Specific gravity of inner and outer beech bark

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Abstract

For beech bark (*Fagus sylvatica*), specific gravity was measured by means of pycnometer and by water immersion. The pycnometer was suitable for measurement of all analysed sample types. Water immersion method could only be applied to beech wood, whole and inner beech bark. Specific gravities of whole beech bark (0.58 ± 0.04), inner beech bark (0.57 ± 0.05) and outer beech bark (0.75 ± 0.06) differed significantly.

1 Introduction

Tree bark is generally composed of two sections—inner bark and outer bark (Holdheide 1951; Fengel and Wegener 1983). Beech (*Fagus sylvatica*) is a “peridermal tree” in which, according to Holdheide (1951), the outer bark only consists of a single periderm and no further periderms nor rhytidome are formed. Indeed, Prislan et al. (2011) showed that the thickness of outer beech bark (0.45 ± 0.22 mm) is small compared to whole beech bark (5.96 ± 0.85 mm).

Fractionation generally enables separate optimized utilization of inner and outer bark differing in anatomy and chemical composition. Birch bark can be fractionated by grinding followed by sieving and/or gravity separation due to differences in particle size and density, respectively (Krasutsky et al. 2005). This is possible because outer birch bark has a lower density compared to inner birch bark (Krasutsky et al. 2005). For whole beech bark, oven-dry densities of 0.82 g/cm³ (Dimitri 1968) and 0.78 g/cm³ (Parameswaran and Liese 1978) are indicated in the literature. However, to the author’s knowledge, the density and specific gravity of inner and outer beech bark haven’t been reported yet.

In the present work, density and specific gravity of inner and outer beech bark were measured in order to understand if differences exist between inner and outer bark, potentially enabling fractionation into inner and outer beech bark for separate utilization.

2 Material and methods

Beech wood (reference material) and beech bark were provided by Holzwerk Keck (Ehningen, Germany). 22 defect-free beech wood samples ($20 \times 20 \times 10$ mm³; $r \times t \times l$) were prepared. In total 40 intact beech bark pieces from four different batches with feed sizes of approximately 2–6 cm were chosen. Each beech bark piece was divided into four sections with two sections for whole bark measurements, one section for measurement of inner and outer bark and the last section for further experiments. Inner and outer bark were separated mechanically by wood chisel and scalpel. The darker outer bark could be optically well distinguished from the brighter inner bark. Prior to volume and mass determinations, all samples were soaked in water until no further mass increase could be detected. In all experiments, samples and water were at room temperature.

Specimen mass was determined with an analytical balance. Specimen volume was measured by two different methods: (1) immersion and (2) pycnometer. In all calculations, water density $\rho_{\text{water}} = 1$ g/cm³ was applied. Moisture content was determined after drying samples at 103 ± 2 °C.

Volume by immersion was based on ASTM D 2395-07a (2007). The specimen with known mass was completely submerged in a water bath. Mass of the displaced water was determined and converted into specimen volume. Low outer bark thickness prohibited its measurement by immersion.

For method (2), a 25 mL pycnometer (NS10/19, BLAU-BRAND, Brand GmbH & Co. KG) was used. The specimen volume by pycnometer ($V_{\text{pycnometer}}$) was calculated with

$$V_{\text{pycnometer}} = \frac{m_1 + m_{\text{sample}} - m_2}{\rho_{\text{water}}} \quad (1)$$

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after measuring the sample mass (m_{sample}), the mass of pycnometer completely filled with water (m_1) and the mass of completely filled pycnometer containing sample and water (m_2). Due to the narrow bottleneck of the pycnometer, the specimen had to be cut into smaller pieces. Experiments indicated that $m_{sample} > 0.3$ g is recommended.

Density (ρ) of specimen was calculated based on wet mass (m_{wet}) and wet volume (V_{wet}) with

$$\rho = \frac{m_{wet}}{V_{wet}} \quad (2)$$

Specific gravity (G) was calculated based on dry mass (m_{dry}) and wet volume (V_{wet}) with

$$G = \frac{\frac{m_{dry}}{V_{wet}}}{\rho_{water}} \quad (3)$$

Maximum moisture content (MC_{max}) was calculated according to Bergman et al. (2010):

$$MC_{max} = \frac{1.54 - G}{1.54 * G} * 100 \quad (4)$$

Statistical significance was tested with R applying a linear mixed model (lme4, lmer, emmeans, pairwise contrast). The figure was created with Ggplot.

3 Results and discussion

The objective of the present work was the determination of density and specific gravity of whole, inner and outer beech bark. Beech wood was measured as reference material. The determination by water immersion is a well established standard for irregularly shaped specimens. However, it is not suited for the thin outer bark specimen of beech. The pycnometer method was chosen as additional method enabling volume determination for all four beech sample types.

3.1 Moisture content

As both methods measure the volume in liquid water, all specimens were soaked in water before volume determination in order to reach maximum swelling and to minimize water uptake by the specimens during volume determination in water. The wet-based moisture content of the samples was between 60% for outer bark and 112% for inner bark (Table 1). Assuming (wood) fibre saturation above $\approx 30\%$ (Bergman et al. 2010), it can be concluded that all samples were fibre-saturated. Comparison of mean moisture content with theoretical maximum moisture content (Table 1) shows that the samples were close to water saturation.

Table 1 Measured moisture content, calculated maximum moisture content and density of the beech wood and beech bark samples

Sample (-)	Moisture content (wet-based)		Density ^b Mean (g/cm ³)
	Mean (%)	Maximum ^a (%)	
Wood	82.5 ± 5.7	95.6 ± 6.5	1.17 ± 0.04
Whole bark	106.0 ± 15.3	107.7 ± 13.7	1.20 ± 0.04
Inner bark	111.8 ± 15.9	112.5 ± 14.6	1.20 ± 0.06
Outer bark	59.9 ± 9.8	68.0 ± 10.2	1.21 ± 0.07

After the sign ± standard deviation values are given

^aCalculated based on Eq. 4 and $G_{pycnometer}$

^bCalculated based on Eq. 2 by pycnometer method

Fig. 1 Mean and standard deviation of specific gravity of beech wood and bark. Volume determination by immersion and/or pycnometer

3.2 Density

The density based on pycnometer method was in the same range for all four sample types (Table 1). As moisture content influences density and the four sample types had different moisture contents (Table 1), the densities can't be compared. Density of beech wood and whole beech bark (Table 1) are close to the literature. Trendelenburg (1939) reports for water saturated beech wood a density of 1.19 g/cm³ and Dimitri (1968) reports a density of 1.12 g/cm³ for whole beech bark at moisture content $\approx 100\%$. To the author's best knowledge, density values for inner and outer beech bark are not reported in the literature. The similar density values indicate that density-based separation of inner and outer beech bark might not be possible at high moisture content.

3.3 Specific gravity

In contrast to density, specific gravity is well suited for comparison of the four sample types. The difference in

moisture content (Table 1) has no influence on the mass part of Eq. 3 because m_{dry} is used. The difference in moisture content has no influence on the volume part (V_{wet}) of Eq. 3 because all samples are above fibre saturation, *i.e.* in a maximum swollen state.

For beech wood, whole and inner beech bark immersion method yields in specific gravities of 0.61 ± 0.02 , 0.58 ± 0.05 , and 0.56 ± 0.05 , respectively (Fig. 1). The pycnometer method results in specific gravities of 0.62 ± 0.03 (beech wood), 0.58 ± 0.04 (whole beech bark), 0.57 ± 0.05 (inner beech bark), and 0.75 ± 0.06 (outer beech bark).

Statistical analysis of beech sample types, wood, whole bark and inner bark illustrate that within the sample type groups, there is no significant difference in specific gravities measured by immersion or pycnometer ($p > 0.05$). Outer beech bark was measured by pycnometer only, but the high accordance of immersion and pycnometer values for the other samples indicates the suitability of the pycnometer method.

Taking pycnometer values as base, specific gravity of outer beech bark is significantly higher compared to inner and whole beech bark ($p < 0.05$). Inner beech bark specific gravity is significantly lower compared to whole beech bark ($p < 0.05$). Specific gravity of beech wood fits with literature values between 0.47 and 0.64 (Trendelenburg 1939). For beech bark, no literature specific gravity values could be found. Parameswaran and Liese (1978) demonstrated a positive correlation for density/hardness of beech bark and showed that outer beech bark has a higher hardness compared to inner beech bark supporting higher specific gravity of outer beech bark (Fig. 1). Weighting the specific gravities of inner and outer beech bark according to their relative respective thickness of 93 and 7% (Prislan et al. 2011), a calculated specific gravity of 0.58 is obtained fitting with the present experimental mean specific gravity for whole beech bark. Dimitri (1968) observed, that oven-dry density and thickness of beech bark are negatively correlated. This result could be explained by (1) the higher specific gravity of outer beech bark (Fig. 1) and (2) the fact that the increase in beech bark thickness by secondary growth is mainly due to phloem increment (Holdheide 1951; Prislan et al. 2011).

The differing specific gravity values indicate that gravity-based separation of inner and outer beech bark might be possible at low bark moisture content. Due to suberin, a potential feedstock for bio-based polymers only occurring in outer bark (Fengel and Wegener 1983), such fractionation might be interesting. Whole beech bark contains $\approx 3\%$ of suberin (Fengel and Wegener 1983), but a successful beech bark fractionation could result in a suberin-enriched outer bark fraction being attractive for suberin isolation.

4 Conclusion

The higher specific gravity of outer beech bark in comparison to inner beech bark might open up the possibility to fractionate inner and outer beech bark for separate utilization. However, detachment of inner from outer bark prior to such fractionation would be a prerequisite, and it has to be analysed whether the difference in specific gravity is sufficient to separate inner and outer beech bark efficiently. The pycnometer method proved to be suitable for specific gravity determination of water-soaked samples and might be an alternative especially for small wood or bark sample amounts.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

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