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EFFECT OF AGRICULTURAL RESIDUE FIBERS ON NEWSPRINT STRENGTH PROPERTIES

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ABSTRACT

As newsprints, mostly made from recycled wood pulp, are not high quality papers according to its optical, mechanical and chemical characteristics, in this research the usage of straw pulp as an alternative raw material was analyzed. For that purpose, straw pulp was mixed with recycled wood pulp and strength properties of laboratory made papers were determined according to TAPPI standards. Selection of agricultural waste for preparing straw pulp was based on annual yield of crop species (*Triticum spp*., *Hordeum vulgare* L. and *Triticale sp*.). Results indicated that straw pulp can be efficiently used in portions up to 20% as a substitute for wood fibers or as an additive in order to obtain particular newsprint properties.

KEYWORDS: Straw, pulp, newsprint, fibers length, strength properties.

INTRODUCTION

In the context of challenging environmental issues, such as reducing deforestation and natural disasters availability of virgin cellulose fibers from wood raw materials is significantly decreased. The global deforestation rate is still high (Indarto and Mutaqin 2016), so there is a potential shortage of conventional wood raw material for the pulp industry. On the other hand, the demand for pulp and paper fiber resources has increased significantly due to increased consumption of various types of paper products and the fast population growth rate (Azeez 2018). In developed countries the rate of paper recycling is growing continuously and many of the mills worldwide use as much as 100% waste paper as raw material base (Rhyner et al. 1995). However, the lack of such raw material is a paper as a final product with poorer mechanical properties due to a decrease in the interfiber bonding (Ibrahim 2003, Fišerová et al. 2013). Therefore, during papermaking process from recycled pulp, definite percentage of pulp with virgin wood fibers must be added to provide the desired strength of paper (Minor and Atalla 1992). For reducing hardwood consumption, either as basic raw material or as supplement, paper industry is forced to find alternative sources of fibrous raw material, particularly those based on agricultural products (Samariha et al. 2013). Considering that all plants contain cellulose in a greater or lesser percentage, pulp can be produced from any wood or non-wood plant. Although the grain of corps is important agricultural product for many countries all around the world, the residues from the corps are largely wasted. One of the most abundant and renewable lignocelullosic agricultural residues is the straw, which is left in the fields, burned or plugged back into the fields after harvesting (Ren et al. 2019). Converting this lignocellulosic residue to pulp for paper would be an advantageous way to utilize it as the consumption of paper is increasing rapidly in in all developed countries.

A rational waste management in some part of the world is recognized because it hides many candidates for paper feedstock. Researches all over the world are dealing with alternative non-wood raw materials for pulp and paper industry, due its: chemical compositions, appropriate process of fibers isolation which will provide quality pulp, usage for different grades of paper products, possibility to provide adequate, optical, mechanical and reproduction quality and recycling efficiency of such products. Until now, only about 2% of the raw materials involved in papermaking in USA and Europe are non-wood fibers (Grossmann 2009), where they are used mainly for cardboards and fluting papers (Schall et al. 2009). One of the most investigated agricultural residues for the pulp and paper industry is wheat straw (Potůček and Gurung 2014). This is understandable as wheat is the most widely cultivated crop in the world (Curtis 2016) which consequently generates substantial quantities of residues of about 529 million tons worldwide every day (Govumoni et al. 2013). Utilization of wheat straw for the pulp and paper production has some deficiencies such as low pulp yield and problems with the recovery of spent pulping liquors by soda pulping process (Veisi and Mahdavi 2016). On a global scale so far wheat straw pulp, carried out by soda-anthraquinone process, has proven to be a good substitute for old corrugated cardboard (OCC) pulp for making fluting paper. Namely, blending of wheat straw soda – anthraquinone pulp with OCC pulp in different ratios significantly improved all the paper properties, except tear index, compared to 100% OCC pulp (Schall et al. 2009).

In previous research (Plazonić et al. 2016) conducted chemical component analysis showed that wheat, barley and triticale straw contain high amounts of cellulose, which was the first step of its valorization as a source of fibers in papermaking industry. In this research, emphasis was placed on the potential value of straw for pulp and papermaking based on strength properties of newsprint produced at laboratory scale. As newsprint represents a lower grade paper, along with accepting four-color printing (CMYK) paper strength properties are important indicators of the quality of newsprint as a printing substrate. For that purpose, the tensile index, tear index and burst index of newsprint, formed from recycled pulp in admixture with a variable content of straw pulp, were determined.

MATERIAL AND METHODS

Materials (straw – pulp – paper)

The straw of three most common crop species in Croatia e.g. wheat (*Triticum spp.*), barley (*Hordeum vulgare* L.) and triticale (*Triticale sp.*) was collected after the harvest. Cleaned straw was manually cut using scissors into approximately 3 cm long pieces and conducted into semi-chemical pulp according soda pulping method (Plazonic et al. 2016) by degrading the lignin and hemicelluloses into small water-soluble molecules which were washed away from the cellulose fibers.

After the thermal treatment which was carried out in automatic autoclave (Kambič) under the controlled and defined conditions (Tab. 1), the pulp slurry was removed from black process liquor by decantation. Thereafter, softened pulp was rinsed in two cycles with tap water and had been transferred into Valley beater (Techlab Systems (TLS)) where appropriate amount of tap water was added in order to maintain the pulp suspension at 1.5% consistency. The fiberization was occurred at pH 9, 24°C and 500 rpm for 40 min. Finally, the pulp was drained and allowed to dry to moisture content of approximately 7% at the room temperature.

Tab. 1: Soda pulping conditions.

Straw	Pulping conditions
Wheat	Temperature of 120°C, alkali level of 16% for 60 min and a 10:1 liquid-biomass ratio.
Barley	
Triticale	

In disintegration stage of paper production process, obtained unbleached straw pulp was added in proportions of 10%, 20% and 30% to reference pulp. Reference pulp was recycled pulp, used for newsprint in many printing presses for printing newspapers, supplied in the form of dry sheets. In order to estimate the effect of straw fibers on newsprint strength properties, laboratory sheets of approximately 45 $g \cdot m^{-2}$ were formed in a Rapid-Köthen sheet former (FRANK-PTI) according to standard EN ISO 5269-2:2001. In total, according to its composition 10 different laboratory made newsprints were formed (Tab. 2).

Tab. 2: Pulp proportions for laboratory made newsprint.

Pulp blends	Proportions
recycled wood	100
recycled wood : wheat	90:10; 80:20; 70:30
recycled wood : barley	90:10; 80:20; 70:30
recycled wood : triticale	90:10; 80:20; 70:30

Methods

Fiber length determination

According to slightly modified Franklin's method (Chaffey 2002), each specimen intended for fiber length determination was macerated in 1:1 (v/v) mixture of glacial acetic acid and 30% hydrogen peroxide. Maceration took place in 35 ml scintillation vials that have been heated for 48 h to 60°C using dry block heater (IKA, Dry block heater 1). After the specified time elapsed almost pure white delignified samples were obtained. Macerating solution was then carefully decanted, and the samples were rinsed with distilled water for several times. In order to neutralize the remaining traces of acetic acid small amounts of sodium carbonate were added to half-filled vials containing samples in distilled water. Sodium carbonate was added in small amounts at the time ensuring that effervescence is not so vigorous that it breaks up the delignified straw samples. When the effervescence has stopped the liquid from the vials was decanted and samples were rinsed several times with distilled water in order to remove the traces of sodium carbonate. Finally, individual fibers were produced by vigorously shaking the delignified straw samples in vials half-filled with distilled water. Such fibers were then dyed using Toluidine Blue O dye and observed using Zeiss AXIO Zoom V16 microscope. For each specimen type, the lengths of 50 randomly selected fibers were measured using AxioVision SE64 (Rel. 4.9.1) software. All the chemicals used in the pulp preparation were purchased from Kemika Ltd., Croatia. Toluidine Blue O dye was purchased from Sigma-Aldrich, Germany.

Strength properties of laboratory made newsprint

All strength properties of laboratory prepared newsprints were tested in accordance with appropriate TAPPI standards (Tab. 3). Each test was repeated ten times and the average of these tests was used to determine the effect of addition of fibers from each straw pulp on newsprint strength properties prepared from recycled wood pulp at laboratory scale. Standard deviation (SD) for each measured and calculated strength property was also noted.

Tab. 3: Analysis of strength properties.

Strength property	TAPPI standard method of analysis
Tensile breaking properties	T494 om-01
Tearing resistance	T414 om-12
Bursting strength	T403 om-97 (Mullen tester)
Surface strength (wax picking test)	T459 om-93

RESULTS AND DISCUSSION

The strength properties of paper samples are substantially influenced by individual characteristics of cellulose fibers as well as by the paper network structure. It is important to say how this research was studied at laboratory scale. Namely, in laboratory made newspapers fibers are not properly oriented as in commercial papers, due to the way of functioning semi-automatic Rapid-Kothen sheet former used for making laboratory sheets. However, lengths of those individual fibers surely define structure of laboratory papers and thus its strength properties (Plazonić et al. 2016). Microscopic images of fibers from each cereal straw captured during fiber length determination are presented at Fig. 1.

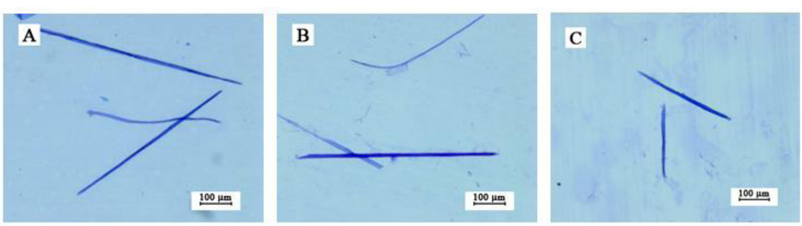

Fig. 1: Micro images of fibres (168x magnification): wheat (A), barley (B) and triticale (C).

Newsprint is predominantly recycled fiber based paper where it is important to emphasize how by each recycling process fibers become shorter. So, blending with longer fibers is extremely important during newsprint production because length is one of the most important fiber properties which effects on the strength properties of the pulp and the paper made of it. A long fiber pulp is good to blend with short fiber pulp to optimize on fiber cost, strength and formation of paper. In general, usage of longer fibers will increase the number of bonds per fiber, which will lead to more strongly bound of fibers into the network, thereby increasing the strength of fiber network in paper (Keränen and Retulainen 2016). As virgin straw fibers should be used as enrichment for recycled fibers instead wood fibers, fibers length determine for each analyzed straw is listed in Tab. 4. The differences among straw of crop species in fiber length are visible.

Tab. 4: Fibers length of straw conducted to pulp for newsprint production.

Raw material	Species	Fibers length (mm)*			
		Mean	SD	Min	Max
Straw	Wheat (*Triticum spp.*)	0.83	0.26	0.45	1.62
	Barley (*Hordeum vulgare* L.)	0.91	0.29	0.40	1.62
	Triticale (*Triticale sp.*)	0.93	0.61	0.27	2.63

*Values based on lengths of 50 fibers measured for each examined species.

If mean values in Tab. 4 are observed it can be concluded that all corps straw contained short fibers with a mean length of 0.83 mm for wheat, 0.91 mm for barley and 0.93 mm for triticale one. It was noted that straw fibers are heterogeneous in a character, with a considerably large range in fiber length. Namely, wheat and barley straw consist of fibers whose length ranges from 0.45 to 1.62 mm, while the range for triticale fibers is much wider (0.27 – 2.63 mm). However, for all analyzed straws most fibers are in the range from 0.5 to 0.9 mm, approximately 76 % of the wheat, 68 % of barley and only 36 % of the triticale fibers (Španić et al. 2018). Generally, gained results for fiber length are in correlation with other researches reports. The most studied straw is wheat straw and consequently the most information about fiber length is available for this type of straw. Mean fiber length of wheat straw publish by Deniz is 0.738 mm by Deniz et al. (2004), by Guo is 0.68 mm by Guo et al. (2009) while by Favadi and by Singh is 1.18 mm (Fadavi et al. 2012, Singh et al. 2011). El Mansouri has published that average length of triticale fibers is 0.926 mm (El Mansouri et al. 2012).

After the experiment data processing, the effects of varies blending levels of two pulp types (straw pulp and recycled pulp) on the strength properties (tensile index, tear index, burst index and critical wax strength number (CWSN) of the laboratory made newsprint sheets was established. All gained strength properties results are summarized in Tab. 5. The effect of each straw pulp on strength properties of laboratory newsprint sample were shown by comparison with reference sample (0% of straw pulp). It is observed that inhomogeneity of all laboratory made newsprint samples affects the results of the mechanical properties measurements and shows results, which have a high standard deviation.

Tab. 5: Strength properties of the laboratory made pulp sheets: a) wheat, b) barley, c) triticale.

a) Wheat		Pulp (%)							
		Straw	*Recycled*	*Straw*	*Recycled*	*Straw*	*Recycled*	*Straw*	*Recycled*
		0	**100**	**10**	**90**	**20**	**80**	**30**	**70**
Tensile index ($Nm\cdot g^{-1}$)	**Mean**	43.61		41.80		41.02		41.02	
	SD	3.45		2.01		2.40		1.61	
	Range	36.62 – 46.23		40.36 – 47.60		39.07 – 47.08		38.26 – 43.35	
Elongation (%)	**Mean**	1.23		1.35		1.4		1.4	
	SD	0.25		0.18		0.09		0.12	
	Range	0.7 – 1.5		1.1 – 1.6		1.3 – 1.5		1.2 – 1.6	
Tear index ($mN\cdot m^2\cdot g^{-1}$)	**Mean**	9.20		10.18		9.12		9.57	
	SD	1.05		0.83		1.01		0.50	
	Range	7.95 – 11.00		9.05 – 11.13		7.97 – 10.50		9.11 – 10.21	
Burst index ($kPa\cdot m^2\cdot g^{-1}$)	**Mean**	13.54		13.69		13.07		13.41	
	SD	0.27		0.25		0.32		0.85	
	Range	13.19 – 13.97		13.26 – 14.23		12.44 – 13.70		12.69 – 15.60	
CWSN		7A		7A		7A		6A	

b) Barley		Pulp (%)							
		Straw	*Recycled*	*Straw*	*Recycled*	*Straw*	*Recycled*	*Straw*	*Recycled*
		0	**100**	**10**	**90**	**20**	**80**	**30**	**70**
Tensile index ($Nm\cdot g^{-1}$)	**Mean**	43.61		43.17		42.52		40.31	
	SD	3.45		2.25		2.15		1.99	
	Range	36.62 – 46.23		39.85 – 48.03		38.97 – 45.33		37.37 – 43.14	
Elongation (%)	**Mean**	1.23		1.26		1.34		1.30	
	SD	0.25		0.12		0.13		0.18	
	Range	0.7 – 1.5		1.1 – 1.4		1.2 – 1.6		1.1 – 1.5	
Tear index ($mN\cdot m^2\cdot g^{-1}$)	**Mean**	9.20		11.52		9.53		8.54	
	SD	1.05		1.75		0.79		0.72	
	Range	7.95 – 11.00		9.97 – 13.75		7.84 – 9.80		7.93 – 9.76	
Burst index ($kPa\cdot m^2\cdot g^{-1}$)	**Mean**	13.54		13.34		13.17		13.05	
	SD	0.27		0.23		0.70		0.46	
	Range	13.19 – 13.97		12.90 – 13.66		12.50 – 14.98		12.60 – 13.96	
CWSN		7A		7A		7A		6A	

c) Triticale		Pulp (%)							
		Straw	*Recycled*	*Straw*	*Recycled*	*Straw*	*Recycled*	*Straw*	*Recycled*
		0	**100**	**10**	**90**	**20**	**80**	**30**	**70**
Tensile index ($Nm\cdot g^{-1}$)	**Mean**	43.61		44.37		41.69		41.15	
	SD	3.45		3.77		1.0		1.91	
	Range	36.62 – 46.23		38.04 – 49.12		39.74 – 42.93		37.63 – 43.43	
Elongation (%)	**Mean**	1.23		1.37		1.37		1.32	
	SD	0.25		0.28		0.17		0.18	
	Range	0.7 – 1.5		1.0 – 1.9		1.0 – 1.6		1.1 – 1.7	

Tear index (mN·m²·g⁻¹)	**Mean**	9.20	9.95	9.10	10.03
	SD	1.05	1.80	0.32	0.82
	Range	7.95 – 11.00	8.28 – 12.55	8.78 – 9.55	9.50 – 11.40
Burst index (kPa·m²·g⁻¹)	**Mean**	13.54	13.61	12.88	13.03
	SD	0.27	0.25	1.42	0.64
	Range	13.19 – 13.97	13.24 – 14.09	10.00 – 15.43	12.31 – 14.56
CWSN		7A	7A	6A	6A

In general, addition of straw pulp, regardless to the crop type, has not shown any significant negative influence on strength properties of paper. Furthermore, reference sample with 0% of straw pulp has the minimum measured tensile index 36.62 $Nm{\cdot}g^{-1}$, while all samples with straw pulp have the higher value of minimum measured tensile index (in range 37.37 – 40.36 $Nm{\cdot}g^{-1}$). The maximum measured tensile index of reference sample was 46.23 $Nm{\cdot}g^{-1}$; while for samples with straw pulp this parameter was in range 43.14 – 48.03 $Nm{\cdot}g^{-1}$. There were no significant differences between tensile index of sheets made of pure recycled pulp and those with 10%-30% straw pulp/90% -70% recycled pulp blended. From tensile index results, it could be expected that commercial papers with addition of straw pulp (wheat, barley or triticale) would have similar or even better tensile index as papers made only from recycled wood pulp. During tensile breaking properties determination, elongation of the strip of each laboratory newsprint sample is recorded as well as an insight into the percentage increase in length of the test strip when fracture occurs divided by the original length of the test strip. From gained results, it is evident that addition of all straw pulp types in all observed shares increases the relative elongation of laboratory newsprint samples. The recorded relative elongation average value of reference sample was 1.21%, while for papers with 10% - 30% wheat pulp was 1.35% - 1.40%; barley pulp was 1.26% - 1.34% and triticale pulp was 1.37% - 1.32%. Again, the minimum measured relative elongation 0.7% was for reference sample, while all samples with straw pulp have the higher value of minimum measured relative elongation (in range 1.0% – 1.3%).

It was noted that the minimum tear index value of all sheets produced with addition of straw pulp was higher comparable with value obtained for reference sample (7.95 $mN{\cdot}m^2{\cdot}g^{-1}$). Results displayed on Tab. 5 showed that the addition of straw pulp produce laboratory newsprint with similar or slightly lower average burst index value compare to recycled pulp in reference sample. In general, from all analyzed straw pulp, wheat pulp has shown the most positive influence on burst index of laboratory newsprint sheets. This result could be connected with fiber length results as the longer and stronger fibers provide higher strength properties. Namely, the smallest measured fiber in macerated wheat straw was 0.45 mm; while in barley and especially in triticale straw the smallest fiber was significantly shorter (min length of barley fiber was 0.40 mm and triticale fiber 0.27 mm).

Since wax sticks are used as analogues for hot melt adhesives, measurements were made of their tensile strength using the pull-off test to determine how well they replicate the properties of the adhesives. The tensile strength of the wax appears to increase with wax number, which means that the higher the CWSN indicate the stronger paper surface strength or its resistance to picking. As newsprint is grade of paper, which is intended entirely for printing, surface strength is an important parameter as it relates to the forces created during printing. Picking denotes damaging the paper surface during printing operation due to forces imposed by lifting-off the printing equipment from the paper surface. These forces depend on ink viscosity and printing speed. If they exceed the surface strength of paper, picking begins. In other words, a low surface strength of paper may create picking problems (Drobchenko 2004). The CWSN results indicate that addition of straw pulp into recycled pulp does not significantly change surface strength of laboratory made newsprint. In comparison with reference sample, where determinate CWSN was 7A, only papers with triticale pulp have shown some lower surface strength (CWSN = 6A) when the share of straw pulp was higher than 10%. Surface strength is the ability of paper to resist a force pulling fibers or fiber bundles from its surface and is strongly influenced by the type of fibers used in papermaking process. As long fibers are improving the surface strength properties of the paper, it is evident why papers with triticale pulp have shown the lower surface strength. Namely, in macerated triticale straw the shortest fibers were detected (fibers with length of 0.27 mm). However, acceptable pick level for commercial uncoated papers is at least 7A (Board 2003) and all laboratory newsprint papers without any surface treatment have sufficient surface strength for printing process.

CONCLUSIONS

The straw as agricultural residues, in general, and wheat straw, in particular, can be successfully considered as an alternative, replacing the pulp produced from recovered paper. It has been noticed from this study that straw pulp gained from wheat, barley and triticale agricultural species can act as a good strength fiber enrichment of paper sheets made from repulped recycled newsprint when added in portions up to 20%, while in range from 20% to 30% strength properties vary depending on straw source. Overall, fiber length of all analyzed straw fibers is satisfactory for papermaking, although, they would be classified as short fibers. Based on gained results it could be concluded that straw fibers can be efficiently used in small portions as a substitute for more expensive wood fibers or as an additive in order to obtain particular paper properties.

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