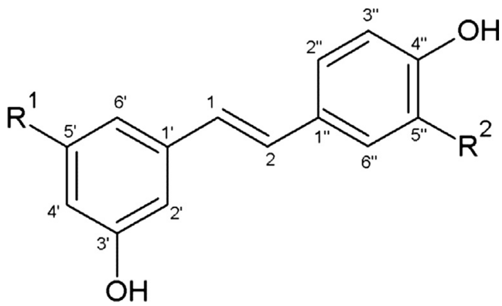

Fig. 1 – Chemical structures of stilbene compounds in Norway spruce phloem and bark. R^1 = OH, R^2 = H, *trans*-resveratrol (501-36-0); R^1 = R^2 = OH, *trans*-piceatannol (10083-24-6); R^1 = OH, R^2 = OCH3; *trans*-isorhapontigenin (32507-66-7); R^1 = OGlc*, R^2 = H, *trans*-piceid (65914-17-2); R^1 = OGlc, R^2 = OH, *trans*-astringin (29884-49-9); R^1 = OGlc, R2 = OCH3, *trans*-isorhapontin (32727-29-0). *OGlc = -O-β-D glucoside. The number in parenthesis is the CAS registry number assigned for each chemical compound by the Chemical Abstracts Service.

compounds, and the trihydroxystilbene *trans*-piceid is a minor compound [2,8] (Fig. 1). Also the aglycons of stilbene glucosides [2,9] as well as several dimers of stilbene glucosides have been identified [10] (Fig. 1).

Due to their antioxidative and protective properties, these compounds are of commercial interest [11–13]. They could contribute in medical and cosmetics industry, as health-promoting substances in food industry, or as protective agents against microbes and pests [14–18]. For example in Finland, ca. 3 Tg of bark waste is annually produced in round wood processing; of which over 1 Tg is from Norway spruce, providing a potential source for high-value extracts [11,19]. At present, a total of 6.5 million cubic metres of bark are annually consumed by heat and power plants [20]. The techno-economical potential of bark is higher, as the technology and value-chains of biorefinery concepts are constantly developing. Bark could be first utilized as a source of high-value extracts, and then be combusted for energy.

In addition to the large-sized stems from final fellings, the small trees from early thinnings may constitute a considerable proportion of the bark residue supply. In Finland, the harvesting of energy wood from young thinning stands is becoming more common after the introduction of state subsidies intended to increase the use of energy wood and, simultaneously, encourage the tending of young stands. However, without subsidies, the energy wood harvesting has not been profitable for the forest owner at the current energy prices [21]. Also the first commercial thinning is usually not economically viable due to small sized stems and lower stump prizes of pulp wood as compared to large-sized round wood for sawn industry. The early thinning operations – the first commercial thinning and energy wood harvesting – would possible become more profitable for forest owners by integrating the procurement of value-added bark to the energy and/or pulp wood supply. However, efficient valorization of the bark biochemicals requires knowledge on their yields and distributions within trees, tissues and cells, but our current understanding on the distribution and localization of these compounds is still fragmentary.

Earlier studies have demonstrated that the highest concentrations of stilbene glucosides are located in the inner bark [3,9,22]. Several studies in different spruce species have also demonstrated quantitative and qualitative changes in the constitutive and inducible defense phenolics in response to bark wounding and/or inoculation with fungal pathogens [23–27], or exogenous treatments with methyl jasmonate [28]. These studies have, however, been based on single-position samplings (e.g., at 1.3 m height on the stem) from the main stems mainly. As an exception, Toscano Underwood and Pearce [22] studied the axial variation in stilbene glucosides in the bark of young saplings and mature trees of Sitka spruce (*Picea sitchensis* (Bong.)). They found that the concentration of stilbenes was highest next to the root collar and decreased towards the tree top. However, only a few individual trees were included in the study [22]. Presently, comprehensive analysis of variations in stilbene concentrations and yields at the whole-tree

Table 1 – Characteristics of the rooted cutting clones and sample trees (±standard deviation).

Variable Clone	19*	20*	51	61*	67	255*
Growth and quality class[a]	*L*	*H*	*H*	*L*	*L*	*H*
Age (years)[b]	12.7 (1.15)	14.0 (1.00)	28.7 (0.58)	26.0 (1.00)	26.0 (1.73)	30.3 (0.58)
D1.3 (cm)	9.1 (2.95)	9.0 (2.71)	22.5 (3.46)	19.6 (3.38)	15.7 (0.96)	23.9 (5.22)
D6 (cm)	3.8 (3.13)	5.4 (2.31)	16.6 (3.50)	16.3 (2.58)	13.9 (7.57)	20.7 (4.47)
Vigour index[c]	0.11 (0.07)	0.10 (0.03)	0.08 (0.02)	0.09 (0.01)	0.05 (0.01)	0.07 (0.02)
Tree height (m)	8.5 (2.04)	8.9 (0.48)	20.1 (1.44)	17.7 (1.10)	17.5 (0.10)	22.2 (0.29)
Crown base (m)	1.77 (0.66)	2.15 (0.18)	7.99 (1.48)	5.70 (1.86)	7.61 (1.68)	10.41 (1.13)
Crown length (m)	6.69 (1.47)	6.77 (0.31)	12.09 (1.12)	12.03 (2.72)	9.85 (1.58)	11.79 (1.31)
Crown ratio[d]	0.79 (0.04)	0.76 (0.01)	0.60 (0.06)	0.67 (0.12)	0.56 (0.09)	0.53 (0.05)
Crown width (m)[e]	2.62 (0.45)	2.21 (0.25)	3.55 (0.61)	3.57 (0.37)	2.82 (0.18)	4.27 (1.64)

*The clones marked with asterisk were chosen for the chemical analysis of bark.
[a] *L*, low growth and quality, *H*, high growth and quality by visual assessments in the 1960s.
[b] The number of annual rings at the height of 1.3 m (BH) on the stem.
[c] The ratio of basal area of last annual ring to the basal area of sapwood at BH.
[d] The ratio of live crown length to tree height.
[e] Crown width was measured as the arithmetic mean of the crown widths at the north-south and east-west directions.