BIOMASS AND BIOENERGY 77 (2015) 123–134

Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

Revealing the morphology and chemical distribution of nodes in wheat straw

Seyed Hamidreza Ghaffar, Mizi Fan *

School of Engineering and Design, Brunel University, Uxbridge, Middlesex UB8 3PH, UK

ARTICLE INFO

Article history:
Received 26 August 2014
Received in revised form
25 March 2015
Accepted 27 March 2015
Available online

Keywords:
Wheat straw
Node
Internode
Morphology
Chemical distribution

ABSTRACT

Morphology and chemical distribution of wheat straw stem, including nodes and internodes, were profiled and thoroughly analysed through a combination of qualitative and quantitative analytical techniques. It was found that the morphology across node area has great variety when the longitudinal profile was investigated in the upwards direction to the grain head; the node core morphology revealed a very dense zone with elliptical shaped rings organised in order to provide the mechanical strength to the overall stem. ATR-FTIR results for the chemical functional groups of outer and inner surfaces of node and internode also showed differences in terms of concentration of functional groups present in each section. It was revealed that the outer surface of wheat straw stem has a higher concentration of aliphatic fraction of waxes compared to the inner surface, with the highest being in the node area. EDX-SEM results were averaged for node and internode and also for inner and outer surfaces for quantitative comparison. It was found that the outer surface of wheat straw had considerable higher Si contents than the inner surface. Also higher content of C in the node outer surface is an indication of high quantity of wax which is in agreement with ATR-FTIR results. The crystallinity of node and internode was investigated using XRD; it was found that node is more amorphous than internode with the crystallinity index of 34.73% compared to 45.00% of internode. The profile of wheat straw morphology in the nodes has never been reported; the results of the quantitative and qualitative structural analysis through in-depth microstructure interpretation, and detailed and accurate chemical composition improved the understanding of straw biomass.

1. Introduction

Research concerning straw biomass has significantly increased due to its renewability and availability and the value added production of straw-based products. Asia is the largest region producing global wheat straw with 43% and then Europe with 32% [1]. Wheat straw is an attractive low cost feedstock for production of fuel alcohol. When compared to corn stover, wheat straw comprises lower amounts of lignin and higher cellulose and hemicellulose [2]. A specific feature of wheat straw cell walls is the presence of a non-core lignin which is simply soluble in alkali and represents up to 20% of total lignin. The removal of this particular lignin increases the digestibility of the material and improves further microbial or enzymatic bioconversion [3]. The amounts of cellulose and

* *Corresponding author*. Department of Civil Engineering, College of Engineering, Design and Physical Sciences, Brunel University, UB8 3PH, UK.
E-mail address: Mizi.fan@brunel.ac.uk (M. Fan).
http://dx.doi.org/10.1016/j.biombioe.2015.03.032
0961-9534/

lignin are in general lower in straws than in wood. Consequently, the amount of hemicellulose is higher [4,5] and a more hydrophilic characteristic of the refined straw fibres is expected compared with wood-based fibres. In addition to three main groups of organic mixtures (cellulose, hemicellulose and lignin), straw also contains various other organic compounds including protein and wax which protect the epidermis of the straw, sugars, salts and insoluble ash including silica, which is significant from those of wood.

Wheat straw is composed on a mass basis of internodes (57 ± 10%), nodes (10 ± 2%), leaves (18 ± 3%), chaffs (9 ± 4%) and rachis (6 ± 2%) [6,7]. The composition of the main chemical substances changes between and within different anatomical parts of the wheat plant. Chemical analysis of wheat straw reveals that internodes have larger cellulose but smaller hot-water-soluble fraction content than either leaves or nodes [8]. Internodes had the highest glucan content compared with chaff, leaves and nodes. All anatomical fractions had similar amount of xylan. More lignin was present in the node and internode fractions. Ash content was higher in chaff and leaves fractions than those in nodes and internodes. The leaves and nodes of wheat straw lose weight more rapidly than the internodes during the early stages of aerobic decomposition. This is at least in part a consequence of the more rapid losses of the polysaccharides in leaves and the hot-water-soluble materials in nodes [9,10].

Most of the studies are comparative studies between different types of straws to establish the structural differences in the overall straw without specifics of anatomical details (e.g. Refs. [11–15]). This paper profiles wheat straw nodes and internodes, and in-depth analyses their chemical distribution and morphology. Due to the complexity of the chemical composition and morphology, combined techniques, both qualitative and quantitative analyses such as ATR-FTIR (attenuated total reflectance-fourier transform infrared spectroscopy), XRD (X-ray diffraction), FEG-SEM (field emission gun-scanning electron microscopy), EDX-SEM (energy dispersive X-ray) and OM (optical microscopy), are used to fully understand the chemical distribution and morphology of wheat straw. The morphologic studies are linked directly to the chemical distribution properties of anatomical sections investigated. The emphases are on node together with the subdivision of the inner and outer surfaces. What is happening morphologically in the node area of wheat straw as it is investigated from down to up (root to grain head) is the question which is answered in this paper for the first time. The results are also compared to internode for better understanding. This in-depth analysis will aid the better utilisation of anatomical parts of wheat straw for different applications as a result of the detailed understanding of morphological and chemical properties.

2. Experimental plan

2.1. Wheat straw

Wheat straw (*Triticum aestivum* L.) for this study was obtained from farms in Rickinghall, Norfolk, United Kingdom (East of England); Dixon Brothers Porters Farm, which was harvested in summer 2012. Wheat straw bales were prepared and dried directly on site. Bales were collected and homogenised carefully. Then, five representative samples of about 40 g were selected for morphological characterisation. The samples were dried in the oven for 24 h at 104 °C and stored for surface chemical characteristics.

2.2. Sample preparation

Nodes and internodes were randomly selected. They were carefully cut in half (using a sharp razorblade) longitudinally so that the inner and outer surface could both be examined quantitatively and qualitatively. The samples of node and internode were also cut transversely for the cross-section investigation (qualitative analysis such as OM and FEG-SEM). For the preparation of samples for FEG-SEM and EDX-SEM, wheat straw nodes and internodes (1–2 cm length) were carefully placed in a small mould in a way to have both inner and outer surface exposed vertically and horizontally (Fig. 1), and then all species were vacuum impregnated with epoxy resin mixture (EpoxiCure 2 Resin; Product number: 203430128 from Buehler UK). After curing of the resin the bottom surface of the sample was first grinded using different level of grinding papers and finally all samples were polished before examinations. The grinding and subsequent polishing of the sample were carried out using EcoMet 250 Grinder-Polisher from Buehler. EDX-SEM and FEG-SEM samples were gold coated prior to tests. The XRD samples of nodes and internodes were ground individually using a coffee grinder and then the samples were sieved (between 250 and 125 μm) to get uniform particle size. The nodes for XRD were carefully extracted to ensure that all samples contained only the crystallinity of the node but without the internode.

3. Results and discussion

3.1. Wheat straw stem

Wheat straw stem comprises internodes separated by nodes, at which leaves are attached to the stem (Fig. 2). The internodes are formed as concentric rings leaving a void or lumen in the centre. The outermost ring is a cellulose-rich dense layer (termed the epidermis), which has a

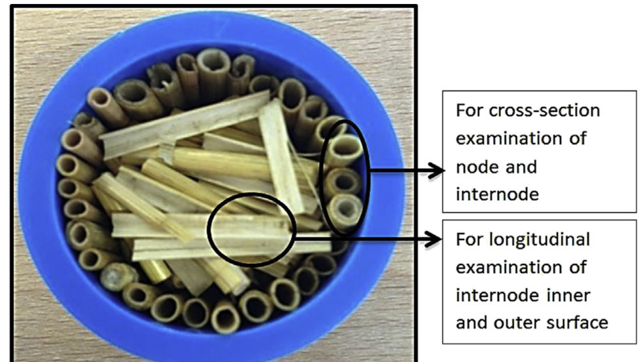

Fig. 1 – Sample fabrication for FEG-SEM, EDX-SEM.