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LIGNIN AND SUGARS CONTENTS OF *LIRIODENDRON TULIPIFERA* L. SAWDUST IMMERSED IN ACIDIC/ALKALINE SOLUTIONS AND THE FUEL CHARACTERISTICS OF WOOD PELLETS FABRICATED WITH THE SAWDUST

Seung-Won Oh
Chonbuk National University, Department of Wood Science and Technology
Deokjin-Gu, Jeonju, South Korea

In Yang
Scion, Te Papa Tipu Innovation Park
Rotorua, New Zealand

Dae Hak Park
Chungbuk National University, Department of Wood and Paper Science
Seowon-Gu, Cheongju, South Korea

Soo Min Lee, Byoung Jun Ahn
National Institute of Forest Science, Division of Wood Chemistry and Microbiology
Dongdaemun-Gu, Seoul, South Korea

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ABSTRACT

This study was conducted to determine the lignin and sugars contents of yellow poplar (YP) sawdust immersed in tap water (TW), sulfuric acid (AC) and sodium hydroxide (AK) solutions. Klason lignin content of TW- and AC-immersed YP sawdust was higher than that of AK-immersed YP sawdust. Glucose showed the highest content among sugars extracted from YP sawdust. Durability of non-immersed YP pellets was the highest, followed by TW-, AC- and AK-immersed YP pellets. YP pellets became more durable by increasing the Klason lignin and xylose contents as well as decreasing the glucose content. Through microscopic observations and quantitative analysis of lignin distribution, lignin content on the surface of non-immersed YP pellets was higher than that of TW-, AC- and AK-immersed YP pellets. In conclusion, there are

significant correlations between lignin or sugars contents of YP sawdust and fuel characteristics of wood pellets fabricated with the YP sawdust.

KEYWORDS: Yellow poplar, immersion, lignin, pellet, durability, energy dispersive X-ray analysis.

INTRODUCTION

Global wood pellet markets, both in the heating and industrial sectors, have experienced rapid growth in the past decade. Annual growth rates have been estimated to be about 10% annually over the most recent four years of data, from about 19.5 million metric tons in 2012 to about 28 million metric tons in 2015 (Wood Pellet Association of Canada 2017). In South Korea, wood pellet market has also developed quickly during the last five years and it is expected to grow rapidly through 2020 (Wood Pellet Association of Canada 2017). However, the growth of both markets can be slowed by fines present in wood pellets or low durability of wood pellets. For instance, wood pellets with low durability tend to break and subsequently generate dust during its frequent handlings and storage (Kaliyan and Morey 2009). The pellet breakage reached approximately 30% of total pellet weight after transport (Hill and Pulkinen 1998). The results suggest that improving the durability of wood pellets is one factor for continued growth in the wood pellet market.

Wood pellets are nearly identical to a binderless wood composite. Therefore, forces contributing to the formation of pellets produced from individual wood particles can be obtained by various bonding theories; 1) solid bridges that are developed by diffusion of molecules from one particle to another at point of contact; 2) mechanical interlocking of particles resulting during the densification process; 3) attraction forces between solid particles (chemical bonds, hydrogen bridges, and van der Waals forces); and 4) adhesion and cohesion forces, which occur when the mixtures include highly viscous binders that adhere to the surface of solid particles to generate strong bonds (Kaliyan and Morey 2008, Kaliyan and Morey 2009, Wilson 2010). Consequently, the durability of wood pellets results from the forces that bond or interlock wood particles mechanically together. Other than those, the durability of wood pellets is influenced by type, size and shape of wood particles, proximity between individual wood particles, as well as the amount and type of binders added for improving the bonding forces (Bergström et al. 2008, Mani et al. 2006, Stakl et al. 2004, Lehtikangas 2001, Bradfield and Levi 1984, Lee et al. 2013, Ahn et al. 2014).

As well as the variables above, the chemical composition, such as cellulose, hemicelluloses and lignin, of a wood biomass has both a positive and negative impact on the durability of wood pellets (Obernberger and Thek 2004). In particular, lignin, an inherent binding component in wood, plays an important role to maintain the structural integrity of wood pellets when sufficient temperature and pressure are provided for plasticizing lignin during pelletizing process (Kaliyan and Morey 2009, Ahn et al. 2014, Brackley and Parrent 2011). Li and Liu (2000) showed that the durability of wood pellets increased significantly by increasing the lignin content of wood particles. However, Wilson (2010) stated that lignin content did not have a significant impact on pellet durability in his study. In addition, cellulose and hemicelluloses can be considered to be responsible for bonding individual wood particles during pelletizing process, since hydrogen and other secondary bonds predominate in inter-fiber bonding areas (Kaliyan and Morey 2009, Beck 1987). As a result, cellulose and hemicelluloses contained in wood particles seem to have

a positive effect on the durability of wood pellets by drawing the wood particles closer together while simultaneously increasing intermolecular bonding. Results of the studies suggest that the main ingredients of woody biomass act as the role of natural binders between individual wood particles during the pelletizing process. Meanwhile, limited works have contributed to locate any specific reference about the relationship between the chemical composition of a wood biomass and the durability of wood pellets fabricated with the wood biomass.

Therefore, in the present study, yellow poplar sawdust was initially immersed in various aqueous solutions and the chemical composition of the sawdust was then determined. Yellow poplar was used as a raw material because it is a major planting species due to its fast growth and high capacity for carbon absorption like tropical wood species (Gwak et al. 2009). As a result, yellow poplar has extensively been planted in South Korea for bioenergy production. In addition, the fuel characteristics of wood pellets fabricated with the immersed sawdust was evaluated. This study is expected to provide considerable information relative to the pelletizing process and explain how the fuel characteristics of wood pellets are influenced by its chemical composition.

MATERIALS AND METHODS

Raw materials

Yellow poplar (*Liriodendron tulipifera* L., YP) was used as a raw material for the fabrication of wood pellets. Ten- to fifteen-year old YP with diameters ranging from 20 to 25 cm was harvested from Chungbuk National University in Cheongju, South Korea. The YP was cut into logs and reduced into sawdust by the lumbering process. YP sawdust was screened through two sieves with size openings 1.41 mm (18 mesh) and 3.1 mm (8 mesh).

In this stage, oversized (>3.17 mm) and undersized (< 1.41 mm) particles were excluded, and particles (1.41 mm < size of sawdust < 3.17 mm) obtained by the screening were used as the source of raw material in the pelletizing process.

Immersion of sawdust

YP sawdust was immersed in tap water (TW), 10 and 20 $kg \cdot m^{-3}$ solutions of sulfuric acid (AC-1% and AC-2%) and sodium hydroxide (AK-1% and AK-2%) for 24, 72 and 120 h. For example, 70 g of YP sawdust was immersed in each solution of 600 ml. Before immersion, YP sawdust was evacuated using an aspirator in desiccators for 30 min. The immersed sawdust was dried to a level $w(H_2O) = 11 \pm 0.5\%$; hereinafter we will refer to the mass fraction of water as moisture content (MC). The sawdust was placed in a sealed plastic bag and stored in a refrigerator before use.

Each solution obtained from the immersion treatment was filtered through filter paper (No. 2, Adventec, Kyoto, Japan) to measure the contents of monomeric sugars eluted from YP sawdust. After filtering, the immersed solution (10 ml) was placed into a vial and stored at 4°C until needed.

Determination of Klason lignin

Lignin content was determined by the Klason lignin (KL) method (Sannigrahi et al. 2008). First, YP sawdust was milled into powder by a Wiley mill and then screened through a sieve with a pore size of 0.42 mm (60 mesh). The powder was extracted with benzene/ethanol in a Soxhlet apparatus for 6 h. Then, 1 g of the extracted powder was placed into an autoclavable glass tube along with 15 ml of 72% sulfuric acid. The mixture was placed into a 30°C water

bath for 2 h while swirling each tube once every ten minutes. The solution was transferred to a 1-L Erlenmeyer flask, diluted with 560 mL of deionized water to a H_2SO_4 concentration of 3%, and refluxed for 4 h. The solution was filtered using by a filtering crucible (1G4). Following filtering, the fine powder remaining in the crucible was dried overnight and was presumed to be the amount of KL on the mass basis of a sample. The KL values were corrected for ash content by gravimetric measurement following incubation of the lignin at 575°C for over 3 h.

Monomeric sugar determination

The composition of sugars, such as glucose, xylose, galactose, arabinose and mannose, extracted from the immersion treatment of YP sawdust was determined by high performance liquid chromatography (HPLC, Dionex Ultimate 3000, Dionex, Palo Alto, CA, USA). The procedure is summarized as followed. Separation of sugars was achieved with an Aminex 87P column (Bio-Rad, USA). During the separation, sugars were eluted with deionized water at a flow rate of 0.5 $ml \cdot min^{-1}$ and at a temperature of 80°C. The separated sugars were quantitated using a refractive index detector (Shodex RI-101, Shodex, Japan). Standard solutions of glucose, xylose, galactose, arabinose and mannose group were purchased to make calibration curves at Sigma–Aldrich Co. Ltd. (St. Louis, USA). Peaks were identified by comparing peak retention times and assessing the concentrations corresponding to the different peaks (Rabemanolontsoa et al. 2011). These analyses were performed in triplicate.

Pelletizing processes

To minimize experimental deviations resulting from differences in pellet size, the amount of sawdust used for the fabrication of each pellet was adjusted to 1.2 g. Pellets were fabricated by using a piston-type single press installed at the laboratory of Chungbuk National University (Ahn et al. 2014). The press consisted of a 7 mm cylindrical die in diameter, made of hardened steel and lagged with heating elements. The end of the die was plugged by using a removable backstop. Pressure (150 MPa) was applied to wood particles using a piston made out of hardened steel and connected to a hydraulic press. The die temperature was adjusted to 180°C, and wood particles were pressed for 3 min. The average diameter and length of the wood pellets fabricated by this process were 7 and 20 mm, respectively. In addition, bulk density measured with the standard procedure of the National Institute of Forest Science (NIFOS), of the fabricated pellets ranged from 639 to 698 $kg \cdot m^{-3}$ (NIFOS 2016). The pellets were placed in an incubation room (25°C and 50% RH) for at least 24 h before the tests of its fuel characteristics.

Fuel characteristics of wood pellets

Moisture content (MC), ash content, higher heating value (HHV) and durability were included in the fuel characteristics of YP pellets tested for this study. MC and ash content for each of YP pellets were determined by the ASTM D 4442-07 and ASTM E 1755-01 methods, respectively (ASTM 2005a, ASTM 2005b). HHV was determined by burning the pellets in an oxygen bomb calorimeter (Parr 6400 Automatic Isoperibol Calorimeter, Parr Instrument Inc., Moline, Illinois, U.S.A.).

To measure durability, pellets (50 g) were placed in a tumbling can, and then tumbled at 0.83 Hz. Subsequently, the pellets tumbled were sieved through a 0.5 mm sieve. The durability of the pellets was calculated as the weight ratio of after tumbling to that before tumbling. Each test was repeated three times (Lee et al. 2013).

Microscopic observations of wood pellets

A fluorescence microscope (Axioscope A1, Zeiss, Germany) and a field emission scanning electron microscopy (FE-SEM, Supra 55VP; Carl Zeiss, Oberkochen, Germany) were used to examine the distribution of lignin on the surface of YP pellets. For microscopic observations, a staining solution was prepared. First, phloroglucinol (2 g) was initially dissolved in 80 ml of 20% ethanol solution, and then hydrochloric acid (12 N) of 20 ml was added to the solution (Gahan 1984). YP sawdust was then stained with the phloroglucinol-HCl staining solution for 24 h and washed with a sufficient amount of distilled water. The stained YP sawdust was used as a raw material for the fabrication of YP pellets. The YP pellets were made from the stained YP sawdust of 0.2 g, and the average pellet size was 3 mm (length) × 7 mm (diameter).

In addition to phloroglucinol-HCl staining, YP sawdust was also stained with a 20 $kg \cdot m^{-3}$ solution of $KMnO_4$ for 24 h to quantitatively determine the distribution of lignin (Lee et al. 2013). The stained YP sawdust was sufficiently washed by distilled water, air-dried for 24 h, and then used to fabricate YP pellets. Outer surface of the pellets was examined by energy dispersive X-ray analysis (EDX, XFlash 4000, Bruker AXS Microanalysis, Berlin, Germany) combined with SEM. The X-rays were collected using a detector fixed at a take-off angle of 35°, and their intensities were recorded in counts per second.

Experimental design and statistical analysis

The statistical analyses were conducted using the SAS software package for personal computers. One-way analysis of variance (ANOVA) was used to analyze the relationship between each variable and the fuel characteristics of YP pellets at a 0.05% significance level. If a significant relationship was found for a variable, the Student t-test was used to determine any significant difference between KL and sugar contents and fuel characteristics of YP pellets fabricated under each condition ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Chemical composition of YP

KL content of non-immersed YP sawdust was 24.3%. The KL content did not differ from that of TW- or AC-immersed YP sawdust, but was higher than that of AK-immersed YP sawdust (Fig. 1). In addition, KL content decreased with the increase of AK concentration in immersion solutions. However, the increase of AC concentration in immersion solutions and the lengthening of immersion time had no significant effect on the KL content. These results indicate that lignin contained in YP might be decomposed significantly only by the AK solution used in this study.

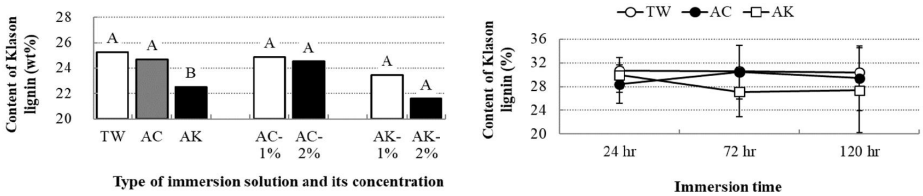

Fig. 1: Effects of type and concentration of immersion solution (left) and time (right) on the content of Klason lignin contained in yellow poplar sawdust. This sawdust was immersed in tap water (TW), 1% and 2% sulfuric acid (AC-1% and AC-2%) and 1% and 2% sodium hydroxide (AK-1% and AK-2%) solutions. Same capital letters denote results that are not significantly different from each other at p = 0.05 (least significant difference test).

Fig. 2 shows the content of monomeric sugars extracted from YP sawdust which were immersed in TW, AC and AK solutions. Glucose showed the highest content among the extracted sugars, followed by xylose, galactose, arabinose and mannose. These results are closely related to the decomposition of hemicelluloses or amorphous cellulose chains composed of YP. However, except for xylose, most sugar contents did not change significantly when AC or AK was used as an immersing solution and concentration of the solutions increased from 1% to 2%.

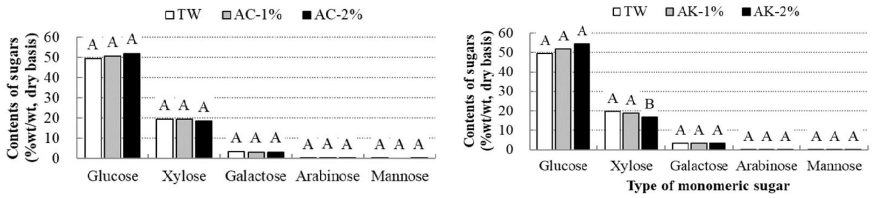

Fig. 2: Effect of type of immersion solution on the monomeric sugars content of yellow poplar sawdust immersed in tap water, sulfuric acid (left) and sodium hydroxide (right) solutions. Same capital letters denote results that are not significantly different from each other at p = 0.05 (least significant difference test).

The decrease of xylose content might be due to the fragmentation reactions of xylose extracted by the AK immersion (Sjostrom 1983). For instance, xylose extracted from the AK immersion of YP is fragmented further into D-glyceraldehyde and dihydroxyacetone under an alkaline solution, resulting in a decrease of xylose content. In the case of galactose, arabinose and mannose, the contents are likely not to be influenced by the AK immersion due to low content of the sugars contained in YP. In summary, holocellulose of YP might be decomposed into monomeric or oligomeric sugars by the TW, AC and AK immersion, but the type and concentration of immersing solution hardly affected the sugar contents owing to the mild immersing treatment used in this study.

Fuel characteristics of wood pellets

MC, HHV, ash content and durability of wood pellets fabricated with non-immersed YP sawdust were measured to 6.6%, 18.6 MJ·kg^{-1}, 0.4% and 95.1%. The fuel characteristics varied with the type and concentration of immersing solutions as well as immersion time. For example, MC of the wood pellets fabricated with TW-, AC- and AK-immersed YP sawdust ranged from 5.8% to 6.9%. Although all wood pellets were fabricated with the YP sawdust adjusted to the MC of 11 ± 0.5%, the MC varied with the type and concentration of immersing solutions as well as immersion time. These results are probably due to the humidity differences in the MC measuring process of the fabricated YP pellets. However, all of the MC values satisfied the specifications of 1st- and A1-grade wood pellets (≤ 10%), which were designated by NIFOS and EN, respectively (NIFOS 2016, ECS 2011).

Fig. 3 shows the HHV, ash content and durability of wood pellets fabricated with immersed YP sawdust and the effects of type and concentration of immersing solutions on HHV, ash content and durability of the YP pellets.

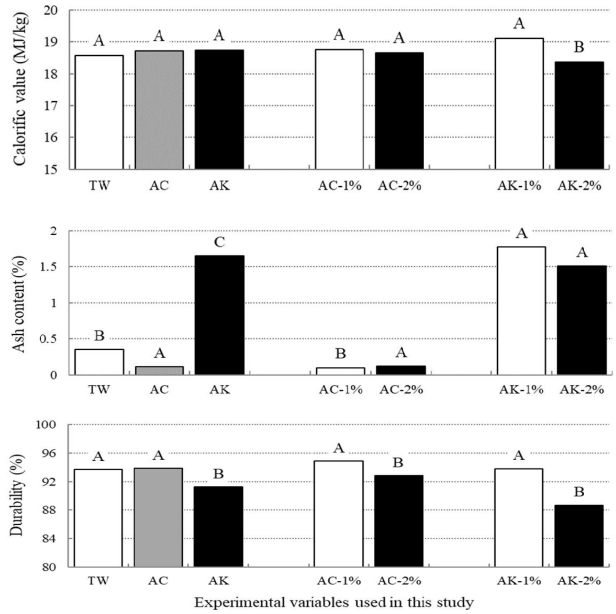

Fig. 3: Effects of type and concentration of immersion solution on the calorific value (top), ash content (middle) and durability (bottom) of wood pellets fabricated with yellow poplar sawdust, which was immersed in tap water (TW), 1% and 2% sulfuric acid (AC-1% and AC-2%) and 1% and 2% sodium hydroxide (AK-1% and AK-2%) solutions. Same capital letters denote results that are not significantly different from each other at p = 0.05 (least significant difference test).

Higher heating value

HHV was not influenced by the type of immersing solution (TW/AC: p = 0.19; TW/AK: p = 0.07; AC/AK: p = 0.44). In addition, when AC concentration in an immersing solution increased from 1 to 2% as shown in Fig. 3, no significant difference between HHV of the AC-immersed YP pellets was found (p = 0.14). However, HHV of AK-immersed YP pellets decreased as AK concentration in an immersing solution increased ($p < 0.01$). These results are most likely associated with the lignin content of AK-immersed YP. White (1987) showed that HHV of a woody biomass was directly proportional to the content of lignin, which had a high HHV compared with that of cellulose and hemicelluloses. As a result, the higher HHV of AK-1%-immersed YP pellets compared to that of AK-2%-immersed YP pellets is thought to be resulted from its high lignin content (Fig. 1).

Ash content

Ash contents of TW- and AC-immersed YP pellets were lower than that of non-immersed YP pellets (Fig. 3). In addition, when AC concentration in an immersing solution increased from 1% to 2%, the ash content of AC-immersed YP pellets decreased (p = 0.03). These results indicate that ashes contained in YP sawdust are leached out during the TW- and AC-immersing treatments. However, AK-immersed YP pellets exhibited quite higher ash content than TW- and AC-immersed YP pellets. The higher ash content is most likely due to the non-combusted sodium remaining after the ash content test of AK-immersed YP pellets.

Durability

Durability of non-immersed YP pellets was higher than that of any other YP pellets tested in this study (97.5%). As shown in Fig. 3, durability of TW-immersed YP pellets did not differ from that of AC-immersed YP pellets ($p = 0.07$), and the TW- and AC-immersed YP pellets showed higher durability than AK-immersed YP pellets ($p < 0.01$). As AC or AK concentration in an immersion solution increased from 1% to 2%, durability of the AC- and AK-immersed YP pellets decreased (AC: $p = 0.04$, AK: $p < 0.01$). These results are closely related to the lignin content of YP sawdust. Lignin is well-known to perform an important role as a binder between individual wood particles during pelletizing process (Kaliyan and Morey 2009, Wilson 2010, Lee et al. 2013, Ahn et al. 2014, Li and Liu, 2000, Beck 1987, Briggs et al. 1999). In this study, TW- and AC-immersed YP sawdust had higher lignin contents than AK-immersed YP sawdust (Fig. 1). Consequently, wood species of high lignin content are thought to be a better raw material for the production of durable wood pellets.

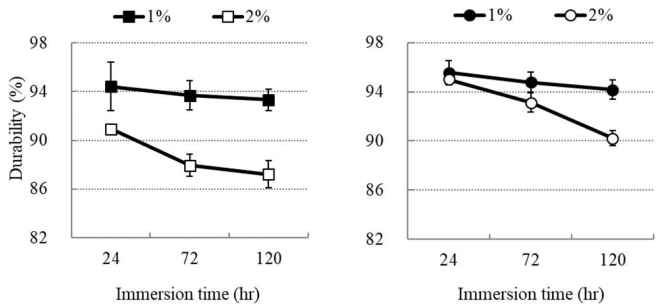

Fig. 4: Interactive effect of immersion time and the concentration of hydrolysis agent used in an immersion solution on the durability of wood pellets fabricated using yellow poplar sawdust immersed in sodium hydroxide (left) and sulfuric acid (right) solutions.

The interactive effect of immersion time and the AK or AC concentration in an immersion solution on the durability of YP pellets is presented in Fig. 4. Durability of AK-1%- and AC-1%-immersed YP pellets were not significantly related to immersion time (AK-1%: $p = 0.32$; AC-1%: $p = 0.08$). However, durability of AK-2%-immersed YP pellets significantly decreased as the immersion time lengthened from 24 to 72 h ($p < 0.01$). In addition, durability of AC-2%-immersed YP pellets steadily decreased with the extension of immersion time. These decreases are attributed to the increase in decomposed lignin or/and holocellulose by lengthening the immersion time at the AK-2% and AC-2% solutions.

Relationship between chemical composition and pellet durability

Graphs of pellet durability vs. content of KL, glucose and xylose for TW-, AC- and AK-immersed YP pellets are presented in Fig. 5.

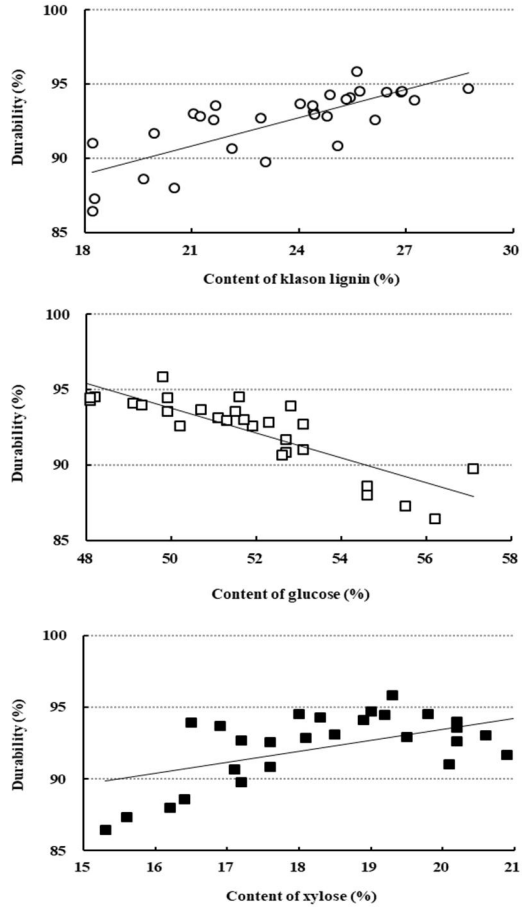

Fig. 5: Durability of wood pellets fabricated with yellow poplar sawdust which was immersed in tap water, sodium hydroxide and sulfuric acid solutions. Results show the relationship between pellet durability and contents of Klason lignin (top), glucose (middle) and xylose (bottom). Pearson's correlation coefficient (r): r of Klason lignin content and pellet durability = 0.77; r of glucose content and pellet durability = −0.85; r of xylose.

YP pellets became more durable as KL or xylose content increased. However, a significant positive correlation was found only between pellet durability and KL content (Pearson's correlation coefficient = 0.77).

Generally, the greater the lignin content of a raw material used for pellet production, the higher the durability value (Kaliyan and Morey 2009, Wilson 2010, Ahn et al. 2014, Li and Liu 2000). On the other hand, durability decreased with the decrease of glucose content. The decrease is possibly due to the decomposition of hemicellulose or amorphous cellulose chains by the immersion treatment of YP. These inferences need to be verified in future studies using other species or increasing the quantities of testing pellets.

Microscopic observation

Surface of wood pellets fabricated with non-, TW-, AC-1%-, AK-1%-, AC-2%- and AK-2%-immersed YP sawdust was examined with a fluorescence microscope to identify the lignin distribution. In general, cinnamaldehyde end groups of lignin appeared to react with phloroglucinol-HCl to give a dark color (Lee et al. 2013, Gahan 1984). As shown in Fig. 6, a significantly darker area can be seen on the non- and TW-immersed YP pellets than on AC- and AK-immersed YP pellets.

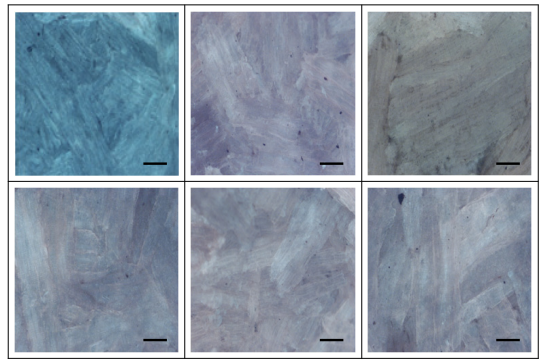

Fig. 6: Fluorescent microscopic images of the surface, which was pressured by piston of wood pellets fabricated with non- (top-left), tap water- (top-middle), 1% sulfuric acid- (top-right), 1% sodium hydroxide- (bottom-left), 2% sulfuric acid- (bottom-middle) and 2% sodium hydroxide- (bottom-right) immersed yellow poplar sawdust. The sawdust was stained with a phloroglucinol-HCl solution for 24 h. Bars = 2 mm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

These observations indicate that non- and TW-immersed YP contains more lignin than AC- and AK-immersed YP. On the other hand, when AC or AK concentration in an immersion solution increased from 1% to 2%, the decrease of dark area on the surface of the YP pellets was not observed clearly. The result might be due to the narrow increasing range of AC and AK concentration in the immersion solution. The speculation was to be investigated through SEM observation and quantitative analysis of the lignin distribution on the surface of the YP pellets.

Fig. 7 shows the SEM images of YP pellets along with the corresponding SEM-EDX (energy disperse X-ray spectrometer) maps taken from the same area. In general, EDX mapping provides further details on the distribution of lignin (Lee et al. 2013). The SEM-EDX analysis showed that lignin is widely distributed on the non- and TW-immersed YP pellets, but is more concentrated on the AC- and AK-immersed YP pellets. A quantitative analysis of lignin distribution on the surface of the YP pellets also shows that the amount of lignin was dependent on the type of immersing solutions (Fig. 8). For example, non-immersed YP pellets (NI) had the highest lignin content among all YP pellets tested in this study (NI/TW: $p = 0.02$; NI/AC: $p = 0.03$; NI/AK: $p < 0.01$).

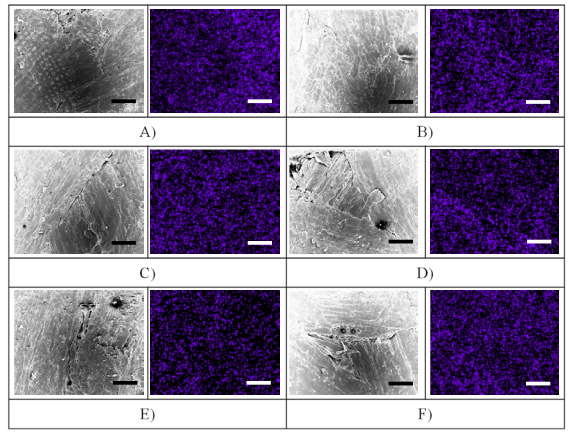

Fig. 7: Scanning electron microscopic (SEM) images of wood pellets fabricated with A) non-, B) tap water, C) 1% sulfuric acid, D) 1% sodium hydroxide, E) 2% sulfuric acid and F) 2% sodium hydroxide immersed yellow poplar sawdust. SEM image (left) and corresponding SEM-EDX (energy dispersive X-ray spectrometer) maps (right) were taken of the same area of the wood pellets. Bright purple spots and arrow indicate the existence of lignin. Bars = 60 μm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

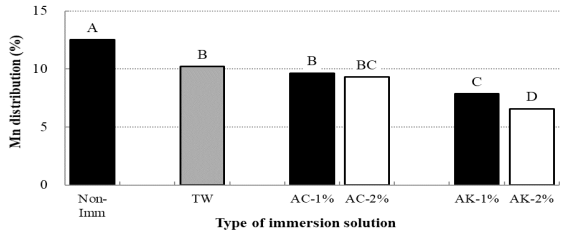

Fig. 8: Content of manganese distributed on the surface of wood pellets fabricated with non-tap water, tap water, 1%- & 2%-sulfuric acid- and 1%- & 2%-sodium hydroxide-immersed yellow poplar sawdust. The results were obtained by SEM-EDX analysis. Same capital letters denote results that are not significantly different from each other at p = 0.05 (least significant difference test).

Lignin content of TW-immersed YP pellets did not differ from that of AC-immersed YP pellets ($p = 0.18$), but was higher than that of AK-immersed YP pellets (TW/AK: $p = 0.02$; AC/AK: $p = 0.04$). On the other hand, there was no difference in lignin contents between AC-1%- and AC-2%-immersed YP pellets ($p = 0.24$), but lignin content of AK-1%-immersed YP pellets was higher than that of AK-2%-immersed YP pellets ($p < 0.01$). These results indicate that lignin might increase inter-particle bonding in YP pellets, resulting in an increased durability of YP pellets (Fig. 3). However, this assumption needs to be verified in future experiments using other wood species.

CONCLUSIONS

This study was conducted to investigate the impact of lignin and sugars contents on fuel characteristics of wood pellets fabricated with YP sawdust, which was immersed in various aqueous acidic/alkaline solutions. KL content was the highest in the TW- and AC-immersed YP sawdust. Among the sugars extracted from YP, glucose content was the highest, followed by xylose, galactose, arabinose and mannose. The sugars contents did not change significantly with the increase of concentration in AC or AK solution, but only xylose content decreased when AK concentration in an immersion solution increased from 1% to 2%. For fuel characteristics of wood pellets fabricated with the immersed YP sawdust, HHV of AK-immersed YP pellets decreased as AK concentration in an immersing solution increased. The AK-immersed YP pellets exhibited quite higher ash content than TW- and AC-immersed YP pellets. The higher ash content is most likely due to the non-combusted sodium remaining after the ash content test of AK-immersed YP pellets. For durability, non-immersed YP pellets had the highest, followed by TW-, AC- and AK-immersed YP pellets. YP pellets became more durable with an increase in the KL and xylose contents as well as a decrease in glucose, but a significant correlation was found between KL or glucose content and pellet durability. Through microscopic observations and quantitative SEM-EDX analysis of lignin distribution, lignin content on the surface of non-immersed YP pellets was higher than that on the surface of TW-, AC- and AK-immersed YP pellets. Based on the results, it can be concluded that there are significant correlations between lignin/sugars contents of YP sawdust and fuel characteristics of wood pellets fabricated with the sawdust. Meanwhile, this assumption needs to be verified in future experiments using different wood species or increased pellets quantities.

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Seung-Won Oh
Chonbuk National University
Department of Wood Science and Technology
567 Baekjedae - Ro
Deokjin-Gu
Jeonju 54896
South Korea

*In Yang
Scion – Te Papa Tipu Innovation Park
49 Sala Street
Private Bag 3020
Rotorua, 3046
New Zealand
*Corresponding author: dahadad@naver.com

Dae Hak Park
Chungbuk National University
Department of Wood and Paper Science
I Chungdae - Ro
Seowon-Gu
Cheongju 28644
South Korea

Soo Min Lee, Byoung Jun Ahn
National Institute of Forest Science
Division of Wood Chemistry & Microbiology
57 Hoegi - ro
Dongdaemun-Gu
Seoul 02455
South Korea