Evaluation of the Chemical Composition and Pulp and Paper making Potential of *Acacia melanoxylon* Grown at Chencha woreda in SNNPR, Ethiopia

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Abstract

The aim of this study was to investigate the chemical composition of *Acacia melanoxylon* and its potential for pulp and paper making. The samples consisted of 6 trees, and sample discs were taken at 10%, 50% and 90% along the merchantable tree height. Chemical compositions were determined and their change with tree height was evaluated. All chemical analysis were determined in accordance with the standards outlined in American Society for Testing Material (ASTM) except, cellulose and hemicellulose content which was conducted using Kurschner-Hoffer and Alkali extraction method, respectively. Data were analyzed using one-way analysis of variance and Duncan multiple range test for mean comparison at $\alpha = 0.05$. The results of the study showed that the overall average values of chemical composition were 45.02%, 21.94%, 23.79%, 5.52%, 3.24% and 0.48%, for cellulose, hemicellulose, Klason lignin, hot-water solube extractives, alcohol-benzene extractives and ash content, respectively. A significant amount of chemical composition variation was observed between the bottom and the top portion of the tree, except, hot-water soluble extractives. In view of experimental results, it was observed that tree height had a significant impact on the amount of chemical composition.

Keywords: Acacia melanoxylon, Chemical composition, Paper, Pulp, Tree height

Introduction

The worldwide paper consumption is estimated to be 400 million tons per year and expected to increase to 500 million tons by 2020 (Sharma *et al*., 2013). The global consumption of paper and paperboard products increases continuously due to numerous reasons, which include population growth and industrialization in developing countries (Hurter and Riccio, 1998).

Pulp is produced from hardwood, softwood, and agro-residues. Hardwood and softwood pulping accounts for 95% of the total worldwide pulp production, and the rest 5% comes from non-wood raw materials, mainly agro-residues and grasses (Jimenez *et al*., 2005).

The chemical composition of raw materials is the basis for many properties of the pulp and paper. Different scholars reported the relationship between chemical composition and pulp and paper properties. For instance, Kiaei *et al.* (2014) reported that, cellulose content has a positive relationship with pulp quality and high cellulose content gives high mechanical strength for pulp, especially tensile strength (Madakadze*et al*., 1999). According to Ates *et al*. (2008), high extractive content will be an indicator of low pulp yield as well as higher chemical consumptions both in pulping and bleaching. Moreover, hardness, bleachability and other pulp properties, such as color, are associated with the lignin content of the raw material (Malik *et al*., 2004).

In Ethiopia, paper demand is growing by 10 percent every year (ERCA, 2015). For instance, in 2003, average annual domestic production of paper was 7,266 tons, while in the same year, 127,132 tons of paper was imported which means the average total supply of paper during the period under consideration was 134,398 tons per annum, of which only about 5% was locally produced. Hence, the consideration of some fast-growing wood species in Ethiopia as a potential raw material for pulp production is a right step towards meeting the demand for pulp and paper. In this regard, *Acacia melanoxylon* tree is one of the candidate species for pulp and paper production because of its fast growth, ability to coppice and its adaptation to different agro ecological zones and wide range of uses.

Acacia melanoxylon which is locally known as ‘’Omedla’’ is one of the most important multipurpose tree species and found in cooler and wetter upland areas, moist and wet kolla, Weyna dega and Degaagroclimatic zones of Ethiopia. This species has been used mainly for firewood, charcoal, light construction, plywood, flooring, fence posts, shade, ornamental, windbreak, gum, and tannery. It has the ability to coppice from damaged stems and grows fastly on a variety of soils (Bekele, 2007).

Ethiopia fully relies on imported pulps for paper production although there are many indigenous and exotic wood species in Ethiopia that can be used for pulp production (Desalegn *et al*., 2012). This is due to lack of knowledge and information on pulp properties of different tree species and other limitations (Desalegn*et al*., 2012; CCIDI, 2015).

Prior to recommending any wood species for pulp and paper production, adequate information on chemical composition is vital, since it affects the quality of pulp and paper products (Cao *et al*., 2014). Even though *A.melanoxylon* grows in a wide ecological ranges and has multiple uses, its potential for pulp and paper products were not known in Ethiopia. Therefore, the aim of this study was to investigate the chemical compositions of *Acacia melanoxylon* and its potential for pulp and paper production.

Material and Methods

Description of the Study Area

The study sample trees were taken from Chencha woreda of Southern Nations, Nationalities and People Region (SNNPR), which is located at 37 kilometers North of Arbaminch town/city, and 500 kilometers from Addis Ababa. It is situated at 37^{o} 26’0” - 37^{o} 40’0”E and 6^{o} 8’0”- 6^{o} 26’0”N longitude and latitude, respectively. The annual rainfall distribution of the area varies between 900 to 1200 mm (Ogato, 2006).

Sample collection and preparation

Wood discs with thicknesses of 25 mm were taken systematically from bottom (10%), middle (50%) and top (90%) portions along the merchantable tree height (Latib *et al*., 2014).

Table 1: Stem diameter (DBH) and merchantable height of sample trees

Tree No.	Stem diameter (cm)	merchantable tree height (m)
1	25	15
2	26.5	16.5
3	24	17.7
4	28.5	18.5
5	26	15

6	27	17

Thereafter, the collected discs were cut into small strips with a knife and dried. The strips were small enough to be placed in grinding machine and chips were ground in the Wiley mill. Then, the milled material placed in a shaker with sieves to pass through a number 40 mesh sieve (450 µm) yet retained on a number 60 mesh sieve (250µm). Finally, each chemical composition analysis was carried according to international standards (Table 2).

Table 2: Standard followed for chemical composition analysis

Chemical composition	Replication	Standards
Cellulose	3	Kurschner-Hoffer
Hemicellulose	3	Direct extraction with aqueous alkali
Klason lignin (72% H_2SO_4)*	3	ASTM D 1106-56
Alcohol-benzene solubility	3	ASTM D 1107-56
Hot-water solubility	3	ASTM 1110-56
Ash Content	3	ASTM D 1102-84

*Klason lignin is the residue obtained after total acid hydrolysis of the carbohydrate portion of wood.

Experimental design

Sample collection for the investigation of chemical compositions was systematically randomized. Six trees were selected for sample collection and three discs were taken from each tree (bottom (10%), middle (50%), and top (90%)) of the merchantable height. Therefore, a total of 18 discs were taken from six trees. Each chemical analysis was repeated three times.

Data analysis

Statistical analysis was conducted using statistical analysis software (SAS). Differences in chemical composition among the tree heights were analyzed using one-way analysis of variance. Duncan multiple range test was used to compare mean values for each chemical composition along tree height levels at $\alpha = 0.05$.

Results and Discussion

The results showed that the studied species had the highest value of cellulose and Klason lignin at the top portion of wood. While, the bottom portion gave the higher value of hemicellulose, alcohol-benzene, hot-water solubility and ash content (Table3).

Table 3: Mean and standard deviation of chemical composition along tree height levels

	Height levels (%)		
Chemical composition (%)	Bottom (10%)	Middle (50%)	Top (90%)
Cellulose	42.93 ± 0.40^{a}	45.10 ± 2.87^{ab}	47.03 ± 1.46^{b}
Hemicellulose	24.73 ± 0.60^{b}	21.56 ± 2.48^{ab}	19.51 ± 1.42^{a}
Klason lignin	23.13 ± 0.25^{a}	23.31 ± 0.10^{a}	24.93 ± 0.77^{b}
Alcohol-benzene	4.06 ± 0.79^{b}	3.19 ± 0.06^{ab}	2.46 ± 0.39^{a}
Hot-water solubility	5.68 ± 0.30^{a}	5.45 ± 0.05^{a}	5.42 ± 0.49^{a}
Ash	0.56 ± 0.05^{b}	0.52 ± 0.025^{b}	0.37 ± 0.02^{a}

Mean of the same row with different superscript are significantly different (p<0.05)

Cellulose Content

Table 3 shows that the cellulose content of *A. melanoxylon* increased from bottom (42.93%) to the top portion (47.03%). Duncan multiple range test showed that a significant cellulose content variation was observed between the bottom (10%) of the tree height and the top (90%) of the tree height , however the top and bottom portions showed insignificant cellulose content variation from the middle (50%) of the tree height at $p<0.05$ (Table 3). In this study increasing amount of cellulose content was observed from bottom to top which is similar to result reported by Amini *et al*. (2006) on *A. mangium.* The mean cellulose content (45.02%) is similar to other acacia species such as in *Acacia tortilis* (46.92%), and *Acacia origina* (45.54%) (Nasser and Aref, 2014). However, the results lower than the amount reported for *A.mangium* (48.42%) (Amini*et al*., 2006) and *E.globulus* (50%), *E. urograndis* (48.6%) (Evtuguin and Neto, 2007).

Cellulose content directly affects the physical and mechanical properties of a paper sheet (Ghalehno and Nazerian, 2013). Furthermore, high cellulose content gives a high pulp yield reported by Khoo and Peh (1982). According to Abdul-Khalil *et al*. (2006), cellulose content close to or above 40% were satisfactory for pulp and paper production. Therefore, *A. melanoxylon* having 45% cellulose content is suitable to use as a raw material for pulp and paper production.

Klason Lignin Content

Hardness, bleach ability, and other pulp properties, such as color, are associated with the lignin content (Malik *et al*., 2004). Softwoods contain around 25-33% lignin and in hardwoods it can vary between 18- 25% (Bowyer *et al*., 2007).

Klason lignin content of *A. melanoxylon* wood increased from the bottom to top of the tree portion. Duncan multiple range tests showed that Klason lignin of both bottom and middle of tree portions significantly varies from the top portion at $p<0.05$ (Table 3).

The mean of Klason lignin in *A. melanoxylon* obtained in this study (23.79%) was higher than the report of Santos *et al*. (2012) (21.10%) and Lourenco *et al*. (2008), (18.6%) on the same species. The difference in Klason lignin may be due to age and growth environment variation since they affect wood chemical properties (Smook, 1992).However, the result obtained was similar to other *Acacia* species which was studied by Marsoem and Irawati, 2016).They found in the range of 21.6-24.3% and 21.6-24.6% for A. *mangium* and *A. auriculiformis* respectively.

Pulpwood requires a low lignin content since lignin content has been negatively correlated with pulp yield and fiber strength (Amidon 1981; Dutt and Tyagi, 2011). Lignin also causes the paper to become fragile, and because of light oxidation, which results in the production of color bands, it gives the paper a dark or yellowish look (Ghalehno and Nazerian, 2013). According to Ververis *et al*. (2004), the raw material with Klason lignin less than 30% has accepted for pulp and paper production. Therefore, *A.melanoxylon* of the study site were suitable in terms of its Klason lignin for pulp and paper making.

Hemicellulose

According to Bakker and Elbersen (2005), low hemicellulose content in raw material decreases water absorbing capacity and thus minimizing the duration of pulping activity. Duncan multiple range tests showed that the bottom and top portions significantly varied in hemicellulose content, however, the bottom and top portions had no significant variation with the middle portion at $p<0.05$ (Table 3). The mean hemicellulose content obtained in this study (21.93%) was similar with *Acacia tortilis* (21.10%) and *Acacia etbaica* (21.37%) (Nasser and Aref, 2014). However, it is lower than in *A. mangium* (35.5%) (Amini*et al*.,2006).The difference in hemicellulose content may be due to species, age, and growth environment difference of sample trees since it affects chemical compositions of wood (Smook, 1992).

Extractive Content

Extractives of a raw material are undesirable parts since they can have a negative impact on the pulping and bleaching operations. For example, low extractives content was related to higher pulp yields (Lourenço*et al*., 2008). According to Ates*et al*. (2008) high extractive content is an indicator of low pulp yield as well as higher chemical consumptions both in pulpingandbleaching.

Hot -Water Soluble Extractives

The result showed that hot-water extractives of *A.melanoxylon* were higher at the bottom portion (5.68%) and minimum at the top portion (Table 3). However, hot-water extractives were not significantly affected by tree portions at $p<0.05$. The result was similar to tropical pulpwood species: *Gmelina arborea* (5.20%), *Leucaena leucocephala (*5.60%) (Onuorah *et al*., 2015). Thefore, it is suitable for pulp and paper making.

Alcohol benzene soluble Extractives

Based on Table 3, alcohol-benzene extractives were higher at the bottom (4.06%) than the middle and a top portion. Duncan multiple range tests showed that alcohol-benzene extractive content varied significantly between the bottom and top portions (Table 3).

The overall mean obtained in alcohol-benzene extractive (3.24%) was similar to the previous report of Lourenço *et al*. (2008) (3.96%) however, lower than the report of Santos *et al*.

(2012) (6.51%) in *A.melanoxylon.* The differences could be due to differences in methods in which the former studies used alcohol-toluene solution instead of alcohol-benzene solution. The result was higher than *A.mangium* (1.77%) (Amini *et al*., 2006) (Table4).

Ash Content

According to Table 3, the high ash content was observed in the bottom portion (0.56%) while, the lowest value in the top portion (0.37%) of *A.melanoxylon* wood. Ash content variation was not significant between the bottom and middle portion, although the bottom and the middle portions showed a significant variation to top portions at $p<0.05$ (Table 3). The overall mean percentage of ash content obtained in this study (0.48%) is similar to the previous report of Santos *et al*. (2012) (0.43%) on *A.melanoxylon*, however, lower than *Acacia tortilis* (1.94%), *Acacia origina* (1.99%) (Nasser and Aref, 2014) and *E.globulus* (1.0%) (Miranda *et al*., 2012) (Table4). The difference may be due to species, age, and growth environment difference of sample trees since it affects chemical properties of the wood (Smook, 1992).

The result showed that the portion of wood with higher density contributed to the increase in the percentage of ash content because of the transformation of sapwood into heartwood from bottom to top portion of the tree. Panshin and Zeeuw (1980) reported that bottom portion has more heartwood and higher density, consequently higher ash content compared with a top portion of the tree.

Table 4: Comparison of the chemical composition of *Acacia melanoxylon* wood with other paper making raw materials.

	Chemical composition (%)					
Species	Cellulose	KL	Hem	AB	HW	Ash
A.melanoxylon(*)	45.02	23.79	21.93	3.24	5.52	0.48
E. globules (a)	56.90	17.80	n.a	1.40	n.a	1.0
A.mangium(b)	48.34	19.78	35.71	1.77	n.a	n.a
Beech wood(c)	45.80	21.90	n.a	n.a	n.a	0.4
Bagasse fiber(d)	42.34	21.70	n.a	1.85	7.42	2.10
Cotton stalk(e)	43.80	17.60	n.a	n.a	n.a	3.50
O.abyssinica(f)	52.06	22.47	16.90	5.60	6.80	5.30

(*) This study: (*): (a) (Miranda *et al*., 2012): (b) (Amini *et al*., 2006): (c) (Demirbas,1998): (d) (Agnihotri *et al*., 2010): (e) (Ververis *et al*., 2004): (f) (Tolessa*et al*., 2017)

Notes: *KL: Klason lignin, AB: Alcohol-benzene solubility, Hem: Hemicellulose, HW: Hot-water, n .a. not available*

According to Ogunsile *et al*. (2009), high ash content is undesirable for pulping as they affect normal alkali consumption and create problems at waste liquor recovery. The average ash content percentage of *A.melanoxylon* obtained in this study (0.48%) was lower than other tropical pulpwood species; *E.globulus* (1.0%), *Gmelina arborea* (0.84%), *Leucaena leucocephala* (2.50%) (Onuorah*et al*., 2015) which showed better property for pulp and paper production.

Conclusions and Recommendations

The basic information on the chemical composition of *Acacia melanoxylon* as a source of fibrous raw material for pulp and paper production was examined. All chemical composition significantly varied between the bottom and a top portion except, hot-water extractives. Compared to the wood properties related to pulp and paper quality with those of Eucalyptus and other Acacia species currently used for commercial pulpwood, *A.melanoxylon* showed better chemical compositions related to pulp and paper. Generally, the result of the study shows that *A. melanoxylon*is found to be suitable raw material for pulp and paper industry.

Recommendations

Based on the findings of the study, the following points were recommended:

- Since *A. melanoxylon* grown in Chencha woreda is suitable in terms of its chemical composition for pulp and paper making, attention should be given by tree growers, investors, government, and non-governmental organizations on its plantation expansion.
- In addition to the results obtained in this study, production and testing of its pulp and paper is also needed.
- Research institutes, government, and non-governmental organizations should give special attention on evaluation of different raw materials for pulp and paper production.

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