Original Research Article

Analysis of the Mineral Content of Wood Ashes of Selected Plants Traditionally Used for Soil Amendments in Eritrea

ABSTRACT

Wood ash contains all the components of wood in a concentrated form, except for carbon, hydrogen and nitrogen which evaporate during the burning of wood. The mineral concentration of the ashes from seven selected trees namely *Acacia seyal, Acacia etbaica, Acacia albida, Acacia tortilis, Leucaena leucocephala, Olea europea, Musa sapientum* found in Eritrea was studied. Most of the trees are commonly used for household fire in the rural and urban communities of Eritrea. The purpose of this study was to assess the levels of minerals and thus determine the application of the ashes of the selected trees for soil amendment. Moderately sized tree branches were ashed in a furnace at 600 ^{o}C for 6 hours and the resulting ash was homogenized, filtered and digested. Aqua-regia was used to digest the ash samples and ICP-OES was employed to analyse the levels of the elements. Based on the analysis, the digestion method was found to be effective in recovery of minerals from the wood ashes. The percentage of ashes produced from the trees, except *Musa sapientum*, ranged from 0.88 up to 4.66. The results of the study revealed that the ashes of the selected plants contained various concentrations of the minerals vital for soil enrichments. The major elements found in the wood ashes include Ca, K, Mg, P, S, Fe and Na. The level of the major elements in this report was consistent with previously published reports. Moreover, the concentration of heavy metals in the studied plant ashes was below the permissible limits and therefore the ashes can be employed as liming agents and sources of important nutrients in in soil enrichment. This is a very first report related to the levels of minerals in wood ashes in the country and thus can be used as reference for further detailed studies.

Key words: *Wood ash; digestion; mineral concentration; soil amendment.*

1. INTRODUCTION

In the past, ash from the combustion of wood was sent to landfills. The growing expenses associated with landfilling and the reluctance to open new waste landfill sites have brought about increasing interest in alternative methods of disposal. Among these is the use of wood ash for the purposes of soil amelioration and soil refill in agriculture, horticulture and forestry [1, 2]. The application of biomass ash to soil offers an alternative for its disposal and for nutrient recycling. Wood ash contains most of the minerals that a tree will take up during its lifetime. These comprise the three main categories including macronutrients, micronutrients and heavy metals [3, 4]. Wood ash was confirmed to be a good source of K, P, Mg, Ca and other micronutrients [5]. The application of wood ash to soil had a relatively long-term increasing effect on the pH, the concentrations of exchangeable base cations (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}), effective cation exchange capacity and base saturation in the humus layer of soil [6, 7]. The issues concerning wood ashes are still valid, because rural inhabitants continue to use firewood to a large extent [8]. Wood ash contains all the nutrients that were taken up by trees from soil, except nitrogen and sulfur that volatilize during the combustion process and the fertilizer components contained in them are easily absorbed by plants [8, 9].

When loose wood ash is dissolved in water, a highly alkaline solution (pH 11-13) is produced. Oxides, hydroxides, hydrogen carbonates and carbonates are responsible for the rapid change in the pH level [10,11]. Neutralization as well as fertilization effects of wood ash especially on forest soil can be significant and of long duration. When applied according to limestone needs, wood ash would be considered a valuable soil amendment, for the reason that it will not cause additional soil pollution. In addition to base cations, wood ash contains harmful heavy metals such as Cd, Hg and Pb, of which Cd is probably of most concern [10, 12].

The use of ashes from the combustion of biomass in agriculture is found to have a positive effect on the decrease in the amount of toxic exchangeable aluminum [9]. Similarly, in the investigation of the effects of wood ash fertilization on soil chemical properties, it was observed that wood ash significantly increased the effective cation exchange capacity and base saturation [5]. Returning biomass ash to agricultural land is beneficial to the fertilizing potential which is determined by the levels of major- and micronutrients, and the highly alkaline pH [9]. Accordingly, it is crucial to assess the levels of the main elements present in the ashes of the selected plant species contributing to the soil fertility and thus play a good role of fertilizers. The aim of the present study was to assess the levels of the minerals found and thus determine the agricultural usefulness of the wood ashes obtained following the combustion of the woods of the seven trees namely *Acacia seyal, Acacia etbaica, Acacia albida, Acacia tortilis, Leucaena leucocephala, Olea europea,* and *Musa sapientum*. Most of the woods of those plants have been extensively used in household fires in rural and urban communities of Eritrea.

2. MATERIALS AND METHODS

2.1. Sample collection and preparation

Moderately sized tree branches of the plants were collected for the purpose of this study. Four of the seven trees are highly distributed in the lowlands and highlands of Eritrea but *Olea europea* is highly dispersed in the Eastern escarpments. Except *Leucaena leucocephala* and *Musa sapientum,* each plant species is common to specific region of the country (Table 1) and intensively used for household fires and other purposes. The plant species were collected from diverse sites of the country and all were authenticated by a taxonomist in Eritrea Institute of Technology, EIT (Voucher specimen of the plants has already been deposited in the Herbarium of EIT). The wet woods of all the selected plants were chopped and shade dried for several days. Each dry wood was weighed to obtain dry weight and then inserted into a muffle furnace (Carbolite, Shfld.) set at 600 ^{o}C for 6 hrs. The ash residues were collected and allowed to pass through a sieve having mesh size of 0.1 mm and thus were kept in appropriate labeled vials until further use.

2.2. Chemicals and reagents

Analytical grade chemicals and reagents were purchased from Sigma-Aldrich Company. 65% nitric acid (HNO_3) and 32% Hydro chloric acid (HCl) were used for digestion purposes. Ultrapure-deionized water (18Ω) was used throughout the study. The glassware was soaked in 3 M HNO_3 for the whole night and washed and rinsed with deionized water to minimize the chances of interferences. All the chemical analyses were conducted under extractor hood and a digital IR Vortex Mixer (S/N296058 made in Italy) was used for mixing of the solutions.

Table 1. List and details of the plants selected for this study

Scientific Name	Local Name	English Name	Commonly locations In Eritrea	Place Collected
Acacia seyal	Chea	White Whistling thorn	Highlands and lowlands	Hazemo
Acacia etbaica	Seraw	***	Highlands and lowlands	Segeneiti
Acacia tortilis	Ala	***	Highlands and lowlands	Barentu
Acacia albida	Momona	Apple ring acacia	Highlands and lowlands	Shiketi
Olea europea	Awlee	African wild olive	Eastern escarpments	Filfil
Leucaena leucocephala	Luciana	Lucinia	Halhale Research Institute	Halhale
Musa sapientum	Banana	Banana	Lowlands	Teseney

'***' - English name not found

2.3. Instrumental Analysis

A dual viewing ICP-OES (Perkin Elmer Optima 8300, made in Singapore) coupled to an ultrasonic nebulizer CETAC 6000AT + (CETAC, Omaha, NE, USA) was employed for the analysis of the trace and other elements. The Windows 7 compatible S/W provided by Perkin Elmer was used to process the spectral data for calculating sample concentrations by comparing light intensities measured at various wavelengths for standard solutions with intensities from the sample solutions. The operating conditions set for the ICP-OES are shown in Table 2.

2.4. Sample Digestion

The powdered ash samples prepared were digested as follows: Each ash sample (2 g) and certified reference materials were weighed and transferred into a beaker containing about 60 ml of aqua-regia. The mixture was placed in a hot plate at 100 ^{o}C until the volume was reduced to 40 ml. Each solution was then transferred to conical flask and diluted to 100 ml using Ultrapure-deionized water. At last, approximately 20 ml of the diluted solution was transferred into glass test tubes for analysis using ICP-OES. The analysis was conducted with special emphasis to the levels of K, P, Ca, Mg, S, Mn, Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb and Zn.

Table 2: The operating conditions of the ICP-OES used for the analysis

Condition	Setting
Power	1.3 kW
Plasma gas flow	15 L/min
Auxiliary gas flow	1.5 L/min
Spray chamber type	Glass cyclonic (single-pass)
Torch	Standard one-piece quartz axial
Nebulizer type	Sea spray
Nebulizer flow	0.7 L/min
Pump speed	2-4 rpm
Total sample usage	2 mL
Replicate read time	5 s
Number of replicates	3
Sample undertake delay time	15 s
Stabilization time	40 s
Rinse time	20 s
Fast pump	Off
Background correction	Fitted

Before the analysis of the elements, the accuracy of the methods was verified using in-house certified reference materials (CRMs) digested using dry ashing; the method was adopted from Sium *et al*, 2016 [13]. Figure 1 displays the calculated relative errors of some of the elements. Except for Al, all the elements demonstrated negligible relative errors and the deviations from the mean values were very small. There was no significant difference in the measured and certified values. Therefore, the calculated relative errors revealed high accuracy of the method, suggesting that this method can be used for routine analysis of trace and heavy metals in wood ash samples. The concentrations of the elements analysed using the ICP-OES are displayed in Table 4, Figure 2, Figure 3, Figure 4 and Figure 5.

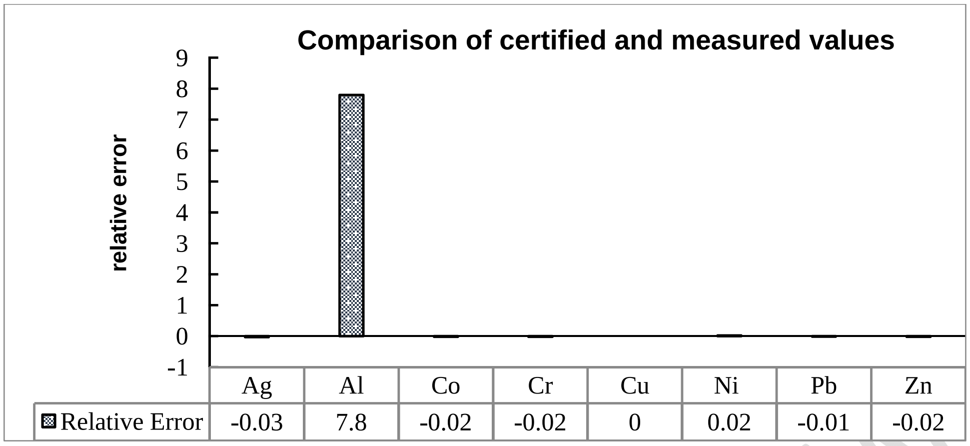


Figure 1: The relative errors calculated based on comparison of the certified and measured values of some elements

3. RESULTS AND DISCUSSIONS

3.1. The ash content

The ash content of the plants, furnished in Table 3, was calculated and *Musa sapientum* gave the highest ash content (7.44 %) among the others. The ash content of the other six plants falls in the range of 0.88 (for *Olea europea*) up to 4.66 % (for *Leucaena leucocephala*). The results of the ash content of the plants in this study are higher than those reported by Wang and Dibdiakova, 2014 [14] and Dibdiakova *et al*., 2015 [15]. The increase in the mass of the ash was relatively higher due to the effect of temperature employed for the ashing process. Usually if the furnace is set over 600 ^{O}C, there is further decomposition of carbonates of both calcium and potassium and thus the ash content decreases [16]. However, the overall percentage of the ashes seems to fit the values for the ash content (3–5% ash) of dominant types wood present available for use [17].

Table 3. The ash content of the seven plants (in % of the dry mass)

Scientific Name	Ash content (%)
Acacia seyal	2.01
Acacia etbaica	3.27
Acacia tortilis	4.21
Acacia albida	3.34
Olea europea	0.88
Leucaena leucocephala	4.66
Musa sapientum	7.34

3.2. Elemental composition of the ashes of the selected trees

The concentration of the elements present in the wood ashes, determined by ICP-OES, is represented in Table 4. The results of the recovery of the elements from the ash samples shows that the digestion method employed was found to be effective in recovering most of the elements. In this report, the main essential minerals found in the wood ash samples were Ca, K, Mg, P, and S. The level of the major elements in ascending order was S< P < Mg < K< Ca, and this was consistent with previously reported results from Czech Republic [9]. The other major elements identified were Na, Fe, Sr, Mn, Ti, Cu, Ba, Zn, V, and Ni. In general, the mineral concentrations including Ca, Cr, Cu, Fe and Ni of the ashes in this study were higher than those reported by Huang *et al*, 1992 [18] and lower than those reported by Etiegni *et al*, 1991 [19] and G´orecka *et al*, 2006 [1]. Moreover, the levels of metals including Al, Cd, Mn, Pb, Sb, Sn and Zn were much lower and the levels of the metals like K, Mg, Na, and Zr were higher than those reported by Huang *et al*, 1992 [18], Etiegni *et al*, 1991 [19] and G´orecka *et al*, 2006 [1] (Table 4 and Table 5). According Demirbas [20], the composition of ash is dependent on the plant species, growth conditions and ash fraction.

The reasons for the difference in concentration of the metals could be attributed to the difference in the type of plant species, soil composition and degree of environmental pollution in which the plants grew up. Many authors reported that the levels of minerals in the wood ashes is variable and depends on the type of the tree species, the segments of the tree used, soil properties and the climate on which the tree grows. The nutrient content of roots and branches is usually much higher than the nutrient content of logs [2, 14]. Ashes formed from the top branches contain substantially high levels of K and P. These two typical mobile elements in plants are often found in twigs containing a large amount of young and biologically active tissues [15]. Likewise, in the present study, moderately sized tree branches were analysed for their mineral content because these tree parts are used intensively for fire in rural and urban Eritrea.

Table 4. The concentrations of elements found in the ashes of the trees studied

Element	*Acacia seyal*	*Acacia etbaica*	*Leucaena leucocephala*	*Olea europea*	*Acacia albida*	*Musa sapientum*	*Acacia tortilis*
Ca (%)	18.66± 0.22	21.78± 0.31	11.77± 0.24	21.53± 0.18	8.96± 0.10	1.44± 0.00	22.93± 0.00
K (%)	11.07± 0.51	11.54± 0.38	3.22± 0.02	0.86± 0.01	25.05± 0.24	31.74± 0.12	5.83± 0.00
Mg (%)	5.37± 0.13	4.07± 0.01	1.91± 0.00	1.03± 0.00	4.21± 0.02	0.76± 0.01	3.52± 0.01
P (%)	1.98± 0.04	2.30± 0.04	0.37± 0.00	0.14± 0.06	4.26± 0.01	1.04± 0.01	1.45± 0.04
Na (%)	0.40± 0.00	0.39± 0.00	1.20± 0.00	0.50± 0.01	0.19± 0.01	0.23± 0.00	0.86± 0.00
Al (%)	0.62± 0.00	0.21± 0.00	0.25± 0.00	1.91± 0.01	0.41± 0.00	0.31± 0.00	0.68± 0.01
Mn (ppm)	224.33±5.06	129.94±2.22	144.81±4.20	329.20±2.70	198.34±1.36	171.92±1.16	783.14±5.69
Ni (ppm)	13.21± 0.76	16.25± 0.15	4.54± 0.15	13.83± 0.10	25.19± 0.20	3.53± 0.03	6.39± 0.05
Fe (%)	0.62± 0.00	0.23± 0.00	0.22± 0.00	1.65± 0.01	0.50± 0.00	0.38± 0.00	0.84± 0.00
S (%)	1.10± 0.02	0.71± 0.00	0.39± 0.00	0.45± 0.00	3.50± 0.00	0.67± 0.01	0.38± 0.01
Sb (ppm)	0.52± 0.04	1.18± 0.06	0.04± 0.01	1.23± 0.07	0.23± 0.04	0.82± 0.06	1.24± 0.08
V (ppm)	13.23± 0.33	4.88± 0.21	5.28± 0.09	39.73± 0.38	10.72± 0.23	10.71± 0.22	28.91± 0.13
Zn (ppm)	277.69±2.26	205.09±3.20	56.09± 0.38	88.95± 0.12	331.44±1.12	101.56±0.33	484.19±7.57

Table 5. The levels of elements of the ashes of various trees previously reported

Published Papers	**Elements Analysed in the Wood Ashes**											
	Al (%)	**Ca (%)**	**Fe (%)**	**K (%)**	**Mg (%)**	**Na (%)**	**P (%)**	**Mn (ppm)**	**Ni (ppm)**	**Zn (ppm)**	**Bi (ppm)**	**Sb (ppm)**
(Etiegni et al 1991) [15]	2.36	31.74	1.95	4.13	2.25	0.34	1.4	6700	47	700	-	-
(Huang et al 1992) [14]	1.3	10.94	0.33	2.86	1.62	0.16	0.69	3470	12	794	-	-
(G´orecka et al 2006) [1]	0.65	29.3	0.85	6.7	2.68	0.3	1.63	8,535	65.17	1,172	39.79	3.31

NB: '-' not reported

***3.2.1 Nitrogen and Sulphur Content*.** The nitrogen content in wood ash is normally insignificant due to the conversion of most of the wood nitrogen to NH_3, NO_X and N_2 during the combustion of wood [7, 9] and sulphur is usually lost during combustion process similar to nitrogen. Furthermore, depending on the amounts of wood ash applied and the consequent rise in the soil pH, the concentrations of nitrogen decrease in the upper soil layers [11]. Consequently, if wood ash is to be used as a fertilizer, nitrogen and sulphur would need to be supplied from other sources. However, wood ash should not be added along with nitrogen fertilizers such as ammonium sulfate, urea or ammonium nitrate as these fertilizers lose their nitrogen in the form of ammonia gas when mixed with high pH material [21]. Here, the highest level of S was found in *Acacia albida* (3.50 %) and lowest in *Acacia tortilis* (0.38 %) collected from Shiketi and Barentu, respectively. The levels of S were significantly different (P < 0.01) among the plants.

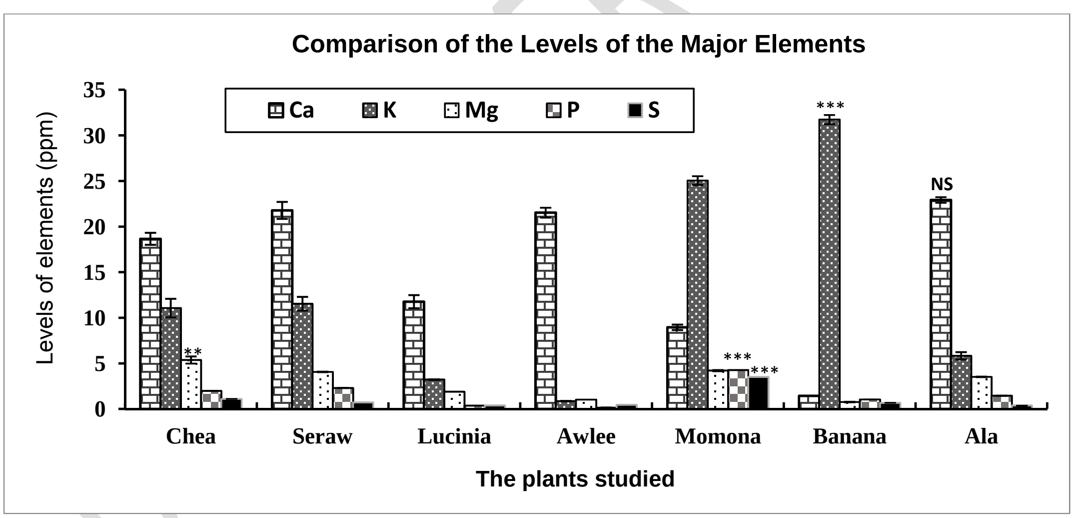
3.2.2 Phosphorus Content. The ash sample of *Acacia albida* was found to contain the highest concentration (4.26 %) of phosphorus followed by *Acacia etbaica* (2.38 %) and *Acacia seyal* (1.98 %) and the lowest concentration (0.14 %) was found in *Olea europea*. The levels of P were significantly different (P < 0.01) among the various plants studied. Even though the phosphorus absorption and bioavailability depends up on pH buffering capacity of the soils [19], the ashes of the tree species *Acacia albida, Acacia etbaica,* and *Acacia seyal* can be used as important sources of phosphorus in P deficient soils. Phosphorus is the second most limiting nutrient in crop production, playing its most critical role in plants in energy transfer and storage. It is a structural component of nucleic acids, nucleotides, and coenzymes. Low availability of phosphorus is a limiting factor to plant growth [22]. Reutilizing biomass ashes in agriculture can substitute inputs of P from finite primary sources [23]. Studies have also reported that better levels of phosphorus supply had a beneficial influence on potassium uptake and potassium concentrations in plants [9]. The processes of anabolism and catabolism of the carbohydrate metabolism in plants would only proceed normally when the organic compounds had been esterified with phosphoric acid [5]. Okmanis *et al.* 2016 [24] reported that fertilization with wood ash shows the best results in stands with visual symptoms of phosphorus deficiency on nitrogen rich drained peat soils. Moreover, these plants being the most important sources of fuel in household fires and other applications, massive amount of ash is produced from them in rural as well urban areas of Eritrea, making them ideal phosphorus suppliers.

3.2.3 Potassium Content. The ash of *Musa sapientum* was found to contain the highest concentration of K (31.74 %) followed by *Acacia albida* (25.05 %) and the lowest concentration of K was observed in *Olea europea* (0.86 %). The levels of P varied significantly (P < 0.01) among the different plants. Since the potassium fertilizers are usually expensive, the ashes from *Musa sapientum, Acacia albida, Acacia etbaica, Acacia seyal* and *Acacia tortilis* could be good alternatives of potassium for potassium deficient soils. Considering that the content of phosphorus in wood ash is low, potassium content is predominantly responsible for a positive impact of the wood ash applied as a fertilizer [24]. The solubility and the potential availability of the macronutrients to plants in wood ash are high, and K has highest bioaccumulation relative to Mg, Ca and P [11]. *Musa sapientum* bears hanging clusters of elongated fruits which are consumed in huge amount per day everywhere in the world and the skins of the fruit are disposed giving little attention to them. Thus, based on the results of this study, collecting the *Musa sapientum* skins and converting them in to ash makes them ideal candidates for potassium deficient soils.

Potassium was found to accumulate in the parts of the plant in which cell division and growth processes were actively proceeding [5]. K balances the charge of organic acids and is known to participate as a cofactor at least in 50 different enzymatic reactions in plants [11]. G´orecka *et al.*, 2006 [1] reported that plant availability of wood ash potassium is the same as in potassium fertilizers, but phosphorus was lower when compared with phosphorus fertilizers. A study on Norway spruce, standing on drained organic and drained mineral soils have shown a correlation between the tree foliage damages and the potassium content in soil [24]. Studies also revealed that soil available potassium levels increased with the application of wood ash and the resulted increase in soil available potassium is attributed to release of potassium by wood ash as well as to the replacement of potassium on soil exchange sites by Ca and other exchangeable cations released directly from wood ash into the soil suspension [1]. Wood ash treatment experiments showed an increase of K, B, Mg, Fe, and Zn in tissues of Scots pine needles [11].

3.2.4 Calcium Content. Based on the results of this study the ash sample of *Acacia tortilis* is found to contain the highest concentration (22.93 %) of Ca followed by *Acacia etbaica* (21.78 %) and *Olea europea* (21.53 %) and lowest concentration of Ca was observed in *Musa sapientum* (1.44 %). The levels of Ca were not significantly different among the plants. Thus, the ash sample from *Acacia tortilis*, which is the dominant plant species in the lowlands of Eritrea, can be applied to Ca demanding soils. Calcium is an important macronutrient which influences the water economy of the plant and the protein carbohydrates in many physiological processes [5]. The high content of Ca and Mg in ash accounts for high pH of the ash. It is reported that wood ashes contain significant amounts of basic oxides which can be used to deacidify acidic soils. When deciding on the use of these ashes for soil deacidification, it should be borne in mind that Ca and Mg are present in the oxide (fast-acting) form [8, 25]. As previously reported, wood ashes have the same liming effects as commercial lime and was comparatively found to give better plant growth responses than limestone because of the additional nutrients that the ash contained [5].

3.2.5 Magnesium Content. The ash sample from *Acacia seyal* was found to contain the highest concentration (5.37 %) of Mg followed by *Acacia albida* (4.21 %), *Acacia etbaica* (4.07 %) and *Acacia tortilis* (3.52 %) and the lowest concentration (0.76 ppm) of Mg was observed in *Musa sapientum*. There was significant difference (P < 0.01) in the levels of Mg among the plants. Thus, the ash samples from these plants can be good sources of Mg. It was confirmed that Mg is a constituent of the chlorophyll, protochlorophyll, pectin and phytin. Micronutrients such as Mg though required in very small quantities, are also involved in the plant metabolic processes [5]. As shown in Figure 2, Ca was the dominant element in most of the plants including *Acacia seyal, Acacia etbaica, Leucaena leucocephala, Olea europea* and *Acacia tortilis*. However, K was the most dominant element in *Acacia albida* and *Musa sapientum*. For most of the plants, the level of Mg was relatively lower as compared to Ca and K.

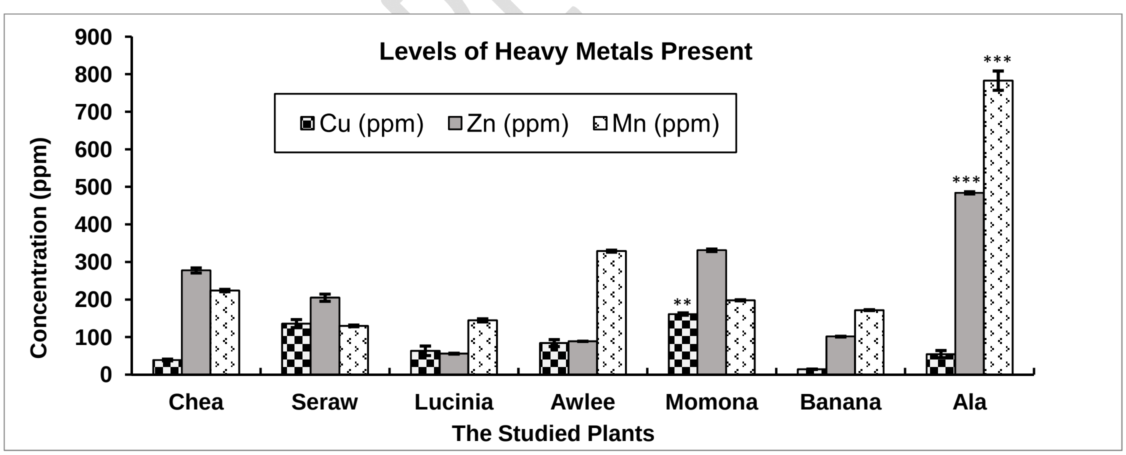


NB: Concentration expressed as mean ± SD (n=3); $^{***}P$ < 0.001, NS - not significant (statistical significance relative to the other plants)

Figure 2: Some of the major and essential elements found in the selected plants

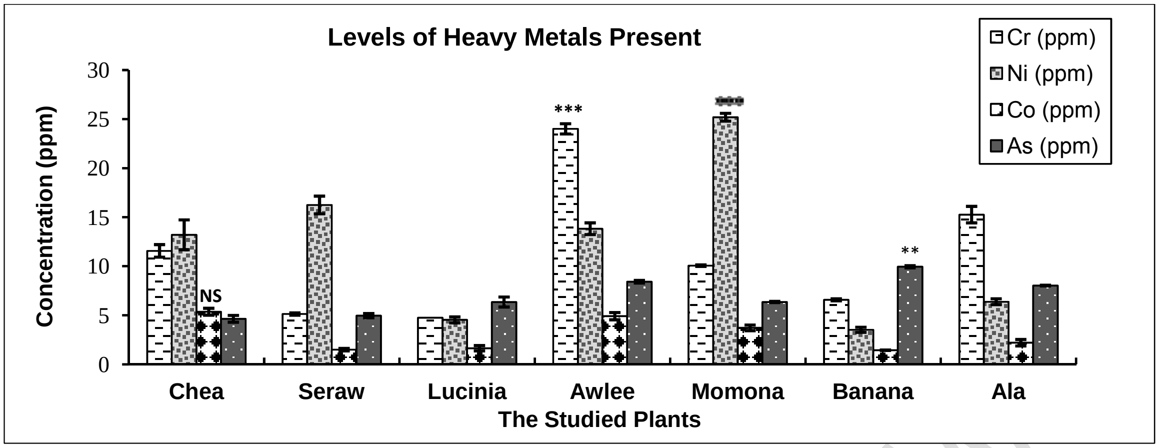
3.2.6 Heavy metal concentrations of the wood ashes. As presented in Figure 3, Figure 4 and Figure 5, the highest levels of Pb was observed in *Olea europea* (9.78 ppm) followed by *Acacia albida* (3.47 ppm) and *Acacia tortilis* (3.13 ppm). Among the trees, the highest levels of Hg and Co were found in *Acacia seyal* (3.92 and 5.37 ppm respectively) and the lowest non-detectable levels of Hg were observed in *Musa sapientum* and *Acacia tortilis.* Though the concentrations were small, relatively the highest level (0.13 ppm) of Cd was found both in *Musa sapientum* and *Olea europea*. Similarly, the highest levels of Zn and Mn were found in *Acacia tortilis* (484 and 783 ppm respectively). The lowest concentrations of Zn (56.09 ppm) and Mn (129.9 ppm) were found in Luciana and *Acacia etbaica* respectively. *Acacia seyal* displayed the highest levels of Cr (11.57 ppm) and Co (5.37 ppm) compared to the other trees. The highest (25.19 ppm) and lowest (3.53 ppm) levels of Ni were found in *Acacia albida* and *Musa sapientum* respectively. The levels of Mn, Zn, Cr, Ni, Pb, Fe and Hg (P < 0.001), Cu and As (P < 0.01) were statistically different among the plants. However, the levels of Co and Cd were not statistically different among the studied plants. Moreover, the concentrations of heavy metals, including the toxic metals (Pb, Cd and Hg), in the studied ashes were below the permissible limits and thus the ashes can be used for soil improvements.

The low concentration of heavy metals in the ash of the studied plants was consistent with some similar studies previously reported [8, 26]. The ashes obtained following the combustion of wood of fourteen tree species from Poland reported by G´orecka et al, 2006 [1] were characterized with higher levels of Cd, Pb, Zn, Cu, Mn, Ni and Cr as compared to the results of the present study. This could be attributed to the diversity of the plants and their geographical location; previous study also describes the relationship between the levels of heavy metals in wood ashes relative to their geographic origins [27]. Olanders et al. [28] in their work reported that the ash from biomass fuel contains only trace amounts of heavy metals, which makes them fairly easy to dispose of and they can be good fertilizers. Biomass incineration has been used increasingly for the generation of heat and/or electricity. The utilization of bottom ash has the advantage of lower heavy metal concentrations but the disadvantage of higher nutrient losses. Mixtures of fly ash and bottom ash may be useful to achieve optimum nutrient delivery within limits for heavy metal concentrations [26, 29].



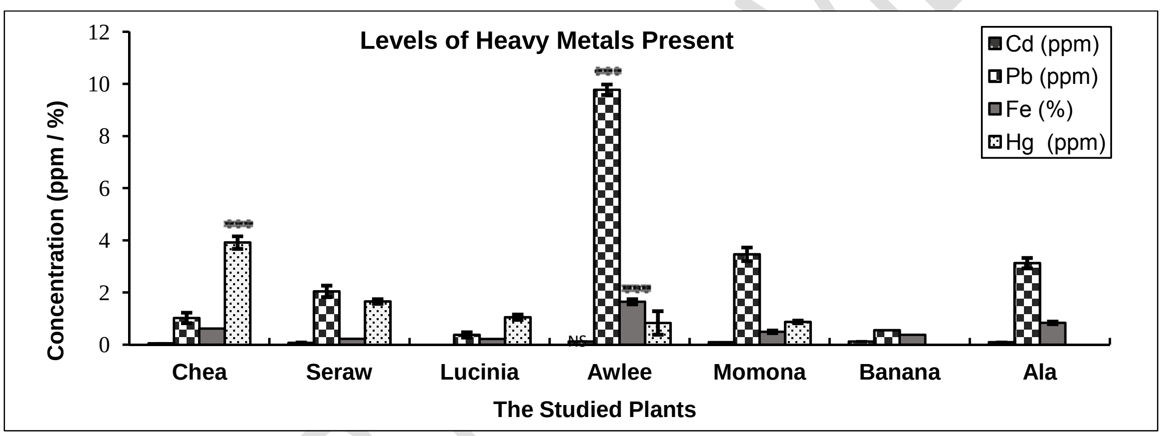
NB: Concentration expressed as mean ± SD (n=3); $^{***}P$ < 0.001, $^{**}P$ < 0.01 (statistical significance relative to the other plants)

Figure 3: Concentration of Cu, Zn and Mn in the selected plants



NB: Concentration expressed as mean ± SD (n=3); $^{***}P < 0.001$, $^{**}P < 0.01$, NS- not significant (statistical significance relative to the other plants)

Figure 4: Concentration of Cr, Ni and Co and As in the selected plants



NB: Concentration expressed as mean ± SD (n=3); $^{***}P < 0.001$, NS - not significant (statistical significance relative to the other plants)

Figure 5: Concentration of Cd, Pb, Fe and Hg in the selected plants

4. CONCLUSION

On the basis of the results observed, the concentration of minerals in the studied wood ashes including *Musa sapientum*, *Acacia albida*, *Acacia seyal* and *Acacia tortilis* were found to be good sources of K, P, Mg and Ca. Moreover, the levels of toxic elements in the wood ashes were in full compliance with the regulatory requirements and therefore the wood ashes investigated in this report can be employed in soil amendments according to the mineral needs of the soil. Although wood ashes could be good sources of various elements, it doesn't mean that they are readily available to plants and environment and therefore their bio-availability to specific plant requires further investigation. This is a very first kind of report related to the levels of minerals in wood ashes in the country and thus be used as reference for further detailed studies.

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