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ANALYSIS OF POSSIBILITIES FOR UTILIZATION OF AGRICULTURAL LIGNOCELLULOSIC RESIDUES AS ALTERNATIVE RAW MATERIAL FOR PRODUCTION OF MEDIUM-DENSITY FIBREBOARDS (MDF)

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ABSTRACT

As a result of performance of tasks from the first year of the project "Effect of content of non-wood lignocellulosic raw material and lignosulphonate in the composition of medium-density fibreboards (FB) (MDF) on their performance", analysis of the possibilities for utilization of agricultural lignocellulosic residues as alternative raw material for production of MDF has been made. The world experience in this respect has been examined and the amount of this type of raw materials in Bulgaria has been determined. It has been established that there is huge amount of publications which report on the satisfactory use of agricultural lignocellulosic residues as alternative raw material for fibreboards, including such ones intended for construction. In Bulgaria, there exist more than sufficient quantities of residual lignocellulosic fibres for meeting the needs of manufacturers of wood-based boards. Nevertheless, this type of raw material is not utilized.

Kew words: agricultural lignocellulosic residues, alternative raw material, MDF

1. INTRODUCTION

On a world-wide scale, the production of medium-density fibreboards (MDF) is characterised with considerable development in the recent years, and this type of boards leave behind, in terms of production, the fibreboards, but still there are problems due to the insufficient raw materials base for this type of production. It should be noted that one of the main advantages of MDF are the reduced requirements for wood raw material, and this assumes the possibility for adding non-wood lignocellulosic raw materials from annual agricultural crops to their composition.

In the production of MDF after the classical method, wood raw material, more particularly the wood raw material from coniferous tree species, is used, but also from broad-leaved tree species, as well as mixedly from different tree species. The needs of wood raw material and wood-based materials increases proportionally to the rate of population growth. The world population increases by about 90 million persons annually (Cooper and Balatinecz, 1999). Moreover, on a world-wide scale, more than 3.5 million tons of wood are consumed per year, which corresponds to about 0.7 t per capita. If the consumption of wood, respectively of wood fibres, and the population growth remained constant, then the need of wood fibres would increase by 60 million tons each year. Therefore, emergence of big unbalance between the wood supply and demand is inevitable. This leads to the conclusion that alternative lignocellulosic fibres (i.e. agricultural waste and other plant fibres), the recycling and the alternative technologies for processing, as well as new products, will play considerable role in the chain of supply and demand of lignocellulosic fibres (Mizi Fan et al., 2009), Cooper and Balatinecz 1999, Rowell, 1995). The above presented clearly shows the shortage of forest resources and the impact of the increased wood consumption. Therefore, the lack of forest resources necessitates partial or full replacement of wood fibres with other lignocellulosic raw materials in the production of fibrous materials. One similar positive example is the mixing of agricultural lignocellulosic residues and wood fibres in the production of MDF (Akgül Mehmet, Cengiz Güler, Birol Üner et al., 2010).

It should not be forgotten, however, that, in the use of these materials as raw material, of great significance are the conditions of their gathering and storage. Very often the expenses for gathering and especially for delivery of certain types of raw material prove to be so high that the production of boards proves to be unprofitable.

The increasingly tangible lack of wood necessitates overcoming these problems and finding suitable ways, methods and technologies for utilization of agricultural lignocellulosic materials as raw material for the production of wood-based boards.

The potential of some agricultural residues for their use in the production of composites on a world-wide scale is presented in Table 1 (Mizi Fan et al., 2009).

Table 1. *Potential of some agricultural lignocellulosic materials*

Type of lignocellulosic residues	Amount on a world-wide scale in oven-dry state, t
Stalks of agricultural grain crops (wheat, rye, oats, etc.)	1,145,000,000
Other stalks (tobacco, rice, cotton, etc.)	970,000,000
Sugar cane	75,000,000
Lake cane	30,000,000
Bamboo	30,000,000
Cotton fibre	15,000,000
Jute, kenaf, hemp fibres	10,900,000
Papyrus	5,000,000
Cotton linters	1,000,000
Esparto grass	500,000
Sisal and abaca leaves	480,000
Sobai grass	200,000

It is the USA where it is especially intensively worked on the matters of utilization of agricultural lignocellulosic residues (ALCR). The scope of this work and the covered matters can be judged by the publications of the organization Forest Products Society that provides an information network about all segments of the forest industry – from standing trees to end products.

During the conference in Winnipeg, Canada, sponsored by Forest Products Society in 1999, the following subjects related to the use of lignocellulosic materials were addressed: use of a “hybrid” gluing system for the production of boards from straw; practical experience in the production of boards based on fibreboards of agricultural origin; utilization of stalks from industrial hemp to obtain composite boards; review of the key issues in utilization of wheat straw for production of MDF; glues on the basis of soya beans for wood and composite products from agricultural fibres; structural boards manufactured from crushed straw (Forest Products Society Publications (http://www.forestprod.org).

Another institution in the USA which performs investigations in this respect and works in support of the concept “Zero Waste California”, is Integrated Waste Management Board – California (CALCRecycle). Part of the investigations performed are related to utilization of the agricultural lignocellulosic residues, with the subject of these investigations being the types of agricultural residues, their amounts and the existing technologies for processing, as well as the products obtained from this raw material (http://www.ciwmb.ca.gov.).

According to the specialists from Resource Conservation Alliance (a non-governmental organization with its headquarters in Washington D.C.), the agricultural residues are a promising alternative to the wood fibres as industrial reserve. They are in abundance, they are cheap, and their use leads to three-sided advantages: economic; advantages related to the environment protection and technological advantages.

To the farmers, the agricultural waste may represent a source of additional funds to the market price of the specific agricultural crop. Traditionally, the farmers gather the grain and burn or dispose of straw and other residues (stalks, etc.) in another way . The increased interest lately in the production of composites and paper from agricultural waste means that the farmers may also “reap” an after-crop from the grain plants.

In addition, due to the high transportation costs of agricultural waste for its processing into pulp (cellulosic mass), it is normal that the mills are built in agricultural areas, close to the farms and areas where these materials are harvested. This would support the local economies through provision of work, different services and higher tax rate. One can also think of encouraging the farmers to maintain reserves in the local mills so that their income increases both from the sale of the agricultural waste and through dividends for industrial risk.

The problem with burning of stubble fields is generally known. Scientists from the USA have calculated that burning of about 1 million tons of straw in California each autumn leads to the release of about 56,000 t of carbon oxide. Utilization of straw in the production of composites and paper would lead to elimination of this hazard. For that purpose, the respective regulatory and administrative acts and documents have been elaborated.

The specialists of FAO also pay attention to this raw material source. According to Leo Lintu from Raw Material and Market Analyses Department at FAO Forestry Department – Forest Industries Division, the use of agricultural residues in the board-type materials and the paper industry is mainly limited by economic factors, whereas the technical problems may be overcome. The use of raw material with non-wood fibres in the production of boards has increased in the recent years, but at lower rates than the production itself. This raw material still remains a very small component of the volume of the whole raw material – annually to the amount of 2-3%.

According to Lintu, the following crops have future in this respect – bagasse (fibrous waste remaining after the extraction of juice from sugar cane in sugar production); straw from different grain crops – predominantly wheat, but also from rye, oats, barley and rice; hemp and flax scutch (www.fao.org/forestry/).

With respect to the matters about utilization of agricultural waste, it is very actively being worked on in Europe, too.

In 1989, in Bangor, Northern Wales, a BioComposites Centre was established, whose goal is to provide fundamental and applied research on world level for products and processes on the basis of wood, industrial crops, recycled materials and industrial waste. As part of the Centre for Advanced & Renewable Materials, in 1982 BioComposites Centre performed a study of the reserves of renewable biomass in Wales. In the study it was shown that paper industry and the industry for production of forest products are an excellent example for enterprises that use these reserves efficiently and profitably. According to the conclusions drawn, the use of industrial crops, besides the other benefits, may also lead to reduction of the greenhouse effect. Measures to improve the activities in this respect have also been laid down (www.bc.bangor.ac.uk).

In order to meet the future demand and to overcome the shortage of wood, several studies in Turkey investigated the suitability of the agricultural residues in the forest industry as component of the raw materials for production of wood-based boards. Chow (1974), Youngquist et al. (1993) and Youngquist et al. (1994) presented investigations related to the use of non-wood plants in the forest industry. Several researchers have studied the possibility for use of wheat straw (Eroğlu and İstek 2000), cotton stalks (Gençer et al. 2001; Güler and Özen 2004), cotton carpel (ALCMa et al. 2005), sunflower stalks (Bektas et al. 2005), kiwi prunings (Nemli et al. 2003), hazelnut husk (Copur et al. 2007) and hazelnut shells and husk (Copur et al. 2008) in the production of wood-based boards.

There are investigations on the respective subject in other European countries, too.

2. CHARACTERIZATION OF SOME TYPES OF ALCR

The characterization of agricultural lignocellulosic residues is of importance during their specification as raw material for production of wood-based boards. The form in which they are harvested depends mostly on their anatomical and chemical characteristic, as well as on the methods, technology and mechanization of use of the main product.

The chemical composition of lignocellulosic materials consists mainly of the organic substances lignin, cellulose, proteins, fats, waxes and resins. The organic substances starch, sugars, proteins and pigments also participate in negligible amounts. The substances from the organic composition of agricultural lignocellulosic materials (ALCM) are built of the chemical elements carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Their percentage is given in Table 2 (Yosifov N. 2005).

Table 2. *Chemical composition of the main organic substances in the plant biomass according to Noger-Pletscher (1998)*

Organic substances	Chemical elements, %			
	C	H	O	N
Lignin	63.1	5.9	31.0	-
Cellulose	44.4	6.2	49.4	-
Proteins	50-55	6.5-7.2	20-23.7	15-19
Fats	76-79	11-13	10-12	-
Waxes	80-82	13-14	4-6	-
Resins	75-85	9-12	5-14	-

Besides the organic matter, minimum amounts of the elements phosphorus (P), potassium (K), calcium (Ca), sulphur (S), iron (Fe), manganese (Mn), magnesium (Mg) and sodium (Na) are contained in ALCM. They constitute the inorganic part of the ash content after biomass burning.

The chemical composition in oven-dry state by chemical elements for different types of lignocellulosic biomass is given in Table 3 (Yosifov N. 2005).

Table 3. *Content of main chemical elements in the natural lignocellulosic materials in oven-dry state according to Hartmann-Kaltschmitt (2000)*

Biomass type	Content of chemical elements, %				
	C	H	O	N	S
Pine (with bark)	49.5	6.5	42.6	0.12	0.014
Spruce (with bark)	49.8	6.3	43.2	0.13	0.015
Beech (with bark)	47.9	6.2	45.2	0.22	0.015
Poplar	47.5	6.2	44.1	0.42	0.031
Willow	47.1	6.1	44.3	0.54	0.045
Bark (from coniferous wood)	51.4	5.7	38.7	0.48	0.085
Wheat straw	45.6	5.8	42.4	0.48	0.082
Rye straw	46.6	6.0	42.1	0.55	0.085
Rape straw	47.1	5.9	40.0	0.84	0.270
Millet straw	47.5	5.8	41.4	0.46	0.089

The percentage of the organic substances in the plant biomass varies within wide limits as follows: lignin – 15 to 30%, cellulose – 38 to 56%, hemicellulose – 17 to 37% and others – 2 to 7%.

The lignocellulosic biomass represents a complex of complex organic substances (cellulose, lignin and hemicellulose) constituting about 96% of its oven-dry mass. Out of them, cellulose is the main organic substance that determines the biomass elasticity.

With respect to resistance to thermal impacts, cellulose has a satisfactory level and may be briefly heated without decomposition up to a temperature of 200-220 °C. It is a high-molecular compound. The exothermal process of its decomposition starts at a temperature of 275 °C.

The lignin contained in the lignocellulosic materials is a high-molecular amorphous compound. It is a combination of several colloidal substances and under certain conditions it may serve as binder. On heating, it acquires good plasticity.

The hemicellulose consists of pentosans and hexosans and has chain structure of the molecules. It plays the role of bond between the cellulose and the lignin. In terms of structure, it is closer to the cellulose than to the lignin.

3. PROPERTIES OF FIBRES

The amount of cellulosic and non-cellulosic constituents of the fibres determines their structure and properties and affects their crystalline structure and elasticity (Ray P. K. and S. B. Bandyopadhyay, 1965). Properties such as density, electric resistance, tensile strength, modulus of elasticity, elastic recovery and crystalline structure are related to the composition and structure of the fibres. Although the strength of the fibres may not be exactly correlated with the cellulose content and the microfibrillar angle, as a whole, fibres with higher cellulose content, higher degree of polymerization and smaller microfibrillar angle show better mechanical properties (Sukumaran, K. et al. 1992). Fibres with higher lignin content, lower slenderness and higher microfibrillar angle show lower strength and modulus of elasticity in bending, but have higher stretchability. The higher amount of cellulose and the smaller spiral angle in banana fibres provide the fibres with higher modulus of elasticity and tensile strength, but lower stretchability in comparison with coir (Kulkarni A. G. et al. 1983). The mechanical properties of the natural fibres are influenced by the composition, structure and number of defects in them. In case of loading, the destruction takes place either in the middle lamella or in the cell walls. In the fibres having higher cellulose content, such as those in the stalks of bananas and pineapples, the cracks propagate due to the weak bonding between the cells, causing intercellular destruction (in the middle lamella) without this leading to formation of cellulose fibrils (Sukumaran, K. et al. 1992). Conversely, the destruction propagates through the cells in the fibres with lower cellulose content, like in the coir, which leads to intracellular rupture and formation of cellulose fibrils (Sukumaran, K. et al. 1992). The elongation of fibres depends on the degree of crystallinity, the orientation and angle of microfibrils with respect to the axis of fibres.

The high stretchability of coir is above all result of the perfect helicoidal spirals formed by the microfibrils around the optical axis (Ray P. K. and S. B. Bandyopadhyay 1965). The cellulose fibrils change their size and properties in case of change in their water content (Mohanty A. K. et al. 2000). The degree of variation of fibres is determined by the amount of hemicellulose, lignin, by their crystalline structure and by surface characteristics of the fibres (Mohanty A. K. et al. 2000). The water content in the fibres affects their degree of crystallization, the orientation of the cellulose crystals, the tensile strength, the behaviour during water absorption and the porosity of the plant fibres (Sukumaran, K. et al. 1992). The increase of the water content reduces the elasticity of fibres and affects the dimensional stability of the components built by cellulose fibres (Mohanty A. K. et al. 2000; Sukumaran, K. et al. 1992). The ability of the fibres for adsorption and desorption must be taken into consideration when assessing the suitability of the fibres for different applications, especially for textile, paper and composite materials.

4. ALCM AS RAW MATERIAL FOR THE PRODUCTION OF MDF

From the short literature review made, it becomes clear that there is certain experience in the production of MDF on the basis of different types of ALCM, viz.:

WHEAT AND RICE STRAW

A team of *Mid Sweden University* and *Metso* published the results of conducted study of the possibilities to use wheat straw as raw material for production of MDF (Halvarsson et al. 2010).

Wheat straw was used for production of medium-density fibreboards (FB) (MDF). At the same time, the physical and chemical properties of fractionated, with reduced size, wheat straw fibres were examined. With the reduction of size of wheat straw fibres, pH, ash content and silicon content increase. The smallest fibres, < 0.2 mm, have highest dust content (15%) and silicon content (18%). The external and internal parts of the straw fibres reduced in size were analyzed by means of scanning electron microscopy (SEM). By means of SEM, the complex substructure containing visible part of thin-walled cells with a thickness of about 1 μm was disclosed. By means of thermomechanical defibration, lignocellulosic fibres with length of about 1.0 mm were produced, but about 24% of smaller particles and dust were present in the composition of the mass. In order to reduce the high water absorption of MDF made of wheat straw, modified melamine-urea-formaldehyde resin was used and removal of the small particles and the dust from the composition of the mass was performed by means of separation. The resin was added to the ratio of 12.5%, 13.1% and 14% with respect to the oven-dry lignocellulosic mass. With respect to the hydrophobic properties of MDF with thickness of 12 mm, this type of boards composed entirely of wheat straw mass show swelling in thickness below 10%, which completely meets the requirements of EN 622-5. It has been concluded that for production of MDF from rice straw, which meet the quality requirements, removal of the small particles and the dust from the mass and application of modified melamine-urea-formaldehyde resin in the capacity of binder are necessary.

Next step in the examined aspect is a study of a team from the Architecture Engineering Department of the Menoufia University, Egypt. The purpose of the study was to develop an economical, sustained and environmentally friendly technology with possibility for overall industrial application for production of ECO-MDF from straw, meeting the standard requirements (Shehata Salwa Mostafa 2016). The study is directed to use of rice straw. It has been concluded that the use of agricultural lignocellulosic residues from widely distributed local plantations is of main significance for the environment protection, the development of rural areas and agricultural communities. On account of the above said, such type of investigations should be with high degree of priority in view of sustainable development.

5. MAIZE AND COTTON STALKS

In their investigations, scientists from the Faculty of Forest Industry of the university in Düz, Turkey, examined the suitability of maize stalks for production of FB. This type of stalks were bioresource with limited application in industry. From the point of view of chemical composition, maize stalks have smaller amount of water-resistant lignin, which leads to increase of the swelling in thickness and water absorption of boards with participation of mass of maize stalks in their composition. Maize stalks have higher ash content and higher content of water-soluble extracts in comparison with wood from coniferous and broad-leaved tree species. In addition, the fibres from maize stalks are similar to those of industrially used ones from wood from coniferous and broad-leaved tree species. As a whole, participation of fibres from maize stalks in the composition of boards leads to deterioration of their properties. Nevertheless, the production of FB with participation of maize fibres and fibres of Scots pine and oak, without this leading to deterioration of the indicators of boards under the standard indicators (Akgül Mehmet, Cengiz Güler, Yalçın Çöpür (2010); Akgül Mehmet, Cengiz Güler, Birol Üner 2010).

Iranian scientists conduct a study aiming at establishing the potential for application in MDF of fibres from cotton and from maize stalks. Laboratory boards with urea-formaldehyde resin (UFR) were manufactured at 170, 180 and 190 °C. Physical and mechanical properties (PMP) of the boards produced were tested after standard methods. The results show that the bending strength and the modulus of elasticity in bending of boards manufactured from maize stalks are by nearly 25% higher than of those manufactured from cotton stalks. The swelling in thickness of MDF from maize stalks is lower than that in boards from cotton stalks. During comparative study of the strength indicators it has been established that those in boards from hard broad-leaved wood raw material and from fibres from maize stalks are similar, whereas those of boards from cotton fibres are lower. The results presented in Table 4 completely meet the requirements of EN 622-5 (Kargarfard Abolfazi, Ahmad Jahan-Latibari 2011).

***Table 4**. Temperature of hot pressing and indicators of MDF from maize and cotton stalks*

Raw material	Pressing temperature, °C	Bending strength (MOR) N/mm^2	Modulus of elasticity in bending (MOE) N/mm^2	Transverse tensile strength (IB) N/mm^2	Swelling in thickness for 2 h %	Swelling in thickness for 24 h %
Maize stalks	170	22.26	1886	0.415	17.39	25.21
	180	22.16	1950	0.523	15.53	23.48
	190	22.10	1794	0.475	16.57	25.55
Cotton stalks	170	17.64	1546	0.438	26.64	31.37
	180	17.61	1494	0.640	24.06	32.38
	190	22.40	1896	0.482	20.30	29.55

6. TOBACCO STALKS

A team of Iranian scientists from the Department of Wood and Paper Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, and the Department of Forestry Science and Technology, University of Tehran, have conducted a study presenting the tobacco stalks as promising lignocellulosic material. The results show that the morphological characteristic of tobacco stalks are similar to those in wood from broad-leaved tree species. Comparison between the dimensional characteristic of fibres from tobacco stalks and that in other fibrous materials is presented in Table 5 (Shakhes Jalal, Morteza A.B.Marandi, Farhad Zeinaly, Ahmadreza Saraian and Tayebe Saghafi 2011).

Table 5. *Main indicators of fibres from tobacco stalks in comparison with those in other fibrous materials*

Indicator of fibres	Tobacco stalks	Maize stalks	Bamboo	Rice straw	Paulownia
Length (mm)	1.23	1.32	2.3	0.89	0.82
Diameter (μm)	24.31	24.3	15.1	14.80	36.3
Lumen width (μm)	15.38	10.7	6.9	6.40	19.2
Cell wall thickness (μm)	8.93	6.8	4.17	6.36	8.6

7. HEMP

In the Leibniz Institute of Agricultural Engineering and Bio-economy, Potsdam-Bornim, Germany, a new technology and a pilot enterprise for production and preparation of hemp fibres for application in the production of FB has been developed (Fürll Ch. et al. 2005; Kühne G. 2004). The raw material is obtained by means of anaerobic wet storage of gathered and cut whole hemp plants. The raw material is processed by means of extruding mill, followed by a process of defibration with attrition mill and a drying process. The subsequent stages are glue application, formation of wood fibre mat and hot pressing. The new production line offers alternative income for the farmers and environmentally friendly diversification of crops. FB as well as press-formed products may be used in production of furniture, motor cars and in construction (Radosavljevic Ljubomir, Ralf Pecenka, Christian Fürll. 2008).

8. ASSESSMENT OF AVAILABLE AMOUNTS OF ALCR IN BULGARIA

In order to make assessment of the available amounts of ALCR in Bulgaria, data from Agrostatistics Directorate of the Ministry of Agriculture and Forests (MAF) (bulletins No. 291/June 2015; No. 316/June 2016; No. 328/May 2017 www.mzgar.government.bg/) was used.

Out of the main agricultural crops monitored by MAF, which are of interest for this paper, are wheat, sunflower, grain maize, tobacco, rice and cotton. The areas sown with these crops in the last three years are presented in Table 6, and the production in Table 7.

As seen from the data presented, the areas sown with wheat in the last years remain relatively constant. The areas sown with wheat, in which there is a decrease by 166,369 ha in 2015 in comparison with 2014 and increase in 2016 by 82,327 ha in comparison with 2015, have biggest share. On the second place, in terms of areas under crop, is the sunflower with which 849,476 ha were sown in 2014. In 2015, reduction of areas under crop by 33,867 ha with respect to the said in 2014 is observed, whereas in 2016 the areas sown with sunflower increased by 3,932 ha with respect to 2015. The grain maize is the third agricultural crop in terms of size of areas under crop – from 420,470 ha in 2014, in 2015 the areas under crop increased by 80,432 ha that decreased in 2016 with respect to 2015 by 89,836 ha. In the areas sown with tobacco, a clearly expressed trend to reduction is observed – from 17,572 ha in 2014, 13,557 ha in 2015 and 10,049 ha in 2016. The areas sown with rice in 2014 are 11,636 ha, with them slightly increasing in 2015 – by 791 ha, which in 2016 show decrease by 393 ha with respect to 2015. The areas sown with cotton increased considerably in the three observed years

– from 315 ha in 2014, they increased to 2,920 ha in 2015, and in 2016 they increased substantially once more to 5,116 ha.

Table 6. *Areas sown with some main agricultural crops for the period 2014-2016*

Crop	Areas under crop 2014 (ha)	Areas under crop 2015 (ha)	Areas under crop 2016 (ha)
Wheat	1,279,930	1,113,561	1,195,888
Sunflower	849,476	815,609	819,541
Grain maize	420,470	500,902	411,066
Tobacco	17,572	13,557	10,049
Rice	11,636	12,427	12,034
Cotton	315	2,920	5,116

As regards the realized production from the field crops sown, the wheat yield, as seen from the data in Table 7, increased in 2016 considerably with respect to 2014 despite the reduction of the areas under crop – from 5,347,078 t for 2014 to 5,662,721 t in 2016 at 84,042 ha less areas under crop. The harvest gathered in for the remaining three types of agricultural crops: sunflower, maize and tobacco, decreased, with the decrease of the tobacco yield being more tangible. The cotton yield gathered in the observed years, naturally, increased considerably, having in mind the increase of the areas under crop – in 2014 326 t of cotton were produced, which increased to 1,558 t in 2015 and 4,251 t in 2016, which is more than 13 times.

Table 7. *Production of some main agricultural crops for the period 2014-2016*

Crop	Harvest 2014 (t)	Harvest 2015 (t)	Harvest 2016 (t)
Wheat	5,347,078	5,011,597	5,662,721
Sunflower	2,010,668	1,699,228	1,837,677
Grain maize	3,137,478	2,696,923	2,226,094
Rice	54,155	67,684	64,773
Tobacco	29,996	23,480	15,211
Cotton	326	1,558	4,251

It has been assumed that the yield of straw from the cereal crops is within 250-300 kg per decare and in this amount the losses are very small (http://agrobio.elmedia.net AGROBIO TEHNIKA – plant-growing, livestock breeding, biopower industry, Vol. IV, issue 1, 2016). If we assume the average value of 275 kg per decare, then we will obtain that the yield of straw from wheat for the years 2014, 2015 and 2016 amounts 3,519,808 t, 3,062,293 t and 3,288,692 t. respectively.

According to data of the Institute of Agricultural Economics, Sofia, the amount of ALCR in the sunflower is 0.2 t/decare. For the years examined, ALCR from areas sown with sunflower are 1,698,952 t for 2014, 1,631,218 t for 2015 and 1,639,082 t for 2015.

The coefficient for average ratio of the side products with respect to the yield of grain in maize is 1.28 according to data of the Institute of Maize in the town of Knezha. On the basis of the data presented above, for ALCR from maize for 2014, 2015 and 2016, 4,015,972 t, 3,452,061 t and 2,849,400 t were obtained respectively.

Tobacco stalks may also be added to ALCR in Bulgaria suitable for utilization in the production of wood-based boards. Their amounts may be assessed on the basis of average evaluations for the yield of residues per decare according to data of the Institute of Agricultural Economics, Sofia, about tobacco stalks – 125 kg/decare. On the basis of this data and in view of the areas under crop, for the amounts of lignocellulosic materials (LCM) from tobacco, 21,965 t for 2014; 16,946 t for 2015 and 12,561 t for 2016 were obtained.

Cotton crop forms overground biomass from 550 to 720 kg/decare under non-irrigated conditions and from 830 to 1060 kg/decare in case of irrigation. If we assume a norm of 500 kg/decare for the stalks, then for the years examined 1,575 t of ALCR for 2014, 14,600 t of ALCR for 2015 and 25,580 t of ALCR for 2016 were obtained.

The data about ARL from the examined crops, suitable for utilization in the production of wood-based boards in the last three years in Bulgaria, is summarized in Table 8.

Table 8. *Amount of ALCR from some agricultural crops in Bulgaria by years*

Crop	**ALCR, thousand t**		
	2014	**2015**	**2016**
Wheat	3,520	3,062	3,289
Sunflower	1,699	1,631	1,639
Grain maize	4,016	3,452	2,849
Tobacco	22	17	13
Rice	1	8	14
Cotton	2	15	26
Total	9,260	8,185	7,830

The data presented shows a relatively constant value for the amount of ALCR in the years observed. This warrants drawing the conclusion that in Bulgaria there are sufficient amounts of ALCR that may be used to replace the wood raw material in the production of wood-based boards.

9. CONCLUSION

From the short literature review made and the data presented, the following conclusions may be drawn:

- There exist published investigations which report on satisfactory use of fibres from agricultural lignocellulosic residues as raw material for wood-based boards, including for production of MDF.
- In Bulgaria, there is more than sufficient amount of residual lignocellulosic fibres to satisfy the needs of the manufacturers of wood-based boards. Nevertheless, this type of raw material may not be in the right place at the right time.
- As a whole, the quality of the boards from agricultural lignocellulosic residues is more inferior than that in the boards from wood raw material, but the addition in small amounts (10 to 20%) of agricultural fibres does not lead to considerable effect on the indicators of the boards.
- Additional investigations to specify the technological indicators and the type of binders for improvement of the properties of MDF with participation of ALCR are necessary.
- Wheat and rice straw, maize, tobacco and cotton stalks are most promising for future investigations with respect to the possibility for their use as raw material in the wood-based boards.

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REFERENCES

[1] Chen, Z., Lamb, F. (2001): Investigation of boiling front during vacuum drying of wood, Wood and fiber science, Vol. 33(4) pp 639 – 647.

[2] Akgül Mehmet, Cengiz Güler, Birol Üner. (2010): Opportunities in utilization of agricultural residues in bio-composite production: Corn stalk (Zea mays indurate Sturt) and oak wood (Quercus Robur L.) fiber in medium density fiberboard. African Journal of Biotechnology Vol. 9(32), pp. 5090-5098, 9 August, Available online at http://www.academicjournals.org/AJB ISSN 1684–5315 ©2010 Academic Journals.

[3] Akgül Mehmet, Cengiz Güler, Yalçın Çöpür. (2010): Certain physical and mechanical properties of medium density fiberboards manufactured from blends of corn (Zea mays indurate Sturt.) stalks and pine (Pinus nigra) wood. Turk J Agric For 34 (2010) 197-206© TÜBİTAK.

[4] Chow, P. (1974): Dry formed composite board from selected agricultural residues, world consultation on wood based panels. Food and Agriculture Organization of the United Nations. New Delhi, India.

[5] Cooper, Paul A., John J. Balatinecz, Steven J. Flannery. (1999): AGRICULTURAL WASTE MATERIALS FOR COMPOSITES: A CANADIAN REALITY. Presented at: Centre for Management Technology, GLOBAL PANEL BASED Conference, Kuala Lumpur, 18-19 October 1999.

[6] Copur,Y., Güler, C., Taşçıoğlu C., Tozluoğlu, A. (2008): Incorporation of hazelnut shell and husk in MDF production, Bioresource Technology 99: 7402-7406.

[7] Eroğlu, H, .İstek, A. (2000): Medium density fiberboard (MDF) manufacturing from wheat straw (Triticum aestivum L.). Inpaper International 4: 11-14.

[8] Forest Products Society Publications (http://www.forestprod.org).

[9] Fürll, Ch. et al., (2005):Verfahren zur Aufbereitung von Naturfaserpflanzen, Patent DE 103 463 658.

[10] Gençer, A., Eroğlu, H., Özen, R., (2001): Medium density fiberboard manufacturing from cotton stalks (Gossipium hirsutum L.).In paper International 5: 26-28.

[11] Halvarsson, et al., (2010): Fiberboard from wheat straw, BioResources 5(2), pp. 1215-1231.

[12] Kargarfard, Abolfazl, Ahmad Jahan-Latibari., (2011): Corn stalks for MDF, BioResources 6(2), 1147-1157.

[13] Kühne G. (2004): Konzeption einer Verfahrenslinie für die Verarbeitung von konserviertem Hanf, Dresden, (not published).

[14] Kulkarni, A. G. et al., (1983): Mechanical properties of banana fibres, J. Mater. Sci. 18 pp. 2290-2296.

[15] Mohanty A. K. et al. (2000): Biofibres, biodegradable polymers and biocomposites: An overview, Macromol. Mater. Eng. 276/277, pp. 1-24.

[16] Narendra, Reddy., Yiqi, Yang. (2005): Biofibers from agricultural byproducts for industrial applications. Trends in Biotechnology 23:1 (January 2005), pp. 22-27.

[17] Radosavljevic, Lj., Pecenka, R., Fürll., C. (2008): Natural Binders for Fibreboard Made of Hemp. 2008 International Conference on Flax and Other Bast Plants, ISBN #978-0-9809664-0-4.

[18] Ray, P. K., Bandyopadhyay, S. B. (1965): An X-ray study of coir fibre, Indian J. Phys. 39 pp. 421-427.

[19] Shakhes Jalal, Morteza A.B.Marandi, Farhad Zeinaly, Ahmadreza Saraian and Tayebe Saghafi. (2011): Tobacco residuals as promising lignocellulosic materials for pulp and paper industry. Bioresources 6(4), 4481-4493.

[20] Shehata Salwa Mostafa (2016): Straw Wastes from an Environmental Disaster to ECO-Board towards a Sustainable Urban Environment, Procedia Environmental Sciences 34 (2016) 539-546.

[21] Sukumaran, K. et al. (1992): Structure, physical and mechanical properties of plant fibres of Kerala. Met Mater Process. 13, 2-4, 121-136.

[22] Ye XP, James, J., Monlin K, Al W, Deland M., (2007): Properties of medium density fiberboards made from renewable biomass. Bioresource Technology 98: 1077-1084.

[23] Yosifov, N. (2005): Briquettes and Pellets from Plant Biomass. S. ISBN 954-07-2209-8.

[24] Youngquist, J., English, B., Scharmer, S., Chow, P., Shook, S. (1994): Literature review on use of non-wood plant fibers for building materials and panels. Gen. Tech. Rep. FPL-GTR-80. USDA Forest Serv., Forest Products Lab., Madison, Wis.

http://www.ciwmb.ca.gov.;
http://www.ciwmb.ca.gov.;
www.fao.org/forestry;
www.bc.bangor.ac.uk.