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CHEMICAL ANALYSIS DENDROCALAMUS ASPER BAMBOO AND SUITABILITY FOR PULP AND PAPER

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ABSTRACT

The chemical analysis of bamboo species, namely *Dendrocalamusasper* or popular named as *BuluhBetong* has been evaluated. From the age of 3 years, this species shows different chemical properties related to holocellulose, α cellulose, solvent extraction, alkali solubility, lignin, hot water solubility, cold water solubility, ash, silica and pentosan. Holocellulose content of about 60.48% to 64.75%, α cellulose content of about 35.73% to 43.14%, for all bamboo segments indicated as a suitable material for pulp and papermaking. Low level of solvent extractive of about 5.09% to 6.23%, hot water soluble of about 6.29% 9.49% and cold water soluble of about 9.35% to 10.49% also produced the content that cannot interfere with the paper-making process. In addition, the low ash and silica content for all sections of bamboo will indicate a normal alkali consumption and give little challenge to the operational process. High pentosan content in the middle and top sections between 16.32% and 20.88% and lignin content of around 39.27% to 32.51% also promise little challenge for pulping as compared to the bottom section. Therefore, based on the overall findings, the middle section, and the top section had an advantage over the bottom section. As a result, the middle and top sections are best used as a new material in pulp and paper making process.

Keywords: chemical analysis, bamboo, holocellulose, α cellulose, pulp and paper.

1. INTRODUCTION

Bamboo is a member of a particular taxonomic group of large woody grasses (Poaceae). This species compromise a subfamily of Bambusoideae [1]. Bamboo encompasses 1250 species within 75 genera [2]. About 220 000 km^2 of bamboo resources is a vital component of plant and forest resources in the world [3]. Bamboo is relatively fast growing and attain maturity within 3-5 years from 10cm to 40m in height [4, 5]. Bamboo can be harvested annually and potential to become a sustainable material [6].

In Asia, bamboo is utilized for housing, crafts, flooring roofing fabrics, vegetables (bamboo shoot), pulp, paper and composite panel [6]. However, the lack of comprehensive data regarding bamboo's strength and its application in other sectors creates some limitations in usage. Hence, bamboo has not been seen as an important agricultural source for national income.

In Malaysia, bamboo is only utilized as a craft product, chopstick, frame, basket and furniture [7]. The lack of industry support and a low knowledge of the strength of bamboo make much of bamboo abandoned in Malaysia. Encouraging the use of non-wood plant fiber, secondary fiber and waste paper resulted in increased search for an alternative source for pulp and paper industry [8, 9]. Therefore, in order to avoid reliance on wood base alone, another source material must be provided to this industry[10].

The process for papermaking and the suitability of new fiber for paper also depends on the fiber's chemical composition [11]. The chemical constituents of a bamboo culm are very complicated and consist of fiber, parenchyma and conducting tissue [12]. Similar to wood and agricultural residues, bamboo is mainly composed of cellulose, hemicelluloses, and lignin, even though the contents of these compositions are different [13].

The result of chemical composition of Dendrocalamus Asper may perhaps promise a potential strength of bamboo species adapted to papermaking. Not much difference in chemical content as compared to Bambusa vulgaris and Gigantochloascortechinii supports the result [12, 13]. This species could contribute to a replacement of wood base fiber in pulp and papermaking industry.

2. MATERIALS AND METHODS

Dendrocalamusasper fiber is used as a raw material, being supplied by PuluoVillage in Kulai, Johor. One supplier was selected to eliminate the harvest variables that affect the bamboo growth and, consequently affect the result.

The sample was obtained from the age of 3 years old bamboo due to maturity condition of the bamboo [16]. The bamboo culm was separated into 3 sections called section base (SB), section middle (SM), and section top (ST). 100 gm of samples were obtained for every section and ground into sawdust. The volume is enough for 10 experiments that need around 7 gm to 8 gm for every experiment.

The analysis of holocellulose, α cellulose, lignin, solvent extraction, alkali solubility, hot water soluble, cold-water soluble, ash, silica and pentosan was performed to determine its chemical content. The solvent extraction needed to run early as the yield will be used in holocellulose, α cellulose and pentosan analyses. Theethanol toluene extraction process took 6 to 8 hours to boil the sawdust in 200ml of ethanol toluene (ET) using a Soxhlet apparatus and heater. The evaporated solvent from the extraction was dried in water bath and weighed. The procedure follows the TAPPI T204 cm -97 setting. Figure-1 shows the structure of an ethanol toluene extraction apparatus setup.

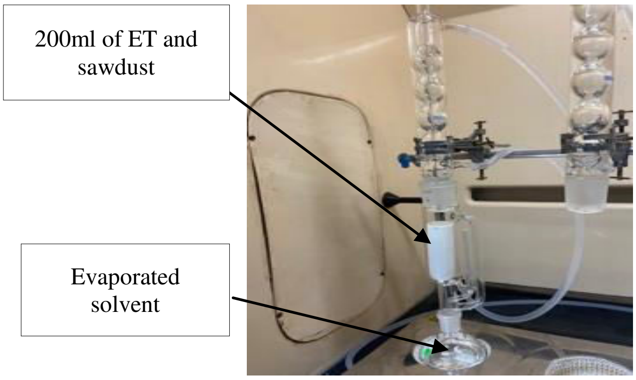

Figure-1. Ethanol toluene setup.

Holocellulose composition was carried out according to the method of Wise (1946). 2g of oven dried extractive free specimen, 1.5g of sodium chlorite and 5ml of acetic acid boiled together in water bath for 30 min. A total 6g of sodium chlorite then added to boiling interval with acetic acid. Fritted glass was used to filter the mixing and oven dried. Figure-2 shows the holocellulose boiling process.

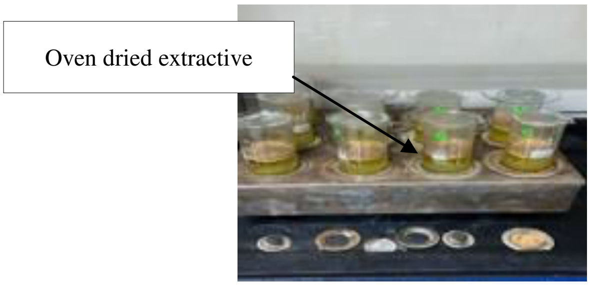

Figure-2. Holocellulose boiling process

α cellulose was taken out from air dried holocellulose. 2g of holocellulose mixed with 17.5% of NaOH for 75 min and filtered by fritted glass. Acetic acid and distilled water were used to clean the mixing and then oven dried.

1g of extractive free specimen was used to measure the pentosan. 100ml at 13.2% of HCl then added to the extractive. Figure-3 shows the apparatus setup and organized according to TAPPI T223 cm-10 setting, then HCl added until 300ml of total volume in a round bottom flask. Next, N/10 bromate and 10% of KBr were added. After that, the extraction mixing was titrated with N/10 Thiosulphate.

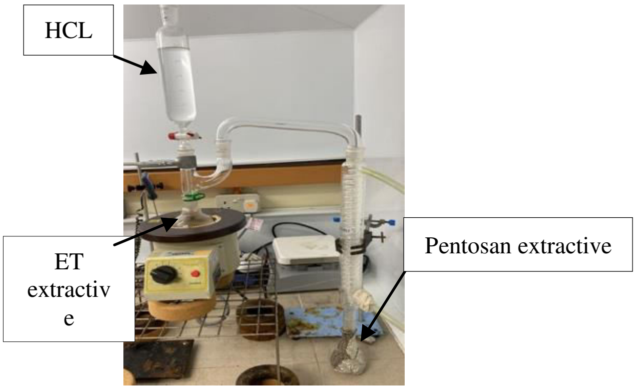

Figure-3. Pentosan extraction process.

The alkali solubility was tested on 2g of bamboo sawdust according to TAPPI T212 om-02 setting. Then, 100ml of NaOH was added and boiled for 60 min at 97^{o}C - 100^{o}C in water bath. Next, this solution was transferred to the filtering crucible, washed using acetic acid and hot distilled water.

Ash composition was determined by carbonized 2.5g of sawdust on Bunsen and furnace at 525^{o}C for 30 min to 60 min. When combustion was completed, the composition was removed from the furnace and weighed. The procedure was carried out based on TAPPI T211 om-02 setting.

The acid insoluble lignin was determined according to TAPPI T222 om-02. Lignin composition was performed on 1g of extraction free sample. 15ml of sulfuric acid was added and stirred for 2 hr at temperature of 20±1^{o}C. Then, the specimen was transferred to a Erlenmeyer flask and diluted with distilled water. The solution was boiled for 4 hr and filtered with a filter crucible. The filtered crucible sample was then oven dried.

Silica content was performed based on TAPPI T245 om-88 setting. Silica composition was determined by using 7g of bamboo sawdust. A platinum crucible adopted to carbonize the sawdust. At first stage, the silica composition was carbonized using H_2SO_4 of around 2ml - 3ml. Then, heated in the furnace for 4 hr at 1050^{o}C. At second stage, 5ml of Hydrofluoric acid was added to the ash as it was being carbonized. Then, the ashes heated in the furnace for 4 hr and weighed the platinum crucible.

Hot and cold-water solubility was evaluated according to TAPPI T207 cm-99 setting. Hot water-soluble composition was prepared by mixing 2g of bamboo sawdust with 100ml of distilled water in a Erlenmeyer flask. The mixture then boiled in water bath for 3 hr. Then, the sample was filtered and washed with hot water.

Cold water solubility was performed by mixing 2g of sawdust with 300ml of distilled water in a 400 cm^3 beaker. Next, the mixture was disrupted in the shaker at a temperature of 23±2^{o}C for 48 hr. After that, the sample was filtered and washed with cold distilled water. Then the sample was oven dried before weighing the crucible.

3. RESULTS AND DISCUSSIONS

The maturity of bamboo section can affect the chemical composition of the bamboo fiber. A comparison of chemical composition of each bamboo section is significant to understand which section is suitable for pulp and paper production. The composition content could challenge the pulping process, papermaking process, bleaching, pulp washing, pulp beating and strength of paper pulps. Table-1 shows the chemical composition analysis results of the Dendrocalamus Asper Bamboo for 3 sections: bottom (SB), middle (SM) and top (ST).

The chemical analysis shown in Table-1 reveals that there was a slight variation in holocellulose content between the bamboo sections. The highest % value was the middle section (65.35%) followed by the bottom section (64.75%), and the top section (60.48%), respectively. The chemical composition presented in this study is in agreement to studies by Tamolang[17],

R. Wahab[18], H. W. S. R. Salim [19] and Sadiku [14] that reported the holocellulose content in bamboo is typically around 50% - 85%. These reporting bamboo species are known as promising material for pulp and papermaking.

Carbohydrate composition is important in determining the response of bamboo fiber to processing conditions and improving the physical properties of hand sheets. This value showed a good fiber response to paper-making process. The meaningful amount of the holocellulose content in pulp and paper is > 60% for soft wood and annual plant [20]. According to the data, all the bamboo's intersections illustrated accepted numbers, although the data backtracks somewhat comparable to the published data. According to all sections, SM section showed a good result of 65.35% for the holocellulose followed by the SB section. However, all the sections still showed above the meaningful value of 60%. Figure-4 shows the comparative value between holocellulose composition and the normal reasonable value.

Table-1. Chemical composition analysis of Dendrocalamus Asper Bamboo

Characteristics	Bottom	Middle	Top
Holocellulose	64.75 (±0.6)	65.35 (±0.4)	60.48 (±0.6)
α cellulose	43.14 (±0.2)	41.14 (±0.7)	35.73 (±0.5)
Lignin	47.62 (±1.6)	35.96 (±0.6)	32,51 (±1.3)
Solvent extractive	5.09 (±0.7)	5.68 (±0.2)	6.23 (±0.8)
Alkali Solubility	33.21 (±0.3)	37.48 (±0.2)	36.44 (±0.5)
Hot water Solubles	6.21 (±0.3)	7.46 (±0.5)	9.49 (±0.4)
Cold water Solubles	9.35 (±0.6)	8.19 (±2.2)	10.49 (±0.6)
Ash	2.75 (±0.2)	3.12 (±0.3)	2.69 (±0.1)
Silica	0.81 (±0.2)	0.17 (±0.2)	0.17 (±0.1)
Pentosan	16.32 (±0.2)	20.49 (±0.1)	20.88 (±0.1)

- All values presented as percentage of oven dried (OD) raw material
- ± = Standard deviation

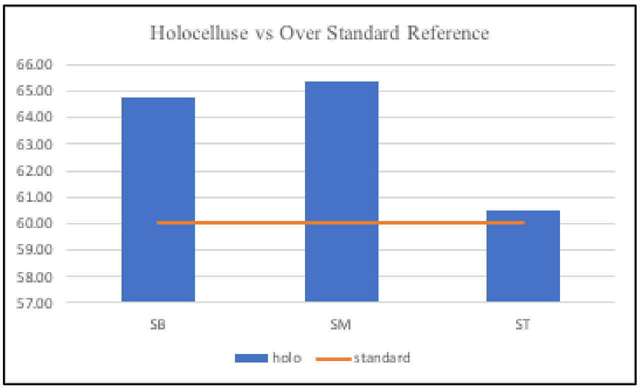

Figure-4. Holocellulose composition as compared to the normal reasonable value.

The α-cellulose is one of the most important findings of the chemical constituents in the holocellulose. The α-cellulose content for the cultivated bamboo genus Dendrocalamus Asper was ranged from 35.73% to 43.14%. The α cellulose content presented in Table-1 shows a small variation between each section. The higher value of 43.14% belongs to the bottom section, followed by the middle section at 41.14% and the top section at 35.73%. The α cellulose composition helps making this bamboo fiber more suitable as its value exceeding the normal reasonable value of >34% as stated by Nieschlag [21]. A similar pattern was found by R. Wahab [18] and A.L. Mohmod [15] that reported the contents of α-cellulose in bamboo G. scortechinii was about 46.11% - 46.87%. Other studies on the α-cellulose content of G. scortechinii ranged from 55.2% by H.W.S.R Salim [19]. Sadiku also reported that they are more α-cellulose content found in bamboo Bambusa vulgaris with 67.07% [14].

However, when comparing the results of this work with the published data for all sections of Dendrocalamus Asper [20, 21], the α celluloses showed a slight decrease, and all sections of bamboo were still considered to be within the accepted range. Figure-5 shows the comparison between accepted value of >34% and the result obtained.

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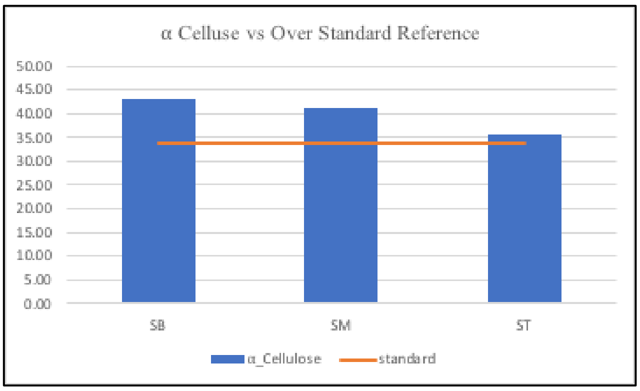

Figure-5. α cellulose composition as compared to the accepted value.

Table-1 also exhibits the solvent extractive content for multiple bamboo sections. The extracted content for all sections of Dendrocalamus Asper bamboo was ranged between 5.09% and 6.23%. A low percentage extraction shows SB of 5.09%. The second is SM at 5.68% and followed by ST at 6.23%. H.W.S.R. Salim [19] found the extractive content of G. scortechinii to be around 8.00%. Meanwhile, Norul Hisham determined the extract content of G. scortechinii to be from 3.4% to 5.8%, respectively [24]. The results of this study as compared to the previous studies have shown that the values were within the acceptable range. Tutus stated that softwoods and hardwoods contained 1% to 6% of extracts [20]. The results showed that the contents of extracts in bamboo were less than 10% but higher than in softwoods and hardwoods [18]. The promising values of the bamboo, however, cannot affect the papermaking process, especially the pitch drawback and corrosion on equipment [25]. Figure-6 shows the significance of extractive as compared to the normal reference of <10%.

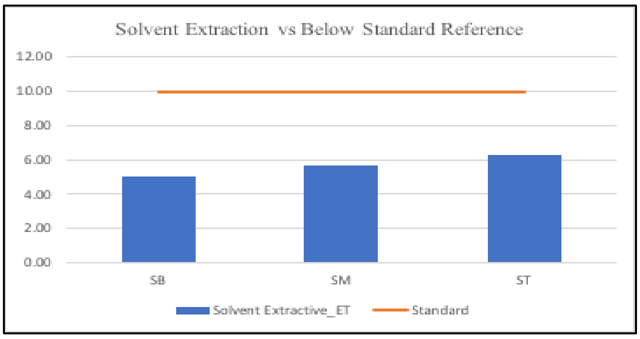

Figure-6. Solvent extractive as compared to below standard reference value of 10%.

Hot water soluble illustrated in Table-1 showed an increasing trend from 6.21% to 9.49%. However, a low composition of SB at 6.21%, SM at 7.46% and ST at 9.49% of hot water soluble in all sections were still in the satisfactory range. Cold water soluble also showed an identical trend from 8.19% to 10.49% and slightly higher. Cold water soluble composition values of 9.35% for SB section, 8.19% and 10.49% for SM and ST sections, respectively. These low values meant that the fiber cannot interfere with the papermaking process, however, the corrosion and foaming problem arise at higher levels [21]. Robles gave a satisfactory value as compared to eucalyptus species and a requirement of less than 16.4% [26]. Figure-7 and Figure-8 show the low composition of hot water and cold-water solubility. This means that a small part of the extraneous components is removed and in general the pulp yield is increased with a low extractable content [25, 26].

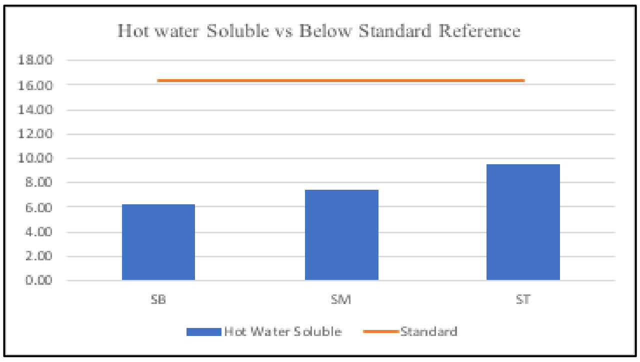

Figure-7. Hot water soluble as compared to below standard reference of 16.4%.

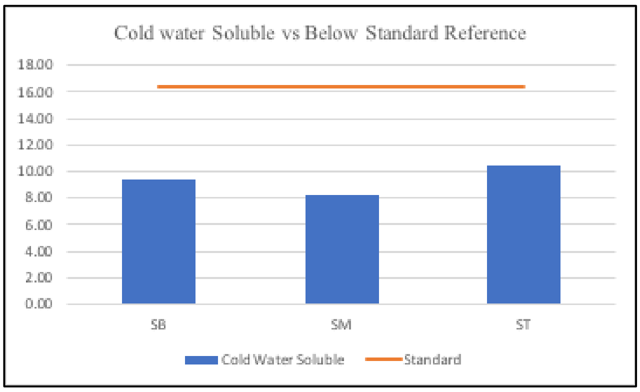

Figure-8. Cold water soluble as compared to below standard reference of 16.4%.

The ash contents of all intervals were low with SB at 2.75%, SM at 3.12% and 2.69% for ST. The ash content was lower than a well-known non-wood fiber in pulping such as kenaf (4.4%) [28]. The ash content also in agreement with studies by Norul Hisham of about 1.9% to 3.5% [24]. The same silica trend also indicated a low value with SB at 0.17%, SM at 0.17% and ST at 0.81%.

A high ash and silica composition interfered the waste liquor recovery. A low silica content of less than 1% showed a backup promising support for reduced pollution of pulp and paper waste [29]. Figure-9 and Figure-10 show the comparison result.

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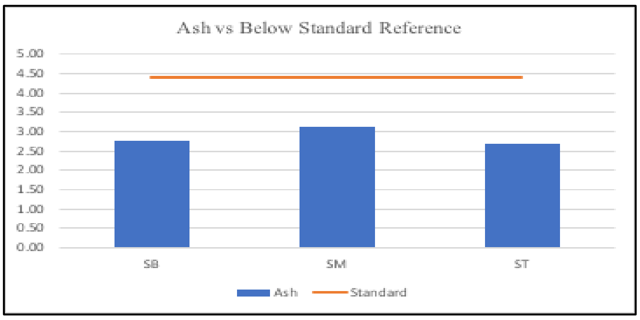

Figure-9. Ash content as compared to standard reference of 4.4%.

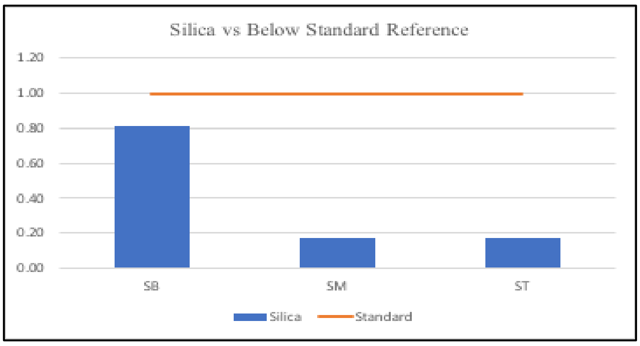

Figure-10. Silica content as compared to standard reference of 1%.

The pentosan composition at SB section showed a low value of 16.32% than SM section at 20.49% and ST section at 20.88%. Higher value > 20% are common in hardwood and is desirable for pulp and paper raw material. The pentosan content for this bamboo is still within the range, especially in SM and ST sections. High pentosan indicated the low retention and loss of hemicellulose during pulping process and interfered with paper strength [30]. (See Figure-11. for comparison values of pentosan).

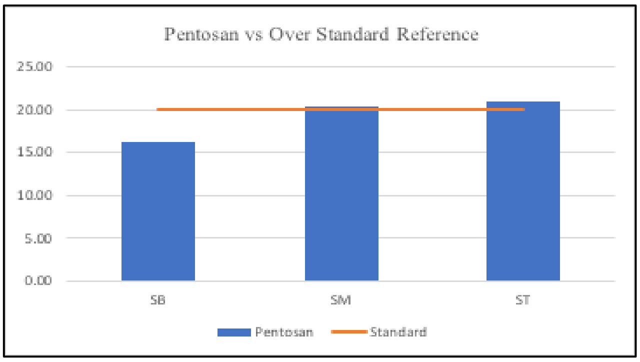

Figure-11. Pentosan composition as compared to standard reference of 20%.

The alkali solubility showed a high value and could interfere with the sieve yield and extent of carbohydrate degradation during the pulping process [30]. SB section at 33.21%, SM section at 37.48% and ST section at 36.44% showed that all sections could cause challenge to fiber degradation and required some modification in the pulping process. The reference content can be compared to about 12.4% of Eucalyptus [26]. Figure-12 shows the alkali solubility result.

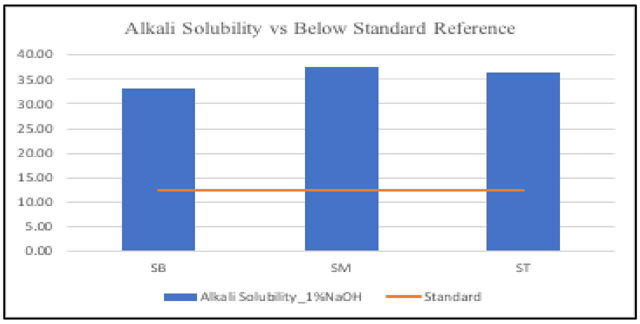

Figure-12. Alkali solubility as compared to standard reference of 12.4%.

The main challenge of bamboo fiber is the lignin composition. The ease of delignification of the material during pulping process depends on the lignin content. A high lignin content could make the fiber tougher and stiffer, which is often referred as plant cell wall glue. The SB section of bamboo has a high composition at 47.62% of lignin. Middle section at 35.96% and at 32.51% of lignin to ST section. However, as compared to Bambusa vulgar is at 36.4% and 32.5% of G. scortechinii, the SM and ST sections were still acceptable to be used as raw material [14].

However, the lignin content is still found to be lower than that of wood fibers by 14% to 37% [31]. The high lignin composition emanating from the bamboo fiber required high cooking chemical and longer cooking time for the pulping process [30]. Figure-13 shows the result over the standard reference value.

Overall, the major chemical analysis of holocellulose, α cellulose, lignin, extractive solubility and ash have shown acceptable data values. The SM and ST sections can be the promising new raw material for pulp and paper making.

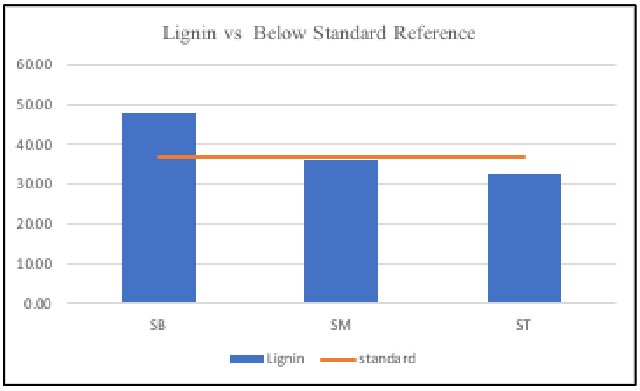

Figure-13. Lignin content as compared to standard reference of 37%.

4. CONCLUSIONS

The findings of this investigation show that each section of Dendrocalamusasper bamboo has a different meaning of chemical composition. All the sections give a good relevance in terms of suitability as potential newer materials for pulp and papermaking. The composition of high holocellulose content in the middle and top sections at 65.35%, 60.48% or >60%, α cellulose at 41.14%, 35.73% or >34% and pentosan at 20.49% and 20.88% illustrated a very good result. The low content of extractive solubility at 5.68% or <10%, hot water soluble at 7.46% or <16.4%, cold water soluble at 8.19% or <16.4%, ash at 3.12% or <4.4%, and silica at 0.17% or <1% also supported the results. Lignin at >37% and low pentosan at <20% showed that the bottom section of bamboo can challenge the pulping process, therefore the middle and the top sections can possibly be used as raw materials for pulp and paper production.

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