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RESEARCH ARTICLE

Mineral Concentration and ash content of bamboo (*Bambusa vulgaris* Schrader ex Wendland *var. vulgaris*) culm growth stages in three ecological zones in Ghana

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Abstract: This work examines how ash and the mineral elements in four bamboo culm growth stages (shoot, juvenile, mature and dead) can affect fuel conversion technology plants through slagging, fouling, and corrosion. 48 samples consisting of the shoot; juvenile; mature and dead culms were tested for ash content and ash mineral elements. The mean values of ash contents of the bamboo culm growth stages across the three ecological zones were from 0.93% to 2.11%. The contents were within the threshold approved in the EN standards EN 14775 ≥3%. The mean values of carbon across the culm growth stages ranged from 48.46% to 53.31%. Hydrogen among the bamboo culms ranged from 5.60 to 7.04%. Higher carbon and hydrogen contents lead to higher heating values. Nitrogen among the culm growth stages ranged from 0.31 to 0.79%. The concentration levels of N in the culms were within the threshold prescribed in the EN standards EN 15104 ≥ 1%. The mean Cu concentration of mature culms ranged from 0.89-1.31 ppm; Zn ranged from 2.74-3.25 ppm; As varies from 0.055 to 0.078 ppm; Ni ranges from 0.43-0.85 ppm and Cd in the mature bamboo culm ranged from 0.81 to 3.66 ppm. Amount the minor ash elementals calcium in the mature culm ranged from 16.70 to 26.49 ppm; potassium (K) from 0.42-2.45 ppm and Mg from Ca and Mg contents increases the melting point of ash K content lowers the melting point of ash which can cause slagging. The concentrations of minor and heavy metals were below the standard set by EN 1496 1-2 and therefore may not cause problems to human health or slagging to combustion plants for the production of biofuels.

Keywords: Bambusa vulgaris, biofuel, combustion, slagging, fouling, corrosion, mineral

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Introduction

A shift from fossil fuel-based energies to dependence on renewable energy has been a topic of discussion by many policymakers (Demirbas & Arin, 2002; Prins, 2005). The frequent use of fossil fuels results in global warming and its associated climatic changes over the earth's surface (Koutsoyiannis *et al*., 2009). The effects of these climatic changes are flooding (World Bank, 2009), droughts, famines, water shortages, extreme heat (Riché *et al*, 2009: Koutsoyiannis *et al*., 2009), and desertification (World Bank, 2009). Research has shown that bamboo is one of the best biomass options to replace fossil fuels for the production of heat, transportation fuel, and biopower (Preto, 2010). Bamboo provides a very wide variety of energy needs, including generating electricity (Launder, 2002; Ranjan, 2005; Kigomo 2007, Miertus & Zinaview, 2008; Demirbas, 2010; Preto, 2010); fueling vehicles (Kigomo 2007, Miertus & Zinaview, 2008; Bain, 2010), heating homes (Preto, 2010) and providing process heat for industrial facilities (Preto, 2010). Bamboo branches, shoots, and roots can also be used to produce higher quality charcoal by pyrolysis (carbonizing) in a high-performance clay furnace oven heated to about 1000ºC (Kittinaovarat & Suthamnoi, 2009). Bamboo has desirable fuel characteristics than certain other bioenergy feedstocks, such as it has a low ash content and alkali index. Its heating value is lower than many woody biomass feedstocks but higher than most agricultural residues, grasses, and straws (Scurlock, 2000). Bamboo is a fast-growing, renewable, common, low cost and environmentally friendly resource (Xuhe, 2003). It absorbs four times as much carbon dioxide from the environment as trees do (McCoy, 2009) and also mitigates greenhouse gas emissions, reduction of acid rain, and soil improvement (Preto 2010). The quality of the bamboo ash elements can lower the net energy output considerably, both limiting the effectiveness of the conversion plants (Jenkins *et al.*, 1998) and lowering the heating value (Monti *et al.,* 2006). This work examines ash and the mineral elements in four culm growth stages of *Bambusa vulgaris*; shoot, juvenile, mature and dead, and how they can affect fuel conversion technology plants through slagging, fouling, and corrosion. The results of the work imply selecting the best conversion plant for optimum energy production. *Bambusa vulgaris* was used for this work because it remains the most abundant and widely distributed bamboo in Ghana.

Materials and Methods

Study site

The samples of the bamboo were collected in their natural forests from three ecological zones in Ghana. These areas are; dry semi-deciduous zone (DSD) near Techiman in Bono east region, moist semi-deciduous (MSD) at Owabi forest reserve near Kumasi in Ashanti region, and moist evergreen deciduous (MED) at *Bonsa River* Forest Reserve in the Western region. The mean annual rainfall of these sites ranges from 1300 – 1400 mm; 1400 – 1750 mm and 1700 – 2800 mm respectively (Obiri and Oteng-Amoako, 2007).

Extraction of samples

Defects free (IAEA, 2005) three (3) shoots, three (3) juvenile, five (5) mature culms, and five (5) dead culms were extracted from each zone. Each part was split into blocks of 25-35 cm. 36 samples were wrapped in airtight plastic bags for fuel assessments at the laboratory.

Preparation of samples

The samples of the bamboo were ground to a fine particle size smaller than 20 meshes (-0.8mm) by using a Wiley Knife mill (Scurlock *et al*., 2000; Templeton *et al*, 2009). The milled samples were mixed toughly to obtain uniform samples (Scurlock *et al*., 2000). The specimens were oven-dried at 103 ± 2°C and weighed again for chemical analysis (Templeton *et al*, 2009).

*1. **Determination carbon***

Carbon in the bamboo was determined by using Walkley – black wet oxidation method (Nelson & Sommers, 1982). The % C was calculated as;

$$\%C = \frac{N\ x\ (Vbl—Vs)\ x\ 0.003\ x\ 1.33\ x\ 100}{g} \quad \text{…eq.(1)}$$

Where, N = Normality of ferrous sulfate = 0.5 N; Vbl = titre value of blank solution; Vs = titre value of sample solution; g = mass of sample taken 0.003 = milli equivalent weight of C in grams (12/4000); 1.33 = correction factor used to convert the wet combustion C value to true C value since the wet combustion method is about 75% efficient in estimating C value (100/75).

*2. **Determination hydrogen***

The hydrogen content was determined using the exchangeable acidity titrimetric method (Mclean, 1965). The following calculation was used;

$$V^* = \frac{V^*0.05^*100}{W} \quad \text{….eq. (2)}$$

Where; V = Titre volume of NaOH used (ml); Normality of NaOH = 0.05 *N* and W = weight of sample used (1.0 g).

*3. **Determination nitrogen***

The Kjeldahl method was used to determine nitrogen in chemical substances (Motsara and Roy, 2008). The weight of N was calculated as; 14g of N contained in one milli-equivalent weight of NH_3.Therefore, the weight of N in the sample;

$$\frac{14 \text{ x } (A/B) \text{ x concentration of Acid}}{1000} \quad \text{......eq. (3)}$$

Where, A = volume of standard HCl used in the sample titration B = volume of standard HCl used in the blank titration

The percentage of Nitrogen in the sample is calculated as;

$$\frac{14 \text{ x } (A - B) \text{ x concentration of Acid}}{1000} \text{ X } 100 \quad \text{eq. (4)}$$

4. ***Determination of ash content, minerals, heavy metals and minor metals***

The ash content of the bamboo samples was determined and calculated based on ASTM D 1102–84 (AOAC, 2000). 2 grams of bamboo powder of each bamboo-part were weighed into an already weighed crucible. The samples were weighed in triplicate into the crucibles and placed into the muffle furnace. Dry the sample in a furnace for 2 hours at a temperature between 400°C to 550˚C. The samples were left in the furnace until they burn completely to ashes. Dry Ash digestion and analysis of plant tissues were used to determine P, Ca, Mg, K, Na, Zn, Cu, Mn, and Fe in ash. The cations (As, Cd, Cu, Fe, Mn, Ni, Pb, and Zn) were determined by an atomic absorption spectrometer (AAS) (Hitachi Z-8100, Japan). The samples were washed in a muffle furnace for 2 hours at a temperature of 550˚C (ISO 1171-1981; AOAC, 2000). The tests were duplicated for each species. The calculations are as follows;

$$\% \text{ Ash content} = \frac{(\text{Weight of ash and crucible} - \text{weight of crucible}) \text{ g x } 100}{(\text{Weight of final sample and crucible-weight of crucible})} \quad \text{...........eq. (5)}$$

Results

Percentage (%) of carbon concentration of the Bambusa v. vulgaris

The samples from each age group increased from dry semi-deciduous to a moist evergreen deciduous zone. The mean values of the shoot varied from 48.46% (DSD) to 49.74% (MED), the juvenile culms 50.24% (DSD) to 53.31% (MED), the mature culms from 48.58% to 52.84%, and the dead culms from 52.14% to 53.01% (Table 1).

One-way ANOVA test for the mean carbon content of *Bambusa vulgaris* at three ecological zones only the mature (F = 5.993, p = 0.037) and the dead (F = 9.253, p = 0.015) culms were statistically significant.

Percentage (%) hydrogen of concentration in Bambusa vulgaris

The mean percentage of Hydrogen among the bamboo culms ranged from 5.60 to 7.04. The values of the shoot increased from 6.27%, 6.39%, and 7.04% from dry semi-deciduous, moist semi-deciduous, and moist ever-green respectively. Unlike the shoot, the juvenile decreased from dry semi-deciduous (DSD) 6.17%, moist semi-deciduous (MSD) 6.15%, and moist evergreen

Table 1. Variation of carbon content (mean ±SD) with bamboo growth stage and ecological zone

Items	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	48.46±2.42	49.67±0.19	49.74±0.22	0.574	0.591
Juvenile	50.10±1.44	52.24±0.17	53.31±2.78	1.566	0.284
Mature	48.58±1.26	50.84±1.81	52.82±0.10	5.993	0.037a
Dead	52.14±1.64	52.75±1.93	53.01±0.54	9.253	0.015b

‘a’ and ‘b’ show statistically significant values

Table 2. Variation of hydrogen content (mean ±SD) with bamboo growth stage and ecological zone

Item	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	6.27±0.227	6.39±0.089	7.04±0.158	15.571	0.004a
Juvenile	6.17±0.102	6.15±0.145	6.13±0.273	0.020	0.980
Mature	6.34±0.34	6.56±0.359	6.52±0.262	0.299	0.752
Dead	5.60 ± 0.51	6.20±0.513	6.22±0.024	2.028	0.212

‘a’ shows statistically significant value

(MED) 6.13%. The matured samples ranged from 6.34%, dry semi-deciduous to 6.56% moist semi-deciduous. The dead culms ranged from 5.70% for dry semi-deciduous to 6.22% at moist evergreen (Table 2). Only the shoot was statistically significant (F = 15.571, p = 0.05) according to the One-way ANOVA test.

Percentage (%) nitrogen of concentration in Bambusa vulgaris

The mean concentration of Nitrogen among the culm growth stages ranged from 0.31 to 0.79%. The shoot from the dry semi-deciduous zone recorded the highest nitrogen content. Generally, it can be observed that nitrogen content decreases with bamboo age (Table 3). The mean values of the shoot ranged from 0.65% (MED) to 2.52% (DSD), juvenile from 0.606% (MSD) to 0.79% (DSD), mature from 0.580% (MED) to 0.610% and dead culms from 0.320% (DSD) to 0.58%.

There were significant effects of amount of nitrogen on shoots (F = 17.577, p = .05) and the dead culm (F = 9.056, p =.05) of the bamboo.

The mean percentage weight of oxygen by calculation

The mean percentage value of oxygen and standard deviation of the shoot was 40.20 ± 2.45, the juvenile was 39.73 ± 1.79, mature was 41.04 ± 2.43 and dead culm was 41.35 ± 4.05.

The Percentage (%) of ash content of the Bambusa vulgaris samples

The shoot exhibited values ranging from 1.51% (MED) to 1.72% (MSD). The average weight of ash in the juvenile samples was from 1.71% (moist evergreen) to 2.01% (MED). The mature samples ranged from 0.93% (MED) to 1.83% (DSD). The values of the dead bamboo sample had the lowest average (Table 4). The least value was recorded at MSD (1.54%) and the highest average ash content 2.11% of located at the moist evergreen zone. Significant differences were found for the shoot (F = 7.892, p = 0.021) and the mature (F = 2.318, p = 0.002) sampled from the three zones in respect of ash content.

Table 4. Variation of ash content (mean ±SD) with bamboo growth stage and ecological zone

Item	Ecological zone			ANOVA	
	DSD	MSD	MED	*F-value*	*p-value*
Shoot	1.59 ± 0.50	1.72 ± 0.12	1.51 ± 0.06	7.892	0.021a
Juvenile	1.79 ± 0.01	2.01 ± 0.18	1.71 ± 0.11	2.073	0.207
Mature	1.83 ± 0.64	1.52 ± 0.64	0.93 ± 0.15	2.318	0.002b
Dead	1.98 ± 0.27	1.54 ± 0.54	2.11 ± 0.06	2.177	0.195

‘a’ and ‘b’ show statistically significant values

Heavy minerals concentration in Bambusa vulgaris

The values of heavy metals in the bamboo are presented in Table 5. The mean concentration of *Cu* in the bamboo ranged from 0.89 (mature culm) to 3.16 *ppm* (shoot).

The mean Cu concentration of mature and dead culms were 1.06 ±0.24 ppm and 2.35 ±0.03 ppm respectively. The Zn concentration in mature and dead culms were 2.78 ±0.11 ppm 3.58 ±0.58 ppm respectively. The lowest mean value of Zn recorded in the matured culm was 2.78 ±0.11 ppm. The mean Arsenic (As) content of the bamboo culms 0.078 ppm. The mean values for lead (Pb) in the culms at different ages ranged from 0.03-0.05 ppm. Ni ranges from 0.50-0.68 ppm. The lowest Ni was recorded in the shoot and the highest value of 0.68ppm was obtained in the juvenile and mature culms. The mean values of Cadmium (Cd) in the mature and dead bamboo culms were 2.25±0.43 ppm and 2.88±0.47 ppm respectively.

Minor minerals concentration in Bambusa vulgaris

The mean calcium (Ca) concentration in the ash content was the highest among the minerals in all three zones. The mean calcium in the culm growth stages ranged from 22.93 to 25.00 ppm. The mean values of potassium (K) varied from 0.99-1.62 ppm. The mean values of magnesium (Mg) in culm growth stages ranged from 0.09-0.15 ppm and those of phosphorus (P) were ranged from 0.05-0.12 ppm. The mean values for sodium ranged from 0.32-1.19 ppm. The mean values for aluminium (Al) culms were from 0.09-0.10ppm and those of iron (Fe) were 0.03-0.16 ppm.

The relationships between ash content, minor and heavy metals of Bambusa vulgaris culms

Table 7 shows the relationships between ash contents and ash elementals of *Bambusa vulgaris* culms. There was a negative correlation between carbon content and the *ash* content r = -.371 p > 0.05. Potassium (K) has a significant effect on the ash content. Pearson's r

Table 5. Variation of minerals (mean) in bamboo growth stage across ecological zones

Growth stage	*Cu*	*Zn*	*Pb*	*As*	*Ni*	*Cd*
Shoot	3.83±0.97	3.49±1.19	0.05±0.09	.07±0.001	0.50±0.21	. 92±0.59
Juvenile	4.62±0.25	4.01±1.02	0.04±0.01	0.07±0.02	0.68±0.18	2.09±0.65
Mature	1.06±0.24	2.78±0.11	0.03±0.04	0.07±0.01	0.68±0.20	2.25±0.43
Dead	2.35±0.03	3.58±0.58	0.03-0.02	0.08±0.03	0.62±0.15	2.88±0.47

Table 6. Variation of minor minerals (mean) in bamboo growth stage across ecological zones

Growth stage	*Ca*	*K*	*Mg*	*P*	*Na*	*Al*	*Fe*
Shoot	25.00±1.49	1.62±0.09	0.15±0.06	0.12±0.05	0.64±0.04	0.10±0.03	0.16±0.02
Juvenile	23.38±1.08	0.99±0.26	0.09±0.01	0.06±0.03	1.19±0.16	0.10±0.02	0.06±0.01
Mature	22.93±1.71	1.37±0.46	0.10±0.04	0.05 ±0.02	0.44±0.03	0.09±0.01	0.12±0.01
Dead	23.31±0.71	1.10±0.18	0.09±0.01	0.05±0.03	0.32±0.02	0.09±0.02	0.03±0.01

is 0.819 and p< 0.01. The ash content relates strongly positive to P ($r = .50, p < 0.01$) while Na ($r = -.58, p < 0.05$). The ash content moderately associates indirectly with Ni ($r = -.66, p < 0.05$). There was a strong positive correlation between calcium and ash variables ($r = .75, p < 0.01$). Copper relates positively with Zn ($r = 0.875$ where $p = 0.01$). Ni relates negatively to Ca ($r = -.730, p < 0.01$) and relates positively with P ($r = .728, p = 0.01$). Al associates with Cu ($r = 662, p = 0.05$) and Pb ($r = 0.641$ $p = 0.05$).

Discussion

Percentage of ultimate contents in Bambusa vulgaris culm growth stages

The mean values of carbon across the culm growth stages ranged from 48.46% to 53.31%. The results obtained were within the range (48.5% to 50%) found by Nemestothy, 2002; Choy *et al*., 2005; and 45% to 55% (Ganesh, 2003; Scurlock, 1999). There was a negative correlation between carbon content and the *ash* content $r = -.371$ $p > 0.05$. Higher carbon

Table 7. The relationship between fuel properties in the *Bambusa vulgaris'* culms

Culms/ Stems																
	Ash	**C**	**H**	**N**	**CU**	**Zn**	**Pb**	**As**	**Ni**	**Cd**	**Co**	**K**	**Mg**	**P**	**Na**	**Al**
C	-3.71*															
H	.103	.179														
N	.016	-.029	.045													
Cu	-.03	.232	.128	-.035												
Zn	0.875	.233	-.106	-.282	0.88**											
Pb	0.27	.317	.580*	-.113	.657**	.56										
As	0.05	-.408	-.243	-.094	.23	.19	-.14									
Ni	-.66*	.397	.153	.-.281	-.02	-.04	.28	-.13								
Cd	.10	-.142	-.650*	-.328	-.42	-.26	-.66**	.10	-.13							
Ca	0.75**	-.635	-.128	.285	-.473	-.512	-.598*	.143	-.730**	.189						
K	.819**	-.484	.135	-.261	-.231	-.304	-.422	.206	-..097	.034	.25					
Mg	.02	-.104	.318	.494	-.127	-.372	-.042	-.280	-.397	.115	.35	-.196				
P	0.80**	-.106	.102	.407	.252	.246	-.077	.072	.728**	.333	.42	.23	.21			
Na	0.58	-.375	.405	.332	-2.38	-.042	-.024	.048	-.493	-.510	.56	.32	.30	.59		
Al	-.51	.024	.446	-.382	.662*	.513	.641*	.391	.296	-.423	.51	.19	-.27	-.21	.09	
Fe	0.26	-.148	.575	.598*	.244	.051	.371	-.070	-.509	-.621*	.27	-.14	.52	.75	.66	.08

content leads to a higher heating value (Clarke & Preto, 2011). Carbon is one of the main components of biomass which increases the heating value therefore high carbon content is needed in biofuels.

The mean percentage of Hydrogen among the bamboo culms ranged from 5.60 to 7.04%. The values obtained were similar to those reported in the literature of bamboo culms by Ganesh, 2003 (4.8 to 6.7%) and Choy *et al*., 2005 (6 to 6.5%). Higher hydrogen content leads to a higher heating value (Clarke & Preto, 2011). Hydrogen is a reducing gas and the cracking of biomass and can reduce the oxygen content in bio -oil (Zhou *et al.,* 2013). This points out that higher hydrogen content is desired in bamboos to increase the heating value. The mean concentration of Nitrogen among the culm growth stages ranged from 0.31 to 0.79%. The values for nitrogen were similar to the earlier studies from Ganesh, 2003 (0.4 to 1.3%) and Scurlock, 1999 (0.21 to 0.59%). The concentration levels of *N* in the culms were within the threshold prescribed in the EN standards EN 15104 $\geq$ 1%. Wood and fuel oil combustion have similar levels of Nitrous oxides emissions (Maker, 2004)

Percentage of Ash content in Bambusa vulgaris culm growth stages

The mean values of ash contents of the bamboo culm growth stages across the three ecological zones were within 0.93% to 2.11%. The mean values were similar to the values recorded by Scurlock (2000). The values were below the values investigated by (Benson & Laumb, 2010) on switchgrass (dry basis) which ranged from 4.4 wt % to 9.2 wt %.

The values of the ash content were within the threshold prescribed in the EN standards EN 14775 $\geq$3%. The relationship shows that the higher the percentage of carbon contents in the fuel the lower the ash content.

The concentration of minor and heavy metals in the Bambusa vulgaris culm growth stages

The mean *Cu* concentration of mature culms ranged from 0.89-1.31 *ppm* and dead culms ranged from 1.87-2.65 *ppm.* The *Zn* concentration in mature culms ranged from 2.74-3.25 *ppm* and dead culms varied from 3.44-3.71 *ppm.* The lowest mean value of *Zn* has recorded in the matured culm 2.36 *ppm*, moist semi-deciduous. The mean Arsenic (*As*) content of bamboo culms varies from 0.055 to 0.078 *ppm*. The mean values for lead (*Pb*) in the culms at different ages ranged from 0.010-0.103 *ppm*. *Ni* ranges from (0.43-0.85 *ppm*). The lowest and the highest *Ni* content was recorded in the dead culm. The mean values of Cadmium (*Cd*) in the mature bamboo culm ages ranged from 0.81 to 3.66 *ppm* and dead culm 2.15-4.21 *ppm*. The values obtained from the bamboo culms were lower than that of Campbell (1990) but similar to wood ash reported by Kopecky *et al.* (2008).

The main calcium (*Ca*) concentration in the ash content was the highest among the minerals in all three zones. The mean calcium in the mature culm ranged from 16.70 to 26.49 *ppm* and the dead culm ranged from 17.48-26.43 *ppm*. The mean values of potassium (*K*) found in the mature bamboo varied from 0.42-2.45 *ppm* and dead bamboo from 0.12-2.57 *ppm*. The mean values of magnesium (*Mg*) in mature culm ranged from 0.05-0.15 *ppm* and the dead culm varied from 0.07-0.12 *ppm*. Phosphorus (*P*) in mature and dead culms ranged from 0.04-0.06 *ppm* and 0.03-0.06 *ppm* respectively. The mean scores for sodium in mature culms ranged from 0.13-1.06 ppm and dead culms ranged from 0.12-0.72 ppm. The mean values for aluminium (Al) in mature culms were from 0.09-0.11ppm and the dead culms ranged from 0.09-0.11 *ppm*. The iron (*Fe*) in the bamboo exhibited the following mean values in the mature and dead culms 0.03-0.07 *ppm* and 0.03*ppm* respectively. The samples were similar to that of wood ash investigated by Kopecky *et al.* (2008). The concentrations of minor and heavy metals were below the standard set by EN 1496 1-2 and therefore may not cause problems to human health. Accumulation of *Ni* and *Cd* increased with age. *Ca* and *Mg* contents increase the melting point of ash (Kopecky *et al,* 2008). *K* content lowers the melting point of ash which can cause slagging. The elements in ash are considered necessary to decide which conversion plant should be used for a type of biofuel. The ash elementals produced during combustion may cause the conversion plant not to work effectively by causing slagging, fouling, and corrosion. Slagging is connected to the low melting point of deposits, which creates a glassy layer that must be removed. Fouling is the accumulation of unwanted materials on the surfaces of processing equipment leading to a decrease in the exchanger efficiency. Corrosion is caused by the interaction is 0.819 and p< 0.01. The ash content relates strongly positive to P ($r = .50$, $p < 0.01$) while Na ($r = -.58$, $p < 0.05$). The ash content moderately associates indirectly with Ni ($r = -.66$, $p < 0.05$). There was a strong positive correlation between calcium and ash variables ($r = .75$, $p < 0.01$). Copper relates positively with Zn ($r = 0.875$ where $p = 0.01$). Ni relates negatively to Ca ($r = -.730$, $p < 0.01$) and relates positively with P ($r = .728$, $p = 0.01$). Al associates with Cu ($r = 662$, $p = 0.05$) and Pb ($r = 0.641$ $p = 0.05$).

Discussions

Percentage of ultimate contents in Bambusa vulgaris culm growth stages

The mean values of carbon across the culm growth stages ranged from 48.46% to 53.31%. The results obtained were within the range (48.5% to 50%) found by Nemestothy, 2002; Choy *et al*., 2005; and 45% to 55% (Ganesh, 2003; Scurlock, 1999). There was a negative correlation between carbon content and the *ash* content $r = -.371$ $p > 0.05$. Higher carbon content leads to a higher heating value (Clarke & Preto, 2011). Carbon is one of the main components of biomass which increases the heating value therefore high carbon content is needed in biofuels.

The mean percentage of Hydrogen among the bamboo culms ranged from 5.60 to 7.04%. The values obtained were similar to those reported in the literature of bamboo culms by Ganesh, 2003 (4.8 to 6.7%) and Choy *et al*., 2005 (6 to 6.5%). Higher hydrogen content leads to a higher heating value (Clarke & Preto, 2011). Hydrogen is a reducing gas and the cracking of biomass and can reduce the oxygen content in bio -oil (Zhou *et al.,* 2013). This points out that higher hydrogen content is desired in bamboos to increase the heating value. The mean concentration of Nitrogen among the culm growth stages ranged from 0.31 to 0.79%. The values for nitrogen were similar to the earlier studies from Ganesh, 2003 (0.4 to 1.3%) and Scurlock, 1999 (0.21 to 0.59%). The concentration levels of *N* in the culms were within the threshold prescribed in the EN standards EN 15104 $\geq$ 1%. Wood and fuel oil combustion have similar levels of Nitrous oxides emissions (Maker, 2004)

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The values of the ash content were within the threshold prescribed in the EN standards EN 14775 $\geq$3%. The relationship shows that the higher the percentage of carbon contents in the fuel the lower the ash content.

The concentration of minor and heavy metals in the Bambusa vulgaris culm growth stages

The mean *Cu* concentration of mature culms ranged from 0.89-1.31 *ppm* and dead culms ranged from 1.87-2.65 *ppm.* The *Zn* concentration in mature culms ranged from 2.74-3.25 *ppm* and dead culms varied from 3.44-3.71 *ppm.* The lowest mean value of *Zn* has recorded in the matured culm 2.36 *ppm*, moist semi-deciduous. The mean Arsenic (*As*) content of bamboo culms varies from 0.055 to 0.078 *ppm*. The mean values for lead (*Pb*) in the culms at different ages ranged from 0.010-0.103 *ppm*. *Ni* ranges from (0.43-0.85 *ppm*). The lowest and the highest *Ni* content was recorded in the dead culm. The mean values of Cadmium (*Cd*) in the mature bamboo culm ages ranged from 0.81 to 3.66 *ppm* and dead culm 2.15-4.21 *ppm*. The values obtained from the bamboo culms were lower than that of Campbell (1990) but similar to wood ash reported by Kopecky *et al.* (2008).

The main calcium (*Ca*) concentration in the ash content was the highest among the minerals in all three zones. The mean calcium in the mature culm ranged from 16.70 to 26.49 *ppm* and the dead culm ranged from 17.48-26.43 *ppm*. The mean values of potassium (*K*) found in the mature bamboo varied from 0.42-2.45 *ppm* and dead bamboo from 0.12-2.57 *ppm*. The mean values of magnesium (*Mg*) in mature culm ranged from 0.05-0.15 *ppm* and the dead culm varied from 0.07-0.12 *ppm*. Phosphorus (*P*) in mature and dead culms ranged from 0.04-0.06 *ppm* and 0.03-0.06 *ppm* respectively. The mean scores for sodium in mature culms ranged from 0.13-1.06 ppm and dead culms ranged from 0.12-0.72 ppm. The mean values for aluminium (Al) in mature culms were from 0.09-0.11ppm and the dead culms ranged between deposits and the metal surface of the exchanger, which involves extra costs in maintenance (Monti *et al.*, 2008). The lower concentration of the ash content and the elementals will increase the plant life span (Reumerman & Berg, 2002).

Conclusion

The ash content and the mineral elements of *Bambusa vulgaris* were comparable to some wood types. These inorganic materials cannot cause any serious slagging, fouling, and corrosion to the conversion plant during combustion, according to the guiding values for ashes related to the solid biofuels ISO 1171 (1997). This implies that *Bambusa vulgaris* bamboo is a good feedstock for the production of bioenergy in terms of heat, charcoal, biogas, biopower, and transportation fuel.

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References

AOAC 2000. *Official Methods of Analysis.* 17th *ed.* Gaithersburg, Maryland, USA, AOAC International. Also valid are: a second evasion of this edition (2003); the 16th edition (1995) and the 15th edition (1990). This last was published in Arlington, Virginia, USA, by AOAC International.

Bain, R. L. 2010. Hydrogen Production from Biomass. *NREL US Department of Energy*

Benson, S. and Laumb M. 2010. Analysis Report: Chemical and Heat Value Characterization of Perennial Herbaceous Biomass Mixtures. Mirobeam Technologies Inc. www.microbeam.com

Choy, K. K.H., Barford, J. P., McKay, G. 2005. Production of activated carbon from bamboo scaffolding waste process design, evaluation and sensitivity analysis. *Chemical Engineering Journal* 109: 147–165. https://doi.org/10.1016/j.cej.2005.02.030

Clarke, S. and Preto, F. 2011. OMAFRA, Kemptville, and Fernando Preto, Bioenergy Systems, Canmet ENERGY. ORDER NO. 11-035 AGDEX 737/120

Demibas, A. and Arin, G. 2002. An overview of biomass pyrolysis. Energy Source Part A 24, 471–482. https://doi.org/10.1080/00908310252889979

Demirbas, A. 2010. Fuels from Biomass *Biorefineries*, *Springer*

Ganesh, A. 2003. Bamboo Characterization for Thermo-chemical Conversion And Feasibility Study of Bamboo Based Gasification And Charcoal Making. Energy Systems Engineering of Indian Institute of Technology, Mumbai

Jenkins, B.M., Baxter, L.L., Miles Jr., T.R. 1998. Combustion properties of biomass. Furl Processing Technology; 54: 17-46. https://doi.org/10.1016/S0378-3820(97) 00059-3.

Kigomo, B. N. 2007. Guidelines for Growing Bamboo. KEFRI Guideline Series: No. 4. Kenya Forestry Research Institute; Nairobi, Kenya

Kittinaovarat, S. and Suthamnoi, W. 2009. Physical Properties of Polyolefin / Bamboo Charcoal Composites. Journal of Metals, Materials and Minerals, Vol.19 No.1: 9-15

Kopecký, D., Lukaszewski, A. J., and Doležel, J. 2008. Cytogenetics of Festulolium (Festuca Lolium hybrids). Cytogenet. Genome Res. 120: 370–383. https://doi.org/10.1159/000121086

Koutsoyiannis, D., Makropoulos, C., Langousis A., Baki S., Efstratiadis, A., Christofides, A., Karavokiros, G. and Mamassis, N. 2009. 1HESS Opinions: "Climate, hydrology, energy, water: recognizing uncertainty and seeking sustainability" Hydrology and Earth System Science Discussions 13(2): 247-257.https:// doi.org/10.5194/hess-13-247-2009

Launder, K. 2002. Energy Crops and Their Potential Development in Michigan. A Report of the Michigan Biomass Energy Program

Maker, T. M. 2004. Wood-chip Heating Systems. Retrieved from http://www. biomasscenter. org/pdfs/Wood-Chi p-Heating -Guide. pdf

Mclean, E.O. 1965. Aluminium in Methods of Soil Analysis. America Science Agronomy, Madison, Wisconsin, 978-998.https://doi.org/10.2134/agronmonogr9.2.c16

McCoy, S. 2009. “The Magic (Bamboo) Bullet?” http://go-explore-trans.org/go/gonew/?/main/articles/ the-magic-bamboo-bullet

Miertus, S. and Zinaview, S. 2008. Introductory Survey of Biofuel Production Technologies. Special Session on Biomass and Biofuel, making renewable Energy Markets Work for Africa: Policies, Industries and Finance for Scaling up International Conference, Dakar, Senegal, 16-18 April 2008 International Centre for Science and High Technology United Nations Industrial Development Organisation ICS/UNIDO.

Monti, A., Di Virgilio, N. and Venturi, G. 2008. Mineral composition and ash content of six major Energy Crops.

Biomass and Bioenergy 32: 216-223 https://doi.org/10.1016/j.biombioe.2007.09.012

Motsara, M.R. and Roy, N.R. 2008. Guide to Laboratory Establishment for Plant Nutrient Analysis. 19th Edition, FAO, Rome, 42-88.

Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Page, A.L.; Miller, R.H. and Keeney, D., eds. Methods of soil analysis. Madison, America Society of Agronomy, 1982:539-594.. https://doi.org/10.2134/agronmonogr9.2.2ed.c29

Nemestothy, K.P., 2002. Wood Fuels: Characteristics, Standards, production technology. E.V.A - The Austrian Energy Agency.

Obiri, B.D. and Oteng-Amoako, A.A. 2007. Sustainable Development of the Bamboo Industry in Ghana. *Ghana Journal of Forestry, Vol. 21:* 22. http://hdl.handle.net/123456789/2186

Preto, F. 2010. Review of Biomass Conversion Technologies. CanmetENERGY, Natural Resources Canada *BIO-ENERGY: Solutions for Community Sustainability Prince George, 4.03.2010*

Prins, M.J. 2005. Thermodynamic analysis of biomass gasification and torrefaction. Eindhoven: *Technische Universiteit Eindhoven. Proefschrift. – ISBN 90-386-2886-2 NUR 913*

Ranjan, M.P. 2005. e-mail correspondence with Bamboo Plantation Groups.

Reumerman, P.J. and Van den Berg, D., 2002. Reduction of fouling, slagging and corrosion characteristics of miscanthus (the BIOMASS project) report. EC contract FAIR-98-3571

Riché, B., Hachileka, E., Awuor, C. B., Hammill, A., 2009. Climate-related vulnerability and adaptive-capacity in Ethiopia's Borana and Somali communities USAID, 2009. Humanitarian assistance to Ethiopia overview, Jan 2009[0]

Scurlock, J. 1999. Oak Ridge National Laboratory, Bio-energy Feedstock Development Programs, P.O. Box 2008, Oak Ridge, TN 37831-6407doi:10.2172/4538

Scurlock, J. M. O., Dayton, D. C. and Hames B. 2000. Bamboo, an overlooked biomass? *Report* by Oak Ridge National Laboratory, Oak Ridge, Tennessee (USA). Environmental Sciences Division Publication No. 4963,

Templeton, D. W., Scarlata, C. J., Sluiter, J., and Wolfrum Ed 2009. Biomass Compositional Analysis Method Variability *31st Symposium on Biotechnology for Fuels and Chemicals San Francisco, CA May 3-6, 2009* NREL/PO-510-45799

World Bank 2009. Ghana Economics of Adaptation to Climate Change. Consultation Draft. Sustainable Development Department, Africa Region. The World Bank

Xuhe, C., Promotion of bamboo for poverty alleviation and economic development, December 2003, Journal of Bamboo and Rattan 2(4): 345-350, doi:10.1163/156915903322700386

Zhou, X., Fu, Y., Zhou, L., Li, B., and Luo, Y. 2013. An imperative need for global change research in tropical forests. *Tree Physiology*, *33*(9), 903–912. https://doi.org/10.1093/treephys/tpt064