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Effect of Sodium Hydroxide Pretreatment on Rice Straw Composition

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Abstract

Background/Objectives: Sodium hydroxide (NaOH) pretreatment was used to determine the effect of pretreatment on chemical composition of pretreated rice straw. The experiment was designed to measure the effects in terms of NaOH concentration and pretreatment time mainly on the total carbohydrate content (TOC) and lignin content of pretreated rice straw. **Methods/Statistical analysis:** Compositional characterization was performed based on the National Renewable Energy Laboratory (NREL) laboratory analysis protocols. Rice straw obtained from Sekinchan, Selangor Malaysia was dried to reduce the moisture content (<15%) and ground to 2 mm particle size. Rice straw was pretreated with different concentration of NaOH (2%w/v, 6%w/v and 12%w/v) and pretreatment time of 1 and 3 hours, while temperature was kept constant at 55°C. **Findings:** Rice straw sample pretreated with 12%w/v NaOH for 1 hour gave the highest glucan content, an increase of 85.6% from the native untreated rice straw. This condition also yielded the best delignification effect which reduced the lignin composition up to 79.6%, while sample pretreated with 2%w/v for 3 hours gave the highest composition on total carbohydrate content of 79.16% for which included glucan, xylan and arabinan. Hence, the pretreatment condition of 2%w/v NaOH concentration for 3 hours was the best condition in order to obtain high total carbohydrate content while severe pretreatment condition of 12%w/v NaOH concentration for 1 hours was best to give the delignification effect to the rice straw. **Application/Improvements:** The results from this work can be used for further evaluation of pretreated rice straw using NAOH particularly for enzymatic hydrolysis.

Keywords: Sodium hydroxide, pretreatment, rice straw, composition

1. Introduction

The increasing usage of fuels as well as the adverse impact towards environment and global warming has long become a great issue nowadays. The heightened awareness about these threats, has led extensive global effort to explore a sustainable and renewable alternative energy sources like biofuels[1]. Now, global attention and effort are focusing and devoting to production of biofuels and biobased products from bioconversion of lignocellulosic biomass[2,3]. Lignocellulosic biomass, such as agricultural residues, wood and energy crops, is an attractive material for biofuel and biobased production since it is the most abundant renewable resource on the earth. Globally, 140 billion metric tons (MT) of lignocellulosic biomass is generated every year from agricultural activities, which can be converted to an enormous amount of energy and raw materials. This agricultural waste of LCB, which is equivalent to approximately 50 billion tons of oil, can substantially displace fossil fuel, reduce emissions of green house gases (GHG) and provide renewable energy to some 1.6 billion people in developing countries, which still lack access to electricity[4].

The basis for exploiting agricultural lignocellulosic in the future industrial bioeconomy is the minimization of waste. It is common today that only a minor portion of a given crop's total biomass is actually used productively, while much is wasted. Agricultural and plantation residues form a major portion of this un-utilized or under-utilized waste stream[5], and are readily available source of ligno-

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cellulosic biomass, which can provide feedstock from current harvesting activities without need for additional land cultivation[6]. The ultimate goal should be the whole crop utilization in the new environment of zero waste production as the bioeconomy will progressively set higher value for agricultural residues of lignocellulosic biomass, in achieving the long term economic sustainability rather than acquiring new alternative raw materials[5].

In addition to abundant availability and minimization of waste, the lignocellulosic biomass is promising feedstock mainly because of its low environmental impacts. Aligned with the global effort to mitigate the climate change, research and development in many countries are now identifying alternative energy source to minimize GHG emissions. Furthermore, the biofuels produced from lignocellulosic biomass are thought to significantly reduce CO_2 generation and it is suggested that only lignocellulosic ethanol offers considerable GHG emission reductions compared to fossil fuel[4].

Lignocellulose biomass is made up from three main structural components which are cellulose, hemicellulose and lignin. Cellulose (C6H10O5)x is the main structural component that exists in most plant cells. Cellulose is a long polymer chain which make up by glucose monomers. The polymer chain of cellulose can vary from hundred monomers of glucose until thousand monomers of glucose. A strong hydrogen bond is formed in between each monomer with the present of –OH molecules. A systematic and rigid arrangement of cellulose monomers with the strong hydrogen bonding in between had increased the stability of plant. Therefore, pretreatment before enzyme hydrolysis is needed to break down lignin wall and to ease the enzymatic hydrolysis process[7].

Hemicellulose (C5H8O4)x is made up from few pentose polymers such as xylose, arabinose, mannose and galactose. Xylose is the main dominant in pentose sugars. Hemicellulose polymer chain is shorter than cellulose and exists in branch arrangement while cellulose exists in linear arrangement. Hemicellulose has lower molecular weight than cellulose and more hydrophilic, therefore it is easier to hydrolyse by enzyme or acid[2].

Lignin $[C_9H_{10}O_3(OCH_3)0.9–1.7]x$ is one of the non-carbohydrate component that exits in lignocellulose biomass. Lignin is a very complex molecule which exists in three dimensional structure. Lignin is the most rigid component and resistance to enzymatic reaction. Cellulose and hemicellulose are protected by lignin wall, therefore pretreatment need to be undergoes to break down lignin and release sugar inside for enzymatic hydrolysis into fermentable sugar[7,8].

Johnson[5] states that among the lignocellulosic biomass, grain crops tend to have the highest overall residue ratio, amounting to as much as double the crop weight and for this reason, utilization of straw from grains should be a much higher priority in lignocellulosic biomass utilization. Among the grain crop residues, rice straw is one of the most plentiful crop residues in the world and is annually produced at the rate of approximately 731 million tons with Asia as the largest producer that contributes about 667.6 million tons. This amount of rice straw can potentially produce 205 billion liter bioethanol annually, which can be the largest amount, produced from a single biomass feedstock[9,10]. Figure 1 shows that 60% of the rice crop production is rice straw and it is physically made up from leaf and sheath (53%), stem (44%) and panicles (3%) when cut at ground level[4]. In Malaysia, rice crop is the main food plantation, and based on the straw to crop ratio of 1-2 [5], the estimated rice straw production could reach to 4.8 million tons annually, based on rice production data in 2007 [8,11]. This amount of rice straw can generate about 1,346 million liter of bioethanol annually, which can substitute approximately 13.5% of gasoline used in transport sector[4].

In practice, most farmers in Malaysia openly burn the rice straw it offers the most cost-effective way to handle the agricultural residues means of removing it[12]. However, this practice leads to the energy being wasted, and creates serious environmental, safety and health threats to the society. Open field- burning causes a lot of problem to mankind and environment such as air pollution and degradation of nutrients in soil[8,13], and therefore there is a strong need to find alternative ways to remove the rice straw after each harvesting season. Recent research findings on producing high value reactive intermediates such as fermentable sugar from rice straw have opened up more technical and economical opportunities to the farmers and societies themselves[9,10,14].

Generally, rice straw contains cellulose 32-47%, hemicellulose 19-27% and lignin 5-24%. Xylose is the pentose dominant and followed by arabinose. Therefore, rice straw has the potential to serve as a relatively inexpensive feedstock for production of biofuel and biobased products because of its abundance and low value for other application[13,15].

Like other sources of lignocellulose biomass, rice straw also requires pretreatment process to improve the efficiency of sugar production upon enzymatic hydrolysis.[16] stated that rice straw is more recalcitrant than other agricultural residues such as corn stover. Therefore, an efficient pretreatment process is required to unlock and convert them to high value products and commodities such as biofuels and biobased chemicals. Pretreatment process is needed to break down lignin wall that protect cellulose and hemicellulose inside to increase the efficiency of enzymatic hydrolysis[14,17,18]. Besides that, pretreatment also used to disrupt the crystalline structure of cellulose so that acids or enzymes can easily access to the cellulose to hydrolyse them into monomers[15]. Although the pretreatment has been viewed as one of the most expensive processing steps within the biomass conversion technology of biomass to fermentable sugar, it also has a great potential for further improvements in the efficiency and the costs through comprehensive research and development (R&D) activities[17,19,27].

Pretreatment can be classified into three main processes, which are physical, biological and chemical or a combination of these processes. Physical pretreatment can used to increase the surface area and accessibility of biomass for acid or enzyme digestibility. While for biological pretreatment, bacteria and fungi are used to degrade lignin and this is the most environmental friendly method among others. Biological pretreatment is attractive due to its advantages over other methods. It involves environmental friendly and low energy process that produces high yield of desired product without generation of toxic products. However, biological pretreatment has some disadvantages where the process consumes longer time, and requires careful and detailed control of growth conditions for microbe[3].

Chemical pretreatment has become one of the most promising methods used to degrade lignin in biomass, decrease the polymerization and crystallinity structure of cellulose and thus increase the biodegradability of cellulose. Acid solution, alkaline solution and ammonia are solution examples in chemical pretreatment. Alkaline pretreatment is the most effective methods compare with acid and ammonia pretreatment. In alkaline pretreatment, different types of alkaline solution can be chosen to degrade lignin such as NaOH, KOH, CaCO3 and other[13].

Chemical pretreatment affects structure of biomass by solubilizing hemicellulose, reducing crystallinity and increase available surface area and pore volume of substrate. In alkaline pretreatment, it solubilizes the hemicellulose, and delignifies the lignin component[13].

Pretreatment using NaOH is one of the effective pretreatments, and could digest the hardwood from 14% to 55% by reducing the lignin composition from 55% to 20% [3,20] states that NaOH pretreatment is the most effective method to break down the lignin.[21,22] states that the parameters that could affect the effectiveness of NaOH pretreatment are the NaOH concentration, ratio of biomass to NaOH solution loading, reaction temperature and residence time.

The objective of this study was to pretreat the rice straw using different concentration of NaOH solution, to compare the rice straw composition of the native and NaOH pretreated rice straw, and finally to determine the NaOH concentration and experimental parameter that affect the most on the rice straw composition in terms of carbohydrate and lignin components.

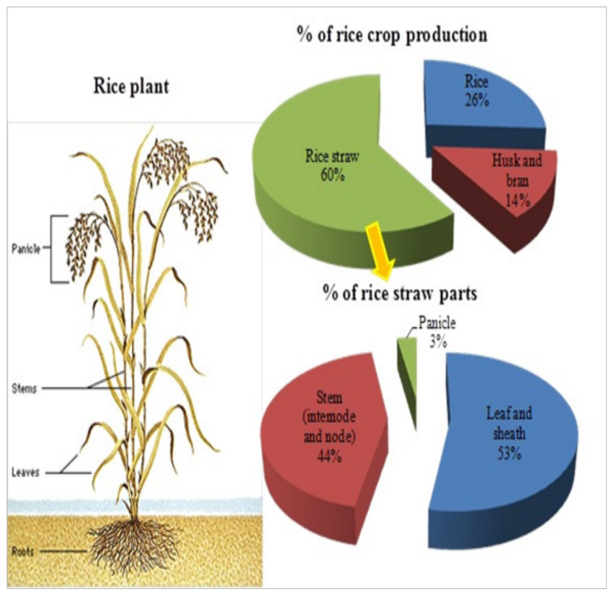

Figure 1. Distribution on rice crop production and rice straw parts[4].

2. Materials and Method

2.1 Sample Preparation

The rice straw was collected from Sekinchan, Selangor, Malaysia. The rice straw was dried by natural air drying method at ambient temperature for one week to attain moisture content of less than 15%. Air-dried rice straw was ground to 2 mm and filtered to remove impurities such as sand and dirts. The sample of rice straw was stored in a plastic bag at room temperature before being subjected to pretreatment.

2.2 NaOH Pretreatment

As stated, NaOH concentration, ratio of biomass to NaOH solution loading, reaction temperature and residence time are the main parameters, which can affect the yield of desired products[21,22]. In this study, rice straws were pretreated with different concentration of NaOH concentration (w/v): 2%, 6% and 12% each with soaking time of 1 and 3 hours at constant reaction temperature of 55°C respectively.

The ratio of rice straw to NaOH solution loading of of 1:20 (w/v) was applied to all the samples in this experiment. NaOH was dissolved in distilled water first to achieve the desired concentration for pretreatment and was preheated in an incubator to 55°C. Once the temperature of the NaOH solution reached 55°C, then it was gradually poured into the rice straw. Figure 2 shows the NaOH pretreatment of rice straw in where the rice straw was soaked in the NaOH solution.

After the pretreatment, the rice straw was separated from the pretreatment liquid known as ‘black liquor’ using cloth filtration. The pretreated rice straw was dried in the oven for at least 24 hours at temperature of 60°C. The black liquor was stored in the plastic container and stored in the chiller for further sugar analysis. The NaOH pretreatment process was repeated on the rice straw at different NaOH concentration of 2, 6 and 12%. The compositional characterization analysis was performed on both the native rice straw and pretreated rice straw.

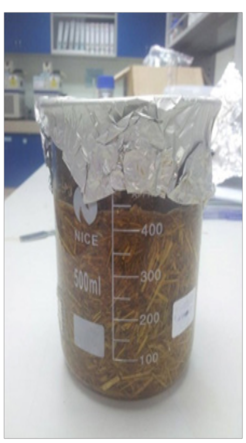

Figure 2. NaOH pretreatment of rice straw

2.3 Compositional Characterization and Analytical Methods

2.3.1 Compositional Characterization

The compositional characterization, which includes the analyses on ash and moisture content, extractives, structural carbohydrates and lignin, was performed using methods adapted from National Renewable Energy Laboratory (NREL).

Ash and moisture content was determined using the furnace and moisture analyzer. Soxhlet equipment was used in water and ethanol extraction in order to determine the total extractives after water and ethanol extractions. Extraction was performed approximately for 6-8 hours for each sample and the temperature was maintained near to the solvent boiling point. Water extraction sample was used to determine the soluble sugar content in the rice straw such as glucose, fructose and sucrose. This sample was further acid hydrolysed using sulfuric acid (H_2SO_4) in order to determine the oligomeric sugar content. Ethanol extraction sample was used to determine the ethanol extractive that include chlorophyll, proteins fats, and oils[23]. Both soluble sugar and oligomeric sugar samples in water extraction were analysed using High Pressure Liquid Chromatography (HPLC) using appropriate column and mobile phase. Total extractive in the rice straw was determined from the mass difference between the native and extracted rice straw sample.

Acid hydrolysis using concentrated 72% sulfuric acid $H_2SO_4$was used to determine the structural carbohydrate and lignin content in the rice straw. Rice straw sample was acid hydrolysed for 1 hour using the incubator shaker at temperature of 55°C and was further autoclave at 121°C for another hour. Solid remained after the acid hydrolysis was filtered using the vacuum filtration to determine the insoluble lignin content while the hydrolysate was further used to determine the sugar content which was then used to estimate the carbohydrate using HPLC system with Refractive Index (RI) detector. The same hydrolysate also was used to determine the acid soluble lignin content using UV-Vis instrument which operated at specific wavelength, 240nm. Absorbance of each sample for acid soluble lignin was determined and calculated by formula.

Water extraction sample was analysed to determine the soluble sugar content using Rezek RPM column (Phenomenex) as the stationary phase. Degassed HPLC grade water was used as the mobile phase at 0.6 ml/min at a column temperature of 60°C. Water extraction acid hydrolysis and rice straw acid hydrolysis samples were also analysed to determine the oligomeric and monomeric sugar content using the Rezek ROA column (Phenomenex) as the stationary phase. Degassed HPLC 0.005M sulfuric acid (H_2SO_4) was used as the mobile phase at 0.6 ml/min at a column temperature of 60°C. The HPLC sample injection volume in both analyses was 10 µl. Standard curves were generated using different concentrations of mixed sugars[4].

3. Result and Discussion

3.1 Composition of Rice Straw Before and After Solvent Extraction

The major structural components of biomass feedstocks are cellulose (glucan), hemicellulose and klason lignin. Hemicellulose is primarily made up of xylan and small amount of arabinose. Besides that, some other sugars that make up the structural components are galactan, arabinan, mannan, acetyl groups and acid soluble lignin while non-structural components are generally measure as protein and extractives[4,15].

Table 1 shows the composition of native, untreated rice straw as well as extractive-free untreated rice straw. The structural carbohydrates, consists of glucan, xylan and a small amount arabinan, in both native and extractive-free untreated rice straw did not significantly vary with 59.3% and 59.6% respectively. Soxhlet extraction was performed to determine the extractives amount in the sample, and it should have solubilized some soluble sugar such as glucose, sucrose and fructose as well as oligomeric sugars. Table 1 shows that small amount of glucose solubilized during water extraction since the glucan composition reduced from 36.41% to 34.91% about 4% reduction. However, both xylan and arabinan composition, hemicellulose component in structural carbohydrates, did not show significant reduction after the extraction as show in Table 1 possibly due to ineffective Soxhlet extraction of oligomeric sugar. Experimental results show that the quantified oligomeric sugar composition in water extractive was the highest for glucose followed by xylose and arabinose with 0.07%, 0.04% and 0.02% respectively (data not shown). Nonetheless, a statistical paired t-test performed on the mean difference of the compositions of glucan, xylan and arabinan between native-whole and extractives-free URS proved that these differences were statistically insignificant ($t\text{-}_{stat} < t_{critical}$ and $p>0.05$).

In contrast to the carbohydrate, the removal of extractives significantly reduced the content of Klason lignin from 26.63% in the native untreated rice straw to 24.28% in extractives-free untreated rice straw ($t\text{-}_{stat} > t_{critical}$ and $p<0.05$), about 8% reduction. This shows that the extractives-free untreated rice straw contained approximately 92% of the acid insoluble lignin in the native untreated rice straw.

In the nonstructural constituents, ash was also affected by the sequential ethanol and water extractions. The ash content slightly decreased from 14.56% in the native untreated rice straw to 13.61% in the extractives-free untreated rice straw. This signifies that the extractive-free untreated rice straw contained approximately 93.5% of the ash in the native untreated rice straw, while the remaining of ash was extracted commonly as soluble salts in the extractives[23]. However, the paired t-test proved that the contents of ash in the native untreated rice straw were not significantly different from the contents in the extractives-free untreated rice straw ($t\text{-}_{stat} < t_{critical}$ and $p>0.05$). The ethanol and water extractions yielded approximately 16.8% of native untreated rice straw dry matter as the extractives.

Compared to the previous study, the composition values of most components such as glucan, xylan, Klason lignin and ash in the current study were approximately the same with the study[24,25]. However, arabinan content in report is considerably higher, about 6.08% compared to others. Overall, the carbohydrates contents for these studies range from 55-65%. The current study also yielded the highest lignin content in both native and extractive-free untreated rice straw with 26.63% and 24.28% when compared to previous study, which the lignin content is in the range of 17-20%. This could be contributed to some contaminant such as silica that could be found in the rice straw.

The summative mass closure for the corrected native untreated rice straw was 113.68% (summation of composition in Table 1). Hames[23] points that the typical mass closures between 96% and 104% confirm that no major components have been overlooked and interferences between methods and double counting of materials are minimized. The composition of the corrected native untreated rice straw was larger than 104% possibly due

Table 1. The composition of native untreated rice straw

Component (%)	Native, untreated rice straw	Extractives-free untreated rice straw	Corrected native untreated rice straw	Yang 2009	Yu Shen et al. 2010
Glucan	36.41±1.57	34.91±1.48	34.99±1.48	36.6	36.32
Xylan	20.29 ±0.67	21.52±1.32	21.55±1.32	18.9	19.45
Arabinan	2.60±0.18	3.18±0.43	3.20±0.43	3.5	6.08
Lignin	26.63±0.29	24.28±1.20	24.28±1.20	15.8	18.01
Ash	14.56±0.43	13.61±0.89	13.61±0.89	19.2	17.6
Extractives	-	16.18±2.96	16.05±2.96	-	-
Total	100.49±1.79	113.68±3.89	113.68±3.89	94	97.46

to some unidentified components that were counted in other components.

3.2 Composition of Rice Straw Before and After NaOH Pretreatment

Five sets of native untreated rice straw samples were prepared and pretreated with different NaOH concentration and reaction time. Table 2 shows the composition of untreated and pretreated rice straw at different pretreatment condition. Theoretically, carbohydrate content will be increased if and only if the delignification process is efficient because carbohydrates such as cellulose and hemicellulose can be released from the lignin wall once the lignin chain is broken down[21]. This study showed that when the rice straw was pretreated with different condition of NaOH pretreatment, generally the glucan content increased from 34.99% in native untreated rice straw to a range between 46.53-64.96%. The highest glucan content was 64.96%, an increase of 85.6% from the glucan content in the native untreated rice straw, observed when the rice straw was pretreated with 12%w/v NaOH for 1 hourpretreatment time.

In contrast to glucan content, the lignin content generally decreased as both NaOH concentration and pretreatment time increased. Table 2 shows that rice straw pretreated with 12%(w/v) NaOH for 1 hour pretreatment time contained the least lignin which is 4.96% in which 2.52% is acid soluble lignin and 2.44% is acid insoluble lignin. This pretreatment condition yielded the highest delignification percentage of 79.6% over the lignin content in native untreated rice straw sample.

The effects of NaOH concentration and pretreatment time were statistically significant towards the delignification process as well as the releasing monomeric glucose sugar amount from lignin carbohydrate complex structure[15,21,26].

However, different scenario was observed for both xylan and arabinan composition where the highest composition was observed only at the lowest NaOH concentration of 6%w/v and shortest pretreatment time of 1 hour. As the NaOH concentration and pretreatment time increased, the xylan and arabinan content decreased.

The hemicellulose components were easily solubilized at mild pretreatment conditions ie. at lower NaOH concentrations and shorter time but easily degraded at harsh pretreatment conditions ie. at higher NaOH concentrations and longer time as reported High NaOH concentration used in the pretreatment caused the hemicellulose to degrade to other unknown byproducts which resulted in low hemicellulose composition.

Figure 3 shows the total carbohydrate (cellulose and hemicellulose) content (TCC) in percentage for untreated native and NaOH pretreated rice straw samples. Generally, TCC increased for all pretreated rice straw sample. The rice straw sample pretreated with 2%w/v NaOH for 3 hours gave the best result of TCC as the carbohydrates content was the highest compare to other samples. This sample consisted of 50.43% glucan, 24.54% xylan and 4.19% arabinan with total carbohydrate of 79.17%. It can be concluded that this sample has undergone the best pretreatment condition among others for this study.

Figure 4 characterizes the composition of the total extractives in the each rice straw sample during water and ethanol extractives. The figure shows that the rice straw pretreated with 12%w/v for 1 hour contained the most total extractive which was 22.58%. This sample contained highest total oligomeric sugar which was 7.74% but with lowest ethanol extractive, such as nonstructural sugar, wax and tannin[27], which was 0.80%. Three major types of sugar oligomer existed in water extractive which were glucose oligomer (GlucoOligo), xylose oligomer (XyloOligo) and arabinose oligomer (AraOligo). The pretreatment condition of 12%w/v NaOH for 1 hour yielded an effective NaOH pretreatment process which was capable to remove as much as possible which resulted in high total extractive and high soluble sugar in this sample. However, untreated rice straw contained the highest ethanol extractive which was 2.49%. This shows that the native untreated rice straw contained large amount of impurities, wax and tannin.

Lignin is one of the major components in rice straw besides carbohydrates. It limits the accessibility of enzyme towards the carbohydrates in lignocellulose biomass, so lignin wall has to be broken down efficiently during pretreatment process. As mentioned above, total lignin consists of acid soluble lignin and acid insoluble lignin. Acid insoluble lignin occurred as solid after acid hydrolysis of rice straw while acid soluble lignin occurred as liquid. Acid soluble lignin was then filtered and separated from liquid through vacuum pump, the weight of the solid on filter paper was the amount of acid insoluble lignin whereas acid soluble lignin was quantified through UV-Vis instrument at absorbance of 240nm. Figure 5 shows that the total amount of lignin in pretreated and untreated rice straw. As stated, it shows that the lignin content generally decreased as both NaOH concentration and pretreatment time increased. Both acid insoluble and acid soluble lignin show the same trend in the pretreated rice straw.

4. Conclusion

The composition of untreated rice straw sample contained total carbohydrate of 59.30% and lignin of 24.28%. In NaOH pretreatment performed at 55°C showed that when the rice straw was pretreated with different condition of NaOH pretreatment, generally the glucan content increased from 34.99% in native untreated rice straw to a range between 46.53-64.96%. The highest glucan content was 64.96%, an increase of 85.6% from the glucan content in the native untreated rice straw, observed when the rice straw was pretreated with 12%w/v NaOH for 1 hour pretreatment time. The same pretreated rice straw sample also contained the most total extractive which was 22.58%. This sample contained highest total oligomeric sugar which was 7.74% but with lowest ethanol extractive. The study also showed that increasing the NaOH concentration and pretreatment time also had significantly improved delignification in rice straw and thus released more sugars from rice straw. Rice straw pretreated with 12%w/v NaOH for 1 hour contained the least lignin which was 4.96% in which 2.52% was acid soluble lignin and 2.44% was acid insoluble lignin. This pretreatment condition yielded the highest delignification percentage of 79.6% over the lignin content in native untreated rice straw sample. The rice straw pretreated with 2%w/v for 3

Table 2. The composition of untreated and pretreated rice straw at different pretreatment conditions

Component	Rice Straw Composition, % (Dry weight basis)					
	Untreated Rice Straw	Pretreated Rice Straw at Different Concentration NaOH (%) and Reaction Time (h)				
		2%, 1h	6%, 1h	12%, 1h	2%, 3h	6%, 3h
Glucan	34.99±1.48	46.53±3.69	56.21±5.02	64.96±1.39	50.43±4.68	57.08±3.93
Xylan	21.55±1.32	25.5±1.83	13.03±0.13	9.07±0.36	24.54±1.77	17.05±0.95
Arabinan	3.20±0.43	5.3±1.35	2.88±0.25	1.57±0.08	4.19±0.24	2.81±0.14
Lignin	24.28±1.20	11.35±1.29	6.29±2.30	4.96±0.33	9.83±1.45	6.27±0.57
Ash	13.61±0.89	ND	ND	ND	ND	ND
Extractives	16.05±2.96	6.54±0.04	12.38±0.23	14.85±0.67	6.54±1.01	9.92±0.14
Total	113.68±3.89	95.17±4.52	90.79±5.54	95.41±1.62	95.53±5.31	93.134.09

ND=Not Determined

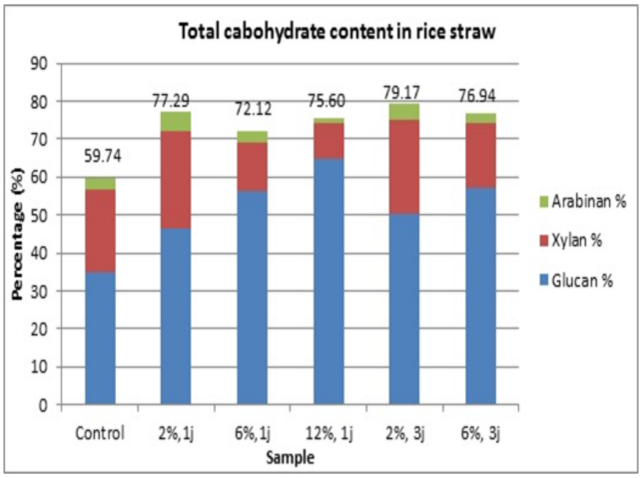

Figure 3. Total carbohydrates content in different type of rice straw.

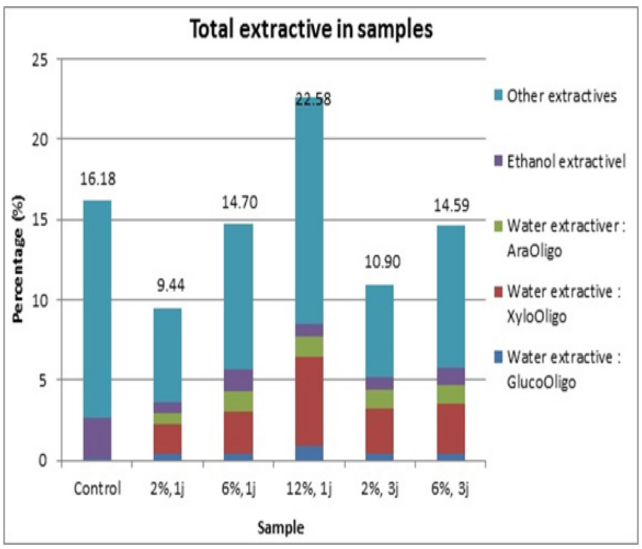

Figure 4. Composition of total extractives in pretreated and untreated rice straw.

hours had achieved the highest total carbohydrate content which was 79.16% including of glucan, xylan and arabinan. Carbohydrate content in pretreated rice straw has been increased compare to untreated rice straw while lignin content has been decreased in pretreated rice straw.

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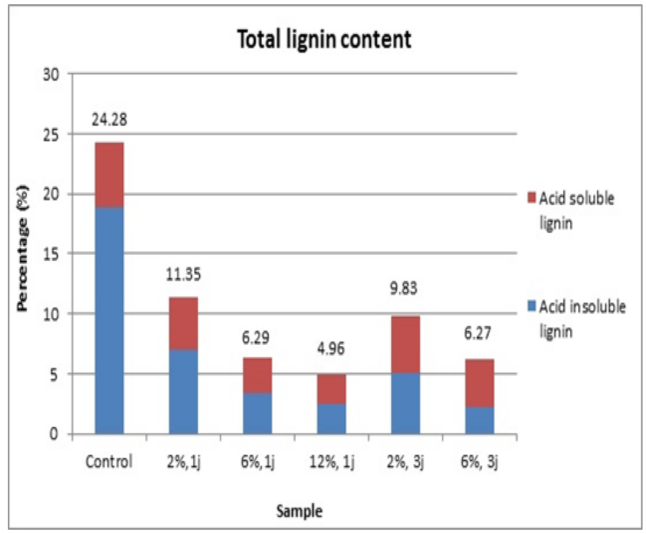

Figure 5. Total lignin content in untreated and pretreated sample.

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