

# Lemon Balm (*Melissa officinalis*) Stalk: Chemical Composition and Fiber Morphology

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**Abstract** This work investigates the potentials of lemon balm (*Melissa officinalis* L.) stalk (LBS), a massive waste part of medicinal plant, for pulp and papermaking by assessing its fiber characteristics and chemical composition. In addition, LBS properties were compared with some important agro-residues such as bagasse stalk (BS), cotton stalk (CS) and tobacco stalk (TS). There is no information about suitability of the LBS in the open literature. Chemically, LBS fibers contain a relatively high percentage of alpha-cellulose (32.7%), but a low percentage of lignin (25%), which benefits pulping and bleaching. The hemicelluloses in LBS are mainly glucose and xylose. Ash content was about 6%, superior to the average value corresponding to woods, which makes pulping difficult. It was verified that the chemical compositions of the studied agro-residues vary significantly. Morphologically, the LBS fibers are comparable to those of hardwoods. Rather a significant amount of parenchyma cells was found in LBS. The TS has the highest average fiber length, while the LBS has the least, and the lengths of BS and CS fibers fall in between. In general, based on the results of this study, some propositions can be made about the possible applications of LBS as

a non-wood renewable source of natural products for use in the production of pulp and paper.

**Keywords** Papermaking · Chemical composition · Morphology · Lemon balm stalks · Non-wood

## Introduction

Forests are the main and most common sources for preparation of raw material, wood, for papermaking. The large amounts of wood used to manufacture paper have raised severe supply problems, leading to much research worldwide to focus on potential alternative raw materials such as non-wood plants [1]. Since the 1970s, the output of pulp from non-wood plants has grown from 7 to 12% of the total pulp output, which is at a rate two to three times higher than that of pulp from conventional wood raw materials [2]. Approximately 2.5 billion tones of non-wood raw materials are available each year worldwide; however, most of this raw material is currently untapped for pulp and papermaking [3]. There is a wide variety of non-wood plant fibers that can be used for papermaking. Most non-wood plants are annual plants that develop their full fiber potential in one growing season [4]. Among non-wood plants, agro-residues appear to be effective alternatives to wood raw materials in some regions [5]. Agro-residues, produced from commercial processing of crop plants, are usually considered to be of little inherent value and represent a disposal problem. However, these materials could in many cases represent an abundant, inexpensive and readily available source of renewable lignocellulosic biomass for different purposes [6]. The most widely used agro-residues for papermaking are cereal straws, sugar cane bagasse and tobacco straw.

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**Fig. 1** Different parts of lemon balm plant



Lemon balm (*Melissa officinalis* L.) is a member of Lamiaceae family, which originates from southern Europe and the Mediterranean region, and is cultivated in Iran as medicinal plant. It grows to a height of 70–150 cm (Fig. 1). The leaves have a gentle lemon scent, related to mint and often used as a repellent for mosquitos or as a flavoring agent in herbal tea. The stalks of this plant, which have no economical value, might be used as a source of lignocellulosic material for pulp and papermaking. However, no information is available on the chemical composition of lemon balm stalk (LBS) in the published literature to date. The aim of the present study is to characterize the chemical and morphological properties of LBS and compare it with some important agro-residues including bagasse stalk (BS), cotton stalk (CS) and tobacco stalk (TS) as raw materials for papermaking.

## Materials and Methods

### Raw Materials

Four species of agro-residues namely LBS, BS, CB and TS were randomly selected and harvested from the western and northern parts of Iran. The air-dried samples were ground into fine particles for chemical analyses according to Tappi T 257 cm-02.

### Chemical Characterization

The chemical characteristics of the above-mentioned samples were carried out following the appropriate Tappi standards [7] and the other published procedures as indicated. The samples were subjected to the following determinations: holocellulose [8],  $\alpha$ -cellulose (T 203 cm-99), Klason lignin (T 222 om-02), acid-soluble lignin (T 250 um-91), pentosans (T 223 cm-01), ethanol–benzene solubility (T 204 cm-97), 1% NaOH solubility (T 212 om-98), hot-water solubility (T 207 cm-99), ash (T 211 om-93) and polysaccharide (T 249 cm-00). Table 1 shows the mean and standard deviations of three replicate determinations of each sample. It is to be noted that benzene was replaced with dichloromethane.

### Fiber Morphology

The samples for fiber maceration were prepared according to the modified Franklin method, as explained elsewhere [9]. Fiber length ( $L$ ), fiber diameter ( $d$ ) and cell wall thickness ( $w$ ) were measured directly from the magnified image, with 50 measurements made on each property, using a Nikon 80i microscope. The calculation of felting factor ( $L/d$ ) was carried out using the measured data.

## Results and Discussion

### Chemical Compositions

The main components of wood and non-wood fibers include holocellulose, lignin, and extractives in various amounts. The results on general chemical composition of samples considered in this study are presented in Table 1. The average holocellulose content of LBS was found to be 53.1%, which is lower than hardwoods (68–74%) and softwoods (70–81%) stated in the literature [10]. The higher content of holocellulose provides a higher yield, and is likely to improve the strength.

In this investigation alpha-cellulose content in LBS was determined to be 32.7%. It has alpha-cellulose content, which is lower than that of hardwoods but comparable with that of cotton and tobacco fibers as given in Table 1. A higher percentage of alpha-cellulose in bark indicates that it should give a better strength, because it functions as a supporting material in the cell walls.

Pentosan content determination measures the total amount of pentose-based carbohydrate in a material. Pentosan content in softwoods is reported to be about 7–10%, and in hardwoods about 19–25% [7]. The pentosan content of LBS, BS, CS and TS were determined in this study to be 9.8, 13.7, 16.9 and 15.7%, respectively.

The carbohydrate composition of a lignocellulosic material is important in determining its response. Carbohydrate constituents in the wood or non-wood have different sensitivities to pulping chemicals, and this affects pulp yield and quality. The principal monosaccharides, which define the carbohydrate composition of lignocellulosic

**Table 1** Chemical compositions of used agro-residues

Components, %	Lemon balm	Bagasse	Cotton	Tobacco
Holocellulose	57.0 ± 1.4	73.7 ± 4.3	64.9 ± 3.1	69.1 ± 3.8
α-Cellulose	42.7 ± 1.8	40.5 ± 3.2	36.0 ± 2.2	37.9 ± 4.3
Hemicellulose	14.3 ± 1.3	33.2 ± 5.3	28.8 ± 4.4	31.2 ± 3.1
Pentosans	9.8 ± 0.8	13.7 ± 2.1	16.9 ± 2.4	15.7 ± 2.2
Ash	9.5 ± 2.6	4.8 ± 1.9	4.5 ± 2.0	12.5 ± 4.3
Lignin				
Acid insoluble	26.5 ± 4.3	27.7 ± 3.5	26.3 ± 5.2	24.5 ± 3.1
Acid soluble	1.30 ± 0.12	0.47 ± 0.08	0.65 ± 0.09	0.78 ± 0.07
Solubles in				
Hot-water	20.0 ± 1.4	6.5 ± 0.6	15.2 ± 1.6	18.9 ± 1.4
1% NaOH	68.9 ± 7.5	31.8 ± 4.3	42.4 ± 2.8	43.5 ± 4.0
E-D <sup>a</sup>	6.7 ± 0.8	3.8 ± 1.1	2.9 ± 0.7	1.65 ± 0.8
Polysaccharides				
Arabinose	1.8 ± 0.2	2.2 ± 0.5	0.5 ± 0.05	–
Mannose	3.2 ± 0.5	5.7 ± 1.0	2.9 ± 0.4	1.7 ± 0.7
Galactose	–	2.6 ± 0.4	0.8 ± 0.2	3.2 ± 0.8
Glucose	68.6 ± 4.7	76.9 ± 5.2	64.7 ± 3.9	78.1 ± 8.2
Xylose	18.4 ± 1.4	14.5 ± 2.1	12.6 ± 2.7	14.8 ± 3.9
Rhamnose	1.4 ± 0.4	0.4 ± 0.4	–	3.8 ± 0.9

<sup>a</sup> Ethanol-dichloromethane mixture

material, are arabinose, mannose, galactose, glucose, xylose and rhamnose. The analysis of monosaccharide composition of LBS (Table 1) allowed some propositions to be made about hemicellulose composition. Accordingly, it contains a significant proportion of glucose as backbone and a rather high proportion of xylose, which may allow the proposition about the presence of significant amounts of xyloglucans.

The value for Klason (acid-insoluble) lignin content found in LBS, 26.5%, is that typically reported for a large variety of gramineaceous species and very similar to values found in other used non-wood plants (24.5–27.7%). In this study, the acid-soluble lignin was measured at 1.30, 0.47, 0.65 and 0.78% for LBS, BS, CS and TS, respectively. The values obtained for lignin are lower than those in softwoods but similar to the values found for most non-wood

and hardwood fibers [2]. The cellulosic sources with lower lignin content are preferred for papermaking, because delignification process for these sources will be relatively easier and consume less chemicals [10]. This point may be considered as a significant advantage of this plant as a raw material for pulp and paper production.

All used non-wood plants contained rather considerable amounts of ash (4.5–12.5%), which are significantly high when compared with fast growing plants ( $\approx$  3%) and woods ( $\leq$  1%). The high ash content in LBS (9.5%) is, probably, due to its important function in nutrient transport. Most of the attention given to the ash content is due to the fact that these impurities affect the processing properties of pulps. Inorganic elements such as silica, potassium and magnesium have negative effect on the kraft pulping, on chemicals and energy recovery and paper quality and yield [6]; thus, high ash content in LBS deserves a special attention, especially when applied to pulping.

The extracts of wood in living plants mainly serve as food reserves (fat, fatty acids, sugars, and starch), protectants (terpenes, resin acids, and phenols) and plant hormones (phytosterols). These can be extracted using suitable solvents. Extractives in plants come in three main categories—those that are soluble in organic solvents (such as “ethanol-dichloromethane” mixtures), those that are soluble in water (“water solubles”), and those that are soluble in aqueous alkali (“alkali solubles”) [7]. In general, the extract content of the LBS is much higher than other studied agro-wastes and woods. As can be seen from Table 1, E-D solubles in LBS fiber are only a little higher than those in BS, CS and TS fibers, but 1% NaOH and hot-water solubles are significantly higher. The alkali solubles contents are higher than the other classes of extractives. Generally, the presence of extraneous materials in the wood reduces yield and necessitates the consumption of chemicals for their removal. Therefore a raw material with little or no extractive content is most desirable.

### Morphology of Fibers

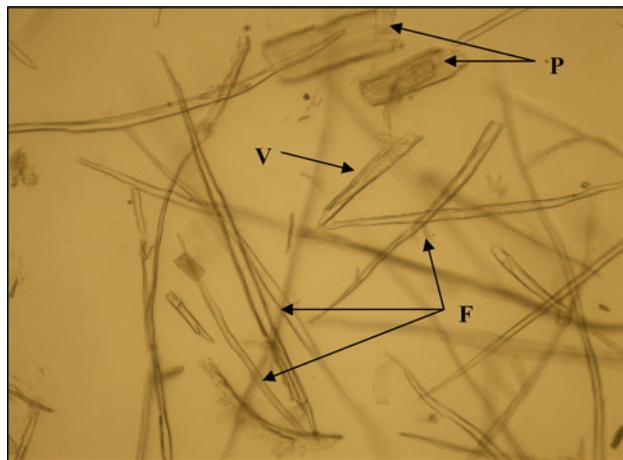
The morphological data for the studied samples are summarized in Table 2. Most of the LBS fiber properties are

**Table 2** Fiber morphology of used agro-residues materials

Fiber characteristic	Lemon balm	Bagasse	Cotton	Tobacco
Fiber length, mm	0.55 (0.11) <sup>a</sup>	0.87 (0.21)	0.88 (0.16)	0.921 (0.12)
Fiber diameter, $\mu\text{m}$	16.38 (3.57)	22.18 (4.06)	7.60 (1.58)	31.00 (4.46)
Wall thickness, $\mu\text{m}$	3.96 (0.85)	5.45 (1.48)	2.01 (0.49)	5.85 (1.11)
Felting factor <sup>b</sup>	35.6 (11.1)	40.8 (12.6)	122.2 (37.3)	30.2 (5.44)

<sup>a</sup> Values in the parenthesis are standard deviation

<sup>b</sup> The ratio of fiber length to fiber width



**Fig. 2** An optical photomicrograph of LBS fibers (10×). *P* parenchyma cell, *F* fiber, *V* vessel

similar to those of the common hardwoods. Although fiber length and cell wall thickness of LBS were similar to those of most of the native hardwoods except for eucalyptus, the LBS fibers contain a significant portion of parenchyma cells (Fig. 2) compared to other studied samples, which is mainly fibrous. The fiber morphology results showed that the mean fiber length for TS fibers was greater than other samples considered in this investigation. The mean fiber length for BS and CS fibers was almost the same.

In contrast to the CS fibers, those from the LBS have a low (35.6) felting factor, resulting in flexible fibers that are rather weak for fiber bonding. In softwood, this ratio is 60–100 [11] and in hardwood 20–60 [12]. On the other hand, the short fibers are expected to give relatively dense paper with good tear and tensile strengths, which might compensate for the low felting factor of the LBS fibers when papers are formed.

## Conclusions

The chemical composition of LBS has been evaluated aiming to estimate its potential applications for pulp and papermaking. In addition, this waste part of medicinal plant was compared with some important agro-residues

including BS, CS and TS. All samples were characterized on basis of carbohydrates, lignin, extractives, polysaccharides and ash content. The results of chemical composition for LBS sample studied in this work showed a remarkable variation in the amounts of the main macromolecular constituents. The LBS had relatively high content of alpha-cellulose and low lignin content compared to the other samples, which benefit pulping and bleaching. It was suggested that the rather high content of ash content in LBS could create problems for their chemical pulping. The LBS contained remarkable amounts of glucose and xylose. The extract content of the LBS is much higher than the other studied agro-wastes and woods. Moreover, the values of LBS fiber lengths, diameters and cell wall thicknesses are in the range of values reported for hardwoods. Based on chemical and morphological characteristics, it is expected that the LBS fibers fulfill the requirements of a good raw material for papermaking.

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