# Food & Nutrition: Current Research

FNCR, 1(2): 61-66
www.scitcentral.com

**Original Review: Open Access**

# Wheat Straw Biomass and its Anatomical Characteristics

**Seyed Hamidreza Ghaffar**[1*]

[1]*College of Engineering, Design and Physical Sciences, Brunel University, Uxbridge, Middlesex, UB8 3PH, United Kingdom*

***Received April 10, 2018; Accepted May 6, 2018; Published** June 27, **2018***

**ABSTRACT**

Understanding the details of microstructure and characterisation/differentiation of properties of wheat straw anatomical parts is essential for their smart bio-refinery. Comprehensive and systematic experimental programmes should be designed in order to thoroughly investigate the node and internode of wheat straw with quantitative appraisals and qualitative interpretations. This could contribute towards straw biomass valorisation in bio-refinery pathways. Utilisation of these inexpensive raw materials leads to socio-economic and environmental benefits by making additional income to the farmers, generating cost-effective high performing bio-products and minimising the burning of the straw in the fields. The bridging between the research-based adaptation of efficient pre-treatments on the extraction, separation and fractionation of waste crops components, has unique potential to yield innovative added value green chemicals. The direct extraction of specifically engineered or naturally occurring chemicals from the complex molecular components of different parts of straw biomass is also a possibility which requires the detailed investigations of anatomical parts.

## INTRODUCTION

Continuing overpopulation and consumptions increase are driving global food demand, with agricultural activity growing to keep pace. Europe has huge agricultural waste problems, annually generating around 700 million tonnes of waste. There is a critical need and major opportunities to addressing the efficient utilisation of agricultural wastes, co-products and by-products towards delivering sustainable value chains in the farming and processing sectors. Low value agricultural waste could be transformed into highly valuable products through holistic elucidation of straw biomass, their detailed anatomical characterisation and by developing a detailed understanding of the waste streams and piloting important number of waste utilisation/valorisation pathways.

Wheat is a major food crop in various countries around the globe with a production of 744 million tons in 2016/17. It is the main proportion of most diets in the EU, US and China. Wheat is one of the ubiquitous grain crops due to its agronomic adaptability, ease of storage, nutritional value and the ability of its flour to produce different products [1].

Throughout the recent years our research has contributed to the comprehensive understanding of wheat straw (***Triticumaestivum*** L.), summarised in the following points:

1) Critical reviews which identify the gaps and future prospective in research fields of i) lignin in straw and its optimisation as an adhesive, i.e. thermosetting resins [2], ii) structural analysis techniques for lignin characterisation with differentiation of quantitative and qualitative analyses [3], and iii) bioengineering concept for straw biomass bio-conversion to bio-energy/bio-composite with specific functions of microorganisms, i.e. fungi and enzymes [4].
2) Revealing the morphology of node and internode in wheat straw with a 3D model of node and its core, investigated from the root to the grain head direction in stem [5].
3) In-depth scientific identification of differential physicochemical properties of node and internode with relative surface profile functionalization [6-8].
4) Environmentally friendly pre-treatment strategy with effective surface modification of wheat straw for the optimisation of interfacial bonding [9].

Interfacial bonding and physical model of failure mechanisms in straw composite [9].

**Corresponding Author**: Seyed Hamidreza Ghaffar, College of Engineering, Design and Physical Sciences, Brunel University, Uxbridge, Middlesex, UB8 3PH, United Kingdom, Email: seyed.ghaffar@brunel.ac.uk

**Citation:** Ghaffar S H. (2018) Wheat Straw Biomass and its Anatomical Characteristics**.** Food Nutr Current Res, 1(2): 61-66.

Bio-based materials can be used for a wide range of products (e.g. food, construction, furniture, paper, textile, chemicals, etc...) and energy use (e.g. biofuels). The bio-economy hence provides alternatives to fossil-based products and energy, and can contribute to the circular economy. Bio-based materials can also present advantages such as renewability, biodegradability or compost-ability.

In this paper some of the outcomes of the research are presented with directions for further research and investments for valorisation of wheat straw.

## Wheat Straw Main Constituents

Lignocellulosic material from cereal straws essentially consists of three different polymeric entities: linear and crystalline (cellulose), branched non-cellulosic and non-crystalline hetero-polysaccharides (hemicelluloses), and branched (non-crystalline) lignin [12]. Lignin is primarily a structural material to add strength and rigidity to cell walls and constitutes between 15 and 40 weight% of the dry matter of plants, whether wood, straw or other natural woody plants [13,14]. Lignin acts as a matrix together with hemicelluloses for the cellulose microfibrials which are formed by ordered polymer chains that contain tightly packed, crystalline regions, represented in **Figure 1.**

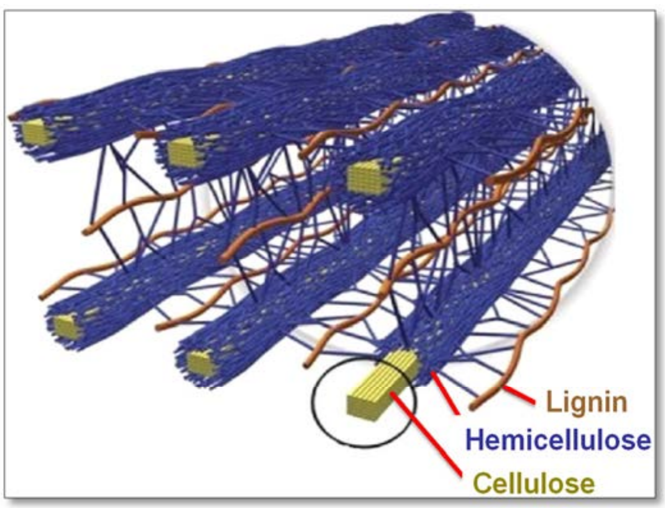


**Figure 1.** Cellulose strands surrounded by hemicellulose and lignin [15]

Cellulose is a long chain of glucose molecules, connected to each other primarily by β (1→4) glycosidic bonds and its non-complicated structure shows that it can be biodegraded. Hemicellulose, just like cellulose, is a macromolecule from different sugars but alters from cellulose in that it is not chemically homogeneous and is a polysaccharide, which has lower molecular weight compared to cellulose. A key alteration among cellulose and hemicellulose is that the latter possesses branches with short lateral chains containing various sugars, and cellulose contains easily hydrolysable oligomers. Hemicelluloses in straw biomass are made mainly of xylan, whereas softwood hemicelluloses have glucomannan [12].

## Wheat Straw Morphological Variations

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%) [10].Wheat straw stem comprises internodes separated by nodes, at which leaves are attached to the stem **(Figure 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 concentration of silica on the surface. Beneath the epidermis is a loose layer containing parenchyma and vascular bundles. The length of the internodes increases from the ground to the top [5].

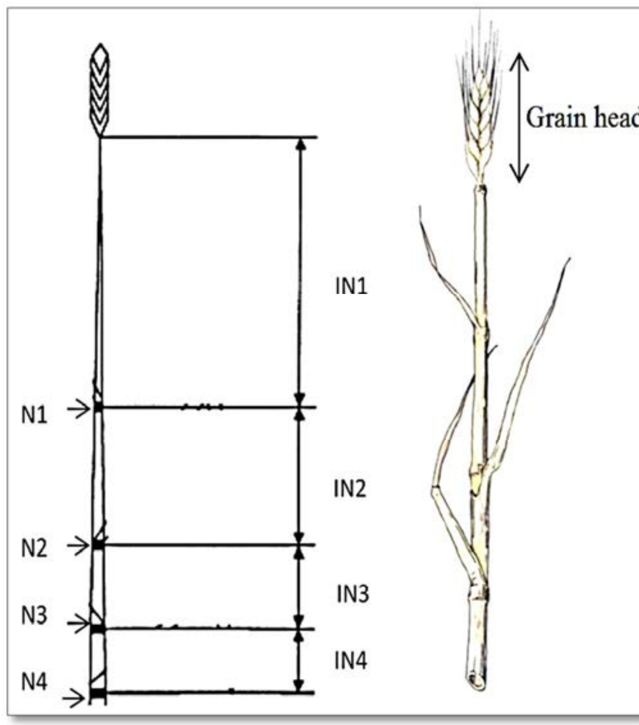


**Figure 2.** Schematic diagram of wheat straw with nodes (N) and internodes (IN)

The material preparation and separation were important steps prior to testing characterisation and/or pre-treatments. As shown in **Figure 3,** the leaves were separated from the stem, and then the stems were grouped and cleaned. The internodes were grouped and nodes were carefully cut and separated. The stem had to be examined carefully for nodes separation, in order to separate the node.


**Figure 3.** a) the separation of leave from stem of wheat straw, b) the straw stems cleaned, c) the internodes separated from the d) nodes.

The examination of the nodes compact architecture in wheat straw revealed a very different morphology from that of the internode. The node structure along the longitudinal direction was investigated by taking cross-section images after carefully grinding layer by layer with smooth abrasive paper moving towards the wheat grain, shown in **Figure 4.** This would then enable the 3D model of the node morphology. **Figure 3** shows the outer and inner surfaces of node region, and their corresponding OM images are shown by the arrows indicating their positions in the node region. The investigation starts from the internode immediately before the node and then enters the node core zone and continues forward to where the brown elliptical rings get smaller and the beginning of the upper internode reveals. Those brown elliptical rings start to get smaller and smaller until they disappear, i.e. the start of the hollow upper internode.

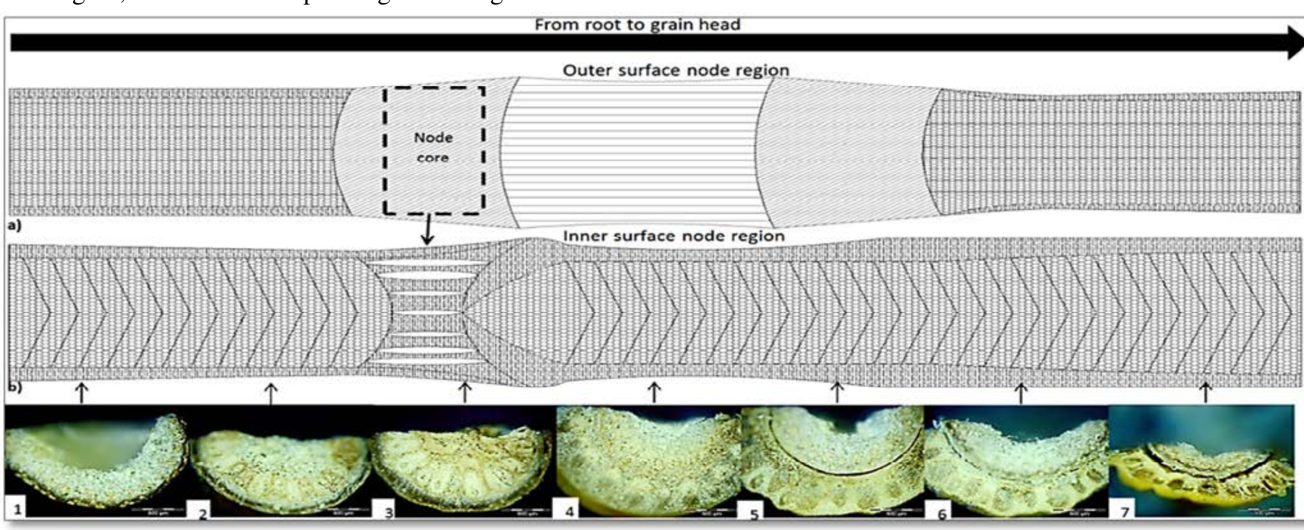


**Figure 4.** The schematic image of the node outer (a) and inner (b) surface longitudinal view and the OM images corresponding to the position in the node shown by the arrows

Unlike node the morphological longitudinal profile of internode was found to be consistent. The outer part of the straw internode contains wax and inorganic substances on the surface, and then follows a region with fibre bundles (vascular bundles) integrated in a region of parenchyma and vessel elements. The epidermis is a complex tissue with bubble-shaped polygonal short and long cell types, see **Figure 5.** Wheat straw epidermis is thin, but has dense and thick-walled cells with an outer wall coated with a waxy film of cutin cuticle[5].

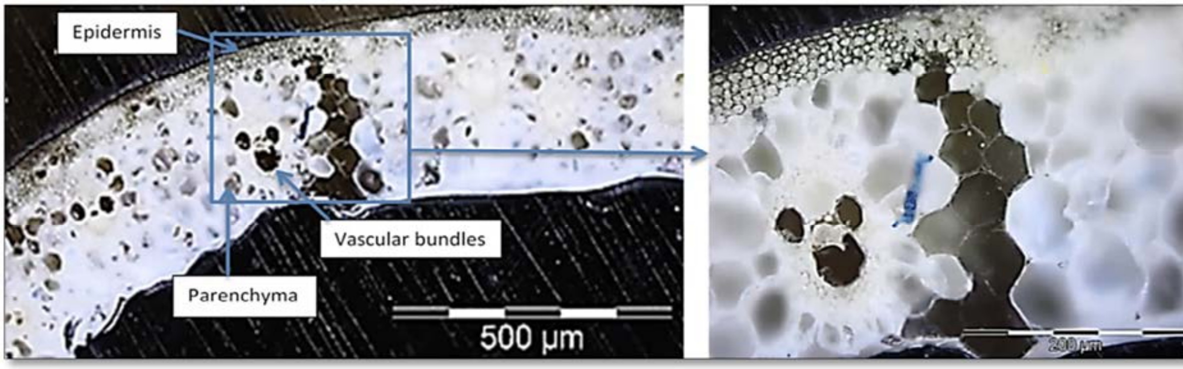


**Figure 5.** Optical microscopy image of internode cross-section

**Physicochemical Properties and Surface Functionalities of Wheat Straw Node and Internode**

The physicochemical and surface functionality characterisations contribute towards the valorisation of wheat straw as improved feedstocks for bio-refinery processes. In order to gain more aggregated understanding of node and internode, the physicochemical characteristics were examined in relation to their cell wall components. Distinct variations were found amongst the physicochemical characteristics and cell wall components of node and internode, making them suitable and/or defect for different specific bio-refinery pathways. Separation of node and internode, possessing different attributes, and utilising them in segregated processing's could lead to higher value added products. For instance node had higher extractives and ash content which could be a defect for bio-composites or bio-energy as these characteristics inhibit the performance of the intended end product.

It must be recognised that not all parts of the straw biomass are equally valuable. For instance biofuel and chemical processors only require the high yielding cellulose and hemicellulose biomass parts delivered. This signifies a strategy for identifying and subsequently reducing the number of undesirable residue parts for feedstock. Additionally the heterogeneous nature of straw, where their chemical composition varies with species, location, storage time, harvest, stage of maturity, environmental conditions and anatomical parts, i.e. node and internode, makes their comprehensive characterisation essential prior to bioconversion process [16,17]. It is almost impossible to control the compositional variability of straw biomass, but it is feasible to monitor the variability and accordingly select the processing technologies for the specific bio-refinery.

**Surface Elemental Composition of Node and Internode**

Elemental composition of wheat straw profiles is shown in **Table 1.** The bulk structure of the wheat straw consisted of carbohydrates and lignin with a considerable amount of carbon (C) and oxygen (O), and a trace amount of silicon (Si) weight percentage. The outer surface of internode has higher Si weight percentage than the inner surface, the former is 5.8% and the latter is 0.8%. By comparing the nodes and internodes, outer to inner surface, it could be concluded that more silicon (in the form of silica) is located mainly on the outer surface (epidermis) of wheat straw.

**Table 1.** Node and internode profile elemental composition based on EDX-SEM analysis

| Profile Surface | Sample | Percentage % | | | O/C |
|---|---|---|---|---|---|
| | | C | O | Si | |
| **Inner** | Internode | 54.1 (2) | 45 (1) | 0.8 (4) | 0.83 |
| | Node | 54.1 (9) | 45.6 (7) | 0.7 (6) | 0.84 |
| **Outer** | Internode | 51.3 (2) | 43.4 (5) | 5.8 (2) | 0.84 |
| | Node | 53.7 (3) | 43.5 (8) | 2.8 (2) | 0.81 |

**** Values in () are Coefficient of Variance %***

## Cell Wall Composition of Node and Internode

The assessment of cell wall composition in straw biomass is traditionally carried out on milled samples of the whole stem, without accurate determination of node and internode separately. However, the cell wall composition of the internode may be rather different from that of the node.

**Table 2** summarises the main chemical components of wheat straw analysed following the NREL/TP-510-42620. The variation of cell wall composition across wheat straw node and internode showed that node yielded slightly higher Klason lignin, extractives and ash content than internode, which could be related to their morphology, precisely the higher ash and extractives content in the node are explained by thicker epidermis tissue.

**Table 2 Chemical analysis of wheat straw (% dry straw)**

| Sample ID | Hot-water extraction (HW) | | | Ethanol extraction (ET) | | | Non-extracted samples |
|---|---|---|---|---|---|---|---|
| | Extractives (%) | Ash content (%) | Klason lignin (%) | Extractives (%) | Ash content (%) | Klason lignin (%) | Ash content (%) |
| **Internode** | 4.2 (4) | 0.9 (8) | 22.0 (2) | 3.8 (9) | 1.5 (2) | 23 .7 (5) | 3.2 (2) |
| **Node** | 4.6 (5) | 1.3 (7) | 26.0 (3) | 4.0 (7) | 1.9 (3) | 27.1 (9) | 5.3 (4) |

**** Values in () are coefficient of variance %***

The extractives are a heterogeneous group of substances in straw biomass. The main extractives are resin acids, sterol esters, waxes, triglycerides, fatty acids, sterols, fatty alcohols and a selection of phenolic compounds [18]. It is evident that the extractives in nodes are higher than in internodes (**Table 2),** for both (hot-water) HW extraction and ethanol (ET) extraction. This observation can be helpful for the selection and process of straw for intended end application i.e. bio-composites as the higher extractives content of the nodes could lead to the inhibition of optimal interfacial bonding between the straw particles. It is also observed that the node of wheat straw contains more ash, in both non-extracted samples (structural ash) and extracted samples through hot-water and ethanol. The higher ash content of the node can cause problems for the pulping and therefore its removal prior to pulping will upgrade straw quality as a feedstock.

## CONCLUSIONS

These are important parameters for optimising the yield and economics of various bioconversion pathways. Unfortunately, despite wheat straw's potential for bio-refinery to value added products; it still remains underutilised due to the lack of understanding the complexity of its constituents. The detailed information from this study shall serve as valuable and fundamental basis/database for researchers and industries in the sector of bio-refinery of straw biomass.

An open central knowledge database with available straw biomass characterisation and specifications should be established. This can be a huge task which researchers are trying to contribute towards but it requires a greater international effort and collaborations. A mutual interest agreement amongst researchers and companies involved in bio-based materials should be introduced. Competition is good for innovation, but in the start-up phase, small companies should collaborate for R&D rather than compete with each other.

## REFERENCES


1. USDA (2016) Economic Research Service. Untied States Department of Agriculture.
2. Ghaffar SH, Fan M (2014) Lignin in straw and its applications as an adhesive. Int J Adhes Adhes 48: 92-101.
3. Ghaffar SH, Fan M (2013) Structural analysis for lignin characteristics in biomass straw. Biomass and Bioenergy 57: 264-79.
4. Ghaffar SH, Fan M, McVicar B (2015) Bioengineering for utilisation and bioconversion of straw biomass into bio-products. Ind Crops Prod 77: 262-274.
5. Ghaffar SH, Fan M (2015) Revealing the morphology and chemical distribution of nodes in wheat straw. Biomass and Bioenergy 77: 123-134.
6. Ghaffar SH, Fan M (2017) An aggregated understanding of physicochemical properties and surface functionalities of wheat straw node and internode. Ind Crops Prod 95.
7. Ghaffar SH, Fan M, Zhou Y, Abo Madyan O (2017) Detailed Analysis of Wheat Straw Node and Internode for Their Prospective Efficient Utilization. J Agric Food Chem 65.

8. Ghaffar SH, Fan M (2015) Differential behaviour of nodes and internodes of wheat straw with various pre-treatments. Biomass and Bioenergy 83: 373-382.
9. Ghaffar SH, Fan M, McVicar B (2017) Interfacial properties with bonding and failure mechanisms of wheat straw node and internode. Compos Part A Appl Sci Manuf 99: 102-112.
10. Motte JC, Escudie R, Beaufils N, Steyer JP, Bernet N, et al. (2014) Morphological structures of wheat straw strongly impacts its anaerobic digestion. Ind Crops Prod 52: 695-701.
11. López-Abelairas M, Álvarez Pallín M, Salvachúa D, Lú-Chau T, Martínez MJ, et al. (2013) Optimisation of the biological pretreatment of wheat straw with white-rot fungi for ethanol production. Bioprocess Biosyst Eng 36: 1251-60.
12. Ghaffar SH (2016) Straw fibre-based construction materials.
13. Akin DE, RB (1988) Degradation of polysaccharides and lignin by ruminal bacteria and fungi. Appl Environ Microbiol 54: 1117-1125.
14. Baurhoo B, Ruiz-Feria CA, Zhao X (2008) Purified lignin: Nutritional and health impacts on farm animals—A review. Anim Feed Sci Technol 144: 175-184.
15. Doherty WOS, Mousavioun P, Fellows CM (2011) Value-adding to cellulosic ethanol: Lignin polymers. Ind Crops Prod 33: 259-276.
16. Harper SHT, Lynch JM (1981) The chemical components and decomposition of wheat straw leaves, internodes and nodes. J Sci Food Agric 32: 1057-1062.
17. Hess JR, Thompson DN, Hoskinson RL, Shaw PG, Grant DR (2003) Physical separation of straw stem components to reduce silica. Appl Biochem Biotechnol 108: 43-51.
18. Sun RC, Tompkinson J (2003) Comparative study of organic solvent and water-soluble lipophilic extractives from wheat straw I: yield and chemical composition. J Wood Sci 49: 47-52.