Basic chemical composition of the biomass components of pine, spruce and birch

The requirements for forest raw material used in biorefining may differ from the traditional uses of wood. The various biorefining processes have certain demands and restrictions for the raw material to produce desired end-products. Since the chemical reactions within refining processes are affected by the chemical properties of the raw material, it is quite important to be aware of the variability in the chemical composition of forest biomasses. The quantity of individual compounds found in different tree parts is large. However, the properties of forest biomasses can roughly be defined by the proportions of cellulose, hemicelluloses, lignin and extractive compounds within tree parts. The basic chemical compositions of different forest biomass components of the most common tree species in the project region were therefore reviewed and are presented in this paper. This information will further be utilized in an estimation of raw material availability for biorefining in the project region.

Composition of tree biomasses

The review of the chemical composition of tree biomasses was based on the most common organic compound groups found in woody biomasses: cellulose, hemicelluloses, lignin and extractives. The polysaccharides cellulose and hemicelluloses consist of long carbohydrate molecules and function as structural components in different plant tissues. Also as a structural component in plant cell walls, lignin strengthens wood to make the formation of tree stems possible. A wide variety of compounds are included in extractives. These non-structural compounds serve multiple functions within plants, for instance as defense against herbivores or other damage. However, the aforementioned compound groups are not all that tree biomasses contain, but other polysaccharides (such as starch and pectins), nitrogen compounds and proteins can be found in variable quantities. The proportions of these other compounds depend on the biomass component at issue. For example, bark can contain large amounts of suberin and some polyphenols, which are usually not included in extractives.

Literature review

Published literature was reviewed in order to establish the chemical composition of stem wood, stem bark, branches, needles or leaves, stump and roots. Only literature sources reporting the complete composition of a biomass component and information on the proportions of the carbohydrates, lignin and extractives were taken into account in this review. Medians were calculated of all the concentration or percentage values obtained from the literature, when there were more than two values available (median can be described as the numerical value separating the higher half of the reported values from the lower half). Compared to the mean, median is less sensitive to extreme values which were occasionally found. The variability of literature values was quite high in some biomass components, especially bark and branches.

This was partly caused by differences in the physical properties, the origin or age of the analyzed material. Additional variability was observed due to differences in analysis methods used in different studies. The variability of the literature values was described by median absolute deviation (m.a.d: median of the absolute deviations from the data's median), which is a robust measure of dispersion and more resilient to outliers than the standard deviation. The medians (and their deviations) of the proportions of the studied chemical compound groups are presented in table 1. The values of the compound groups do not necessarily sum up to 100% and could be even more than that, due to the variability in the literature values and the fact that the concentrations of other compounds are not included in the presented groups.

STEM WOOD AND BARK

The composition of stem wood is generally well known due to the long traditions of its industrial use. Also, the variation in literature values is quite small since wood is a relatively homogeneous material compared to the other biomass components. The largest difference in the basic chemical composition of wood between the tree species is that Silver and Downy birch (Betula pendula and B. pubescens) wood contains less lignin than the conifers pine (Pinus sylvestris) and spruce (Picea Abies). Pine wood is also slightly richer in extractives than the other species. The chemical composition of stem bark is significantly different from stem wood, extractives being the most abundant compound group in all species. However, a large share of the bark content falls in the category “other compounds”. In pine, cellulose, hemicellulose, lignin and extractives form only ca. 70% of the chemical composition, according to the literature. Respectively, these compound groups form 80% of spruce bark and only 60% of birch bark.

CROWN COMPONENTS

Branches consist of both wood and bark and the ratio between these two is determined by branch size. Hence, determining the chemical composition of tree branches can be challenging and can only be made on a very general level. Just one study describing the cellulose and hemicellulose concentration of branches was found for each species and only a few for the other compound groups. In any case, the chemical composition of branches is virtually an average of stem wood and bark, which seems reasonable since branches are comprised of them. Pine and spruce needles and birch leaves are the most extractives-rich components in tree biomass. Unfortunately, no literature was found on the cellulose and hemicellulose content of birch leaves.

STUMPS AND ROOTS

The chemical compositions of tree stumps and roots are not extensively studied – only one study was found for pine and birch, and two for spruce. The use of this underground biomass has so far been mainly restricted to burning of spruce stumps for energy. On the basis of the references, the chemical composition of stumps (including bark) is similar to stem wood’s, excluding the higher concentration of extractives in stumps. The chemical composition of roots depends on their size and is quite similar to that of branches.

Table 1. Proportions of the main chemical compound groups (%) within tree biomass components. Values presented in the tables are medians of values found in the literature. Median absolute deviation is presented in parenthesis if more than two values were obtained from the literature sources.

Scots pine

	Cellulose	Hemicelluloses	Lignin	Extractives
Stem wood [1-7, 11, 12, 27]	40.7 (0.7)	26.9 (0.6)	27.0 (0.0)	5.0 (1.0)
Bark [7-12, 27]	22.2 (3.2)	8.1 (0.4)	13.1 (5.4)	25.2 (5.2)
Branches [11-14, 27]	32.0	32.0	21.5 (5.9)	16.6 (7.1)
Needles [3, 11, 12, 27]	29.1	24.9	6.9 (0.8)	39.6 (1.3)
Stump [12]	36.4	28.2	19.5	18.7
Roots [12]	28.6	18.9	29.8	13.3

Norway spruce

	Cellulose	Hemicelluloses	Lignin	Extractives
Stem wood [3-6, 15-18, 27]	42.0 (1.2)	27.3 (1.6)	27.4 (0.7)	2.0 (0.6)
Bark [9-12, 17, 19, 20, 27]	26.6 (1.3)	9.2 (1.1)	11.8 (0.9)	32.1 (3.8)
Branches [11, 12, 14, 17, 27]	29.0	30.0	22.8 (1.7)	16.4 (2.6)
Needles [3, 11, 12, 27]	28.2	25.4	8.4 (2.1)	43.3 (2.3)
Stump [12, 21]	42.9	27.9	29.4 (1.8)	3.8 (0.2)
Roots [12]	29.5	19.2	25.5	15.7

Silver/Downy birch

	Cellulose	Hemicelluloses	Lignin	Extractives
Stem wood [1, 5, 11, 12 15, 18, 22, 27]	43.9 (2.7)	28.9 (3.7)	20.2 (0.8)	3.8 (1.3)
Bark [11, 12, 23-25, 27]	10.7 (0.3)	11.2 (0.5)	14.7 (3.9)	25.6 (1.1)
Branches [11, 12, 26, 27]	33.3	23.4	20.8 (3.9)	13.5 (3.0)
Leaves [11, 12, 27]	N/A	N/A	11.1 (0.0)	33.0 (0.0)
Stump [12]	29.5	19.4	13.4	4.7
Roots [12]	26.0	17.1	27.1	13.5

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