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Above-ground Biomass and Fuel Value Index of Selected Tree Species for Fuelwood Production in Ethiopia

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Abstract

The present work investigates the appropriate tree species for biomass energy utilization by determining the trees' dry biomass and fuel value index, taking into account that the developing countries rely heavily on the fuelwood for energy consumption. In Ethiopia, biomass currently meets more than 89.5% of the total energy consumption. Despite this reliance on biomass, there is a scarcity of fuelwood as well as data on the dry biomass potential and fuel value indices of the tree species utilized in various parts of the country. This work is carried out on the selection of trees for fuelwood purposes based on their dry biomass potential and fuel quality characteristics. Five highly performed Eucalyptus tree species are selected, and the above-ground biomass is measured using the destructive approach, whereas the fuel value index is computed using an effective method with four parameters (calorific value, wood density, ash content, and moisture content). These parameters are determined following the American Society for Testing and Materials method. Finally, the above-ground biomass and carbon content vary from 13.96 kg to 87.47 kg and from 6.03 kg to 37.86 kg Tree^{-1}, respectively. The biomass and carbon content of *E. globulus* and *E. viminalis* are both high. The maximum fuel value index is 276.34 for *E. saligna*. The computed fuel characteristics are statistically varied among the tree species at $P \leq 0.0001$. Based on the tree fuel characteristics findings, *E. globulus*, *E. viminalis*, and *E. saligna* are identified as the best fuelwood species, and are suggested for future plantations.

Keywords: *Ash Content, Calorific Value, Carbon Content, Moisture Content, Wood Density*.

1. Introduction

Energy has emerged as one of the most pressing challenges in all countries, particularly the developing ones. Most countries have undertaken substantial planning in order to provide the required energy through new energies. Nowadays, one of the proposed options is to use the renewable and local energies [1]. The studies have indicated that the final energy from biomass accounts for around 50 EJ of energy or 14% of global final energy usage; however, the actual potential for final energy from biomass globally might reach 150 EJ by 2035 [2, 3]. More than any other region in the world, Africa relies predominantly on wood-fuels (charcoal and firewood) for its cooking food. In this region, studies have indicated that about half of all energy (commercial and biomass) consumed is used for cooking food, which is nearly double the energy (fossil fuel and electricity) used by the agriculture and industrial sector combined [4]. The biomass fuel is the most important source of energy in the developing countries [5, 6]. According to Reza Alay *et a*l., generating electrical energy from biomass reduces the CO_2 and CO emissions by 77.2 and 7.96 kg/year, respectively, to generate 229,735 kW/year [7]. Fuel-wood is principally traditional but could not phase out from being a major source of household energy for various purposes [8-10]. In Ethiopia, it has been identified that the biomass energy usage is a key issue in the national economy, in general, and the energy sector, in particular [11]. In the country, biomass currently meets more than 89.5% of the total energy consumption [12]. The fuel-wood demand and supply projection and analysis made by the Ethiopian Forestry Action Program in 1996 showed that in the year 2000, the demand for fuel-wood was estimated to be 58.4 million m^3, while the sustainable supply was only 11.2 million m^3, making the deficit to 47.1 million m^3. For the

Year 2014, these figures are projected to be 88.9, 8.8, and 80 million m^3 in the above order [13]. The high-altitude areas of Ethiopia have encountered a multitude of problems such as limited tree species for fuel-wood purposes and less availability of the adapted tree species [14]. Relying heavily on a few species has risks and impacts on the productivity and sustainability of the forest farming systems, particularly in the extreme highland areas of the country [15]. Thus a wider range of tree species would ensure a resilience and decreased sensitivity to the fuel-wood scarcity [16]. The past attempts in Ethiopia to reforest and restore degraded forests, and thereby, fulfill the fuel-wood requirements in the rural areas of the country relied on the screening of multi-purpose tree species in some agro-ecological zones [16, 17]. In order to determine the best species used for fuel-wood, it is important to obtain the biomass potential, carbon content, and fuel value indices of the tree [18]. The carbon stored in wood is only released back to the atmosphere when the wood product is burnt or decays [19]. The amount of carbon stored in the trees depends on several factors including tree species, growth conditions in the environment, age of the tree, and density of the surrounding trees [20]. Diksis plantation, the studied site contains eleven different tree species used for fuel-wood and other construction purposes. Out of eleven planted tree species, six tree species namely *E. saligna*, *E. globulus*, *E. viminalis*, *E. grandis*, *E. camaldulensis*, and *Acacia decurrens* were highly performed based on the growth performance obtained according to Dajenie *et al.* [21]. The present study was conducted in order to determine the biomass potential, carbon content, and fuel characteristics of five highly performing eucalyptus tree species, namely *E. globulus*, *E. saligna*, *E. viminalis*, *E. grandis*, and *E. camaldulensis*, planted for fuelwood purposes in Ethiopia's central highlands. It was done by comparing the fuel characteristics from tree to tree (species type) and per tree (tree part) for appropriate tree species selection for fuelwood purposes.

2. Materials and methods

2.1. Description of studied area

The plantation of the Diksis site is located in the Diksis district, Central Ethiopia "Figure 1". It was a part of successfully planted tree species by the Ethiopian Environment and Forest Research Institute in the year 2013 as a part of the comparative growth performance of the fast-growing tree species for fuel-wood production in the Ethiopian highland' research project. The mean annual minimum and maximum temperatures of the studied area is 6 ˚C and 23 ˚C, respectively. The mean annual precipitation is 1100 mm, most falling between March and October with peaks in July and August. The soil of the studied area is classified as Nitosoils [21].

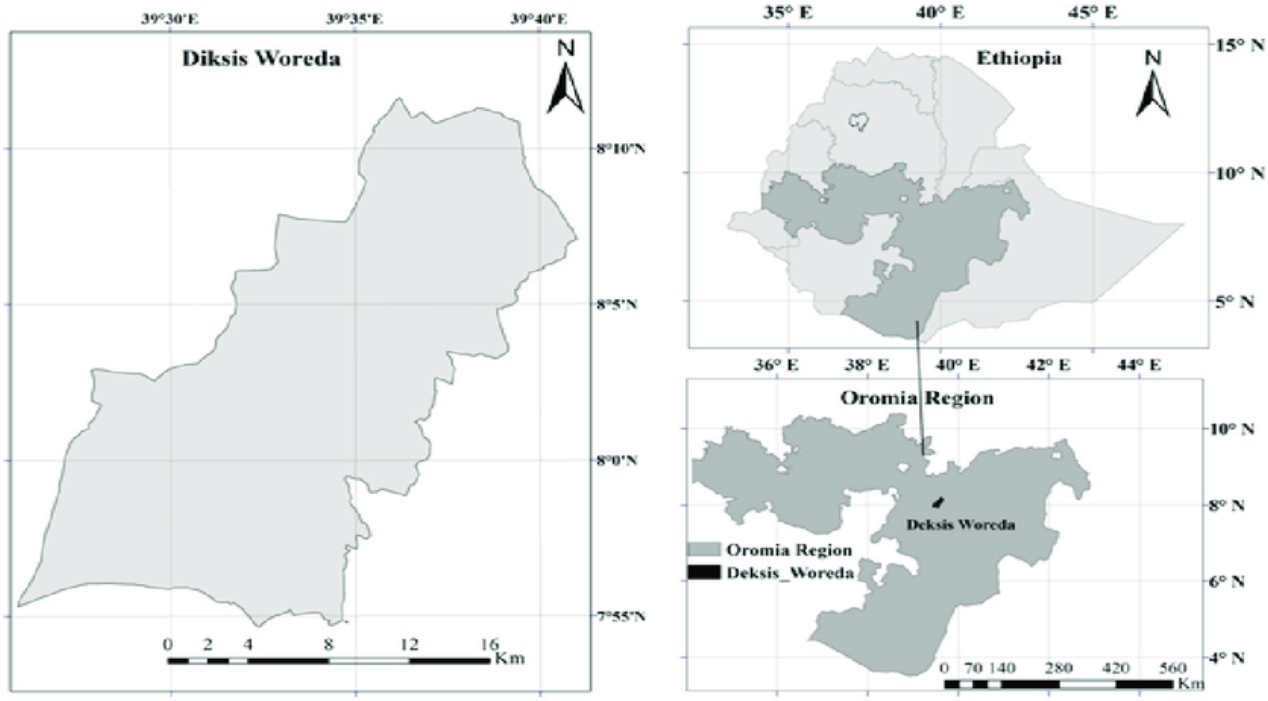

Figure 1. Map of studied area.

2.2. Sampling method and sampling techniques

The Ethiopian Environment and Forest Research Institute planted eleven different tree species in to three blocks in 2013 in order to determine the growth-performance of each tree for the purpose of fuel-wood production. The study identified and selected the best-performing trees for the future investigation on their above-ground biomass and fuel value index at the age of six [21]. Based on the previous research works, the present study selected five high-performing tree species for an additional biomass and fuel characteristics determination. The trees were 7 years old when they were harvested for the purpose of this study. The destruction method was used in order to determine the above-ground biomass. A random sampling method was used to mark five individual tree species from each block. A total of 15 individual sample trees (three trees per species type) were marked and harvested excluding the border trees due to their biomass potential. The harvested trees were assorted into three parts, namely stem, branch, and leaf. The stem parts were cut into bottom, mid, and top and debarked. The above-ground biomass was determined using the methods and equations from [22-29]; refer to equations (1, 2, 3, 4). All the fresh weights were obtained immediately after harvesting each tree species and tree parts. The fuel value index or fuel quality of the trees was determined following the method and equations of [34]; refer to Equation "(6)" for the most effective method with four parameters (calorific value, wood density, ash content, and moisture content). The carbon content was obtained from a combination of the fixed carbon, volatile matter, and ash content of the biomass, as several recent studies [30-33] have suggested this method and equation with correlations of 3.17% and average bias errors of 0.19%. This approach is highly recommended since it incorporates the parameters derived directly from the harvested tree; refer to equation (5).

$$\mathbf{AGB} = \mathbf{SB} + \mathbf{BB} + \mathbf{LB} \tag{1}$$

$$\mathbf{SB} = \dot{\mathbf{T}}\mathbf{FWS} \times \frac{\mathbf{DWS}}{\mathbf{FWS}} \tag{2}$$

$$\mathbf{BB} = \dot{\mathbf{T}}\mathbf{FWB} \times \frac{\mathbf{DWB}}{\mathbf{FWB}} \tag{3}$$

$$\mathbf{LB} = \dot{\mathbf{T}}\mathbf{FWL} \times \frac{\mathbf{DWL}}{\mathbf{FWL}} \tag{4}$$

$$\mathbf{C} = \mathbf{0.635FC} + \mathbf{0.460VM} - \mathbf{0.095ASH} \tag{5}$$

$$\mathbf{FV\dot{I}} = \frac{\mathbf{WD} \times \mathbf{CV}}{\mathbf{Ash} \times \mathbf{MC}} \tag{6}$$

$$\textbf{Wood density} = \frac{\textbf{Oven} - \textbf{dry weight of the sample}}{\textbf{Green volume of the sample}} \tag{7}$$

where AGB is the above-ground biomass, SB is the stem biomass, BB is the branch biomass, LB is the leaf biomass, TFWS is the total fresh weight of the stem, TFWB is the total fresh weight of the branch, TFWL is the total fresh weight of the leaf, DWS is the dry weight of the stem sample, FWS is the fresh weight of the stem sample, DWB is the dry weight of the branch sample, FWB is the fresh weight of the branch sample, DWB is the dry weight of the leaf sample, and FWL is the fresh weight of the leaf sample. FVI = Fuel Value Index, WD = Wood Density, CV = Calorific Value, MC = Moisture Content. C is the carbon content, FC is the fixed carbon, VM is the volatile matter, and ASH is the ash content.

The tree fuel value index-determining parameters (wood density, calorific value, ash content, and moisture content) were determined from all parts of the harvested tree species. The volatile matter and fixed carbon were also determined

The standard method ASTM D3175-18, 2018 [35] was used in order to determine the moisture content, volatile matter, and fixed carbon, whereas ASTM D3174-12, 2012 [36] was used in order to determine the percentage of ash content. The calorific value was determined using the Parr Oxygen bomb calorimeter in accordance with the ASTM D5865-13, 2013 [37] standard method. The standard method and equations from ASTM D2395-17, 2017 [38] and DO7 Committee [39] were used in order to determine the wood density; refer to Equation "(7)". For the analysis of variance, the factorial sample design (completely randomized design) was used. The dependent variables were the above-ground biomass, carbon content, fuel value index, wood density, calorific value, fixed carbon, volatile matter, ash content, and moisture content. The independent variables were the species type (containing five levels or tree types, namely *E. saligna*, *E. globulus*, *E. Viminalis*, *E. grandis*, *E. camaldulensis)* and the tree parts (containing five levels of tree parts, namely bottom, medium, top, branch, and leaf). The interaction effect (species type * tree part) was also included and determined. All the experimental activities were replicated three times.

2.3. Data analysis

The variable determination of the tree species were subjected to the Analysis of Variance (ANOVA) statistical method using the Generalized Linear Model (GLM) procedure suggested by Gomez and Gomez [40]. Five Eucalyptus tree species with two determining factors (species type and tree parts, (each containing five levels)) with different seven parameters was designed in the experiment and tested at ($P \leq 0.05$). Statistical analysis of the data was carried out using the SPSS software, version 26, the SAS software, version 9, and the Microsoft Excel (2010) computer software.

3. Results and Discussion

3.1. Growth performance of selected trees for fuel-wood

The diameter and height are important parameters for estimating the biomass potential of a tree. It is not suggested to compare the tree biomass potentials by diameter and height across different tree species since there are trees with large mean diameters but short heights, and trees with large heights but tiny diameters [41]. In the present study, the growth-performance of the selected tree species (diameter and height) was obtained directly on the studied site. The findings showed that *E. viminalis* had a big bottom and top diameter, whereas *E. camaldulensis* had a small bottom and top diameter "Table 1". The mean diameter and height of *E. camaldulensis* and *E. grandis* were smaller than the other tree species. *E. viminalis* and *E. globulus* were higher than the other trees "Table 1". The result is supported by the previous findings and in line to the study obtained by Delgado-Matas and T. Pukkala [42]. The author measured the eucalyptus species found at the age of seven, which was similar to the present study, and reported the mean diameter and mean height 5 cm to 12 cm, and 8 m to 20 m, respectively. Accordingly, the minimum 4.221 ± 0.916 cm and the maximum 9.408 ± 2.556 cm of mean diameter and the minimum 7.771 ± 2.85m and the maximum 15.983 ± 0.7m mean height were registered during this study "Table 1".

Table 1. Means comparisons of tree growth performance and tree biomass characteristics on species types.

Species	N	Diameter (cm)	Height (m)	Wood density (g/cm^3)	Calorific value (MJ/kg)	Ash content (wt %)	Moisture content (wt %)
E.saligna	15	5.85 ± 2.185	10.72 ± 2.047	0.62 ± 0.055	19.08 ± 1.002	2.02 ± 1.346	9.17 ± 0.72
E. globulus	15	6.84 ± 2.332	13.53 ± 4.08	0.63 ± 0.071	18.17 ± 0.700	2.22 ± 1.16	9.09 ± 0.72
E. viminalis	15	9.408 ± 2.556	15.983 ± 0.7	0.59 ± 0.053	18.87 ± 0.62	2.12 ± 1.566	9.69 ± 1.27
E. grandis	15	5.8 ± 2.004	11.3 ± 3.083	0.61 ± 0.046	18.49 ± 0.79	2.04 ± 1.195	10.07 ± 2.99
E. camaldulensis	15	4.221 ± 0.916	7.771 ± 2.85	0.62 ± 0.059	17.81 ± 0.723	2.50 ± 1.941	9.28 ± 0.67
Total	75	6.37 ± 2.60	11.7 ± 3.90	0.61 ± 0.057	18.48 ± 0.88	2.18 ± 1.44	9.46 ± 1.55

3.2. Above-ground biomass and carbon content

The above-ground biomass and carbon content are the basic prerequisites to consider when selecting the tree species for fuel-wood production based on the biomass potential [43]. In the present study, the above-ground biomass (stem biomass, branch biomass, and leaf biomass) and carbon content were determined. Accordingly, the stem biomass of *E. viminalis* was the highest and followed by *E. globulus*. *E. camaldulensis* had the lowest amount of stem biomass "Figure 2". The results obtained showed that *E. viminalis* was the best of the selected tree species. *E. globulus* and *E. viminalis* had high leaf and branch biomass, whereas *E. grandis* had the smallest leaf and branch biomass, and followed by *E. camaldulensis* "Figure 2". *E. globulus* had the highest above-ground biomass and carbon content, whereas E. *camaldulensis* had the lowest aboveground biomass "Figure 2". The above-ground biomass and carbon content of *E. camaldulensis* and *E. grandis* were smaller than the other selected tree species. As shown by M. Zewdie *et al.* [43], the above-ground biomass of Eucalyptus species is 5.6 + 2 kg at the age of 6-10, and the mean diameter of this species is 6 cm. The recent studies [43, 44] have computed that the above-ground biomass of Eucalyptus can reach up to 90 kg at the age of 6-10 years, and these studies are in line with the present study. The study done by M. A. Tesfaye *et al.* [45] mentioned earlier that the Eucalyptus species are fast-growing species and good to fulfill the fuel-wood demand. Based on the tree's fixed carbon, volatile matter, and ash content, the carbon content of the trees determined was found higher in *E. globulus* and *E. viminalis.* The study obtained on the hybrid eucalyptus species by M. Viera and R. Rodríguez-Soalleiro [46] regarding their carbon content and above-ground biomass is in line and supported the findings of the present study.

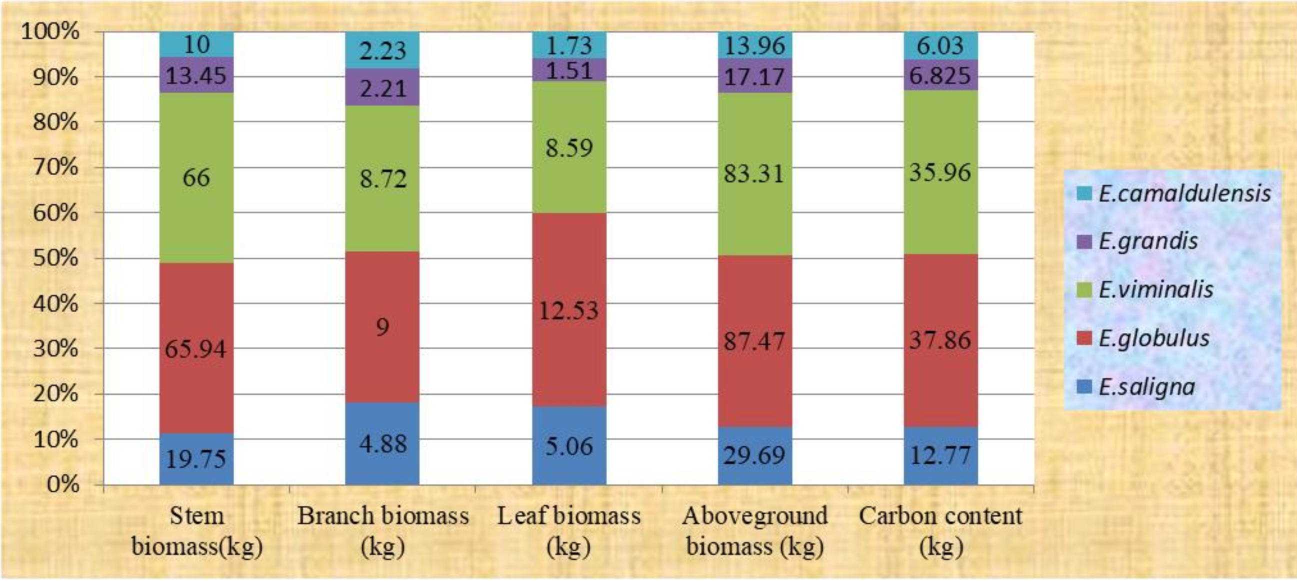

Figure 2. Stem biomass, branch biomass, leaf biomass, above-ground biomass, and carbon content of selected trees.

Statistically, through the ANOVA, the effects of the tree part and species type on the above-ground biomass were considered in the experiment at a ($p \leq 0.0001$) significant level "Table 2". The effects of the tree parts and species type on the above-ground biomass were significantly different at ($p \leq 0.0001$). However, the interaction effect was significant at ($p \leq 0.005$). The variation of the independent factors (species type, tree part, and interaction) on the above-ground biomass accounts for 76.5% of R^2 in the number of cases studied. From the R^2 value (76.5%), the species type effect accounts 27.2% of the total variance, with the tree part effect accounting for 29.6% and the interaction only accounting for 19.7% "Table 2".

The carbon content at each tree parts also showed a significant difference. ANOVA showed that the effect of tree part and species type on the carbon content was considered in the experiment at a ($p \leq 0.0001$) significant level. The effect of species type and tree parts on the carbon content was significantly different at ($p \leq 0.0001$). The interaction effect was significant at ($p \leq 0.005$). Collectively, the variation or effects of the independent variables (species type, tree part, and interaction) account 76.4% of the variance in the number of cases studied. From the R^2 value (76.4%), the species type effect accounts 27% of the total variance, with the tree part effect accounting for 29.64% and the interaction only accounting for 19.76% "Table 2".

Table 2. ANOVA.

Variables	Source	DF	SS	Mean square	F value	Pr > F	R^2 Per sources'	R^2 Total
Above-ground biomass	Species type	4	3141.02	785.25	14.47	< 0.0001	0.272	0.765001
	Tree part	4	3417.30	854.33	15.74	< 0.0001	0.296	
	Interaction	16	2276.65	142.29	2.62	0.0048	0.197	
Carbon content	Species type	4	587.87	146.97	14.27	< 0.0001	0.27	0.763725
	Tree part	4	645.92	161.48	15.68	< 0.0001	0.294	
	Interaction	16	430.66	26.92	2.61	0.0049	0.1976	
Fuel value index	Species type	4	79344.67	19836.17	.621	0.650	0.013	0.261
	Tree part	4	884245.47	221061.37	6.916	0.000	0.1443	
	Interaction	16	636920.75	39807.55	1.245	0.269	0.1044	
Wood density	Species type	4	0.01	0.00	2.16	0.0871	0.04	0.769762
	Tree part	4	0.15	0.04	33.59	< 0.0001	0.62	
	Interaction	16	0.03	0.00	1.51	0.1335	0.11	
Calorific value	Species type	4	913986.92	228496.73	7.62	< 0.0001	0.2733	0.551455
	Tree part	4	608491.59	152122.90	5.07	0.0017	0.182	
	Interaction	16	321706.75	20106.67	0.67	0.8084	0.096	
Moisture content	Species type	4	10.27	2.57	1.42	0.2407	0.057	0.496739
	Tree part	4	35.57	8.89	4.92	0.0020	0.1981	
	Interaction	16	43.33	2.71	1.50	0.1378	0.2414	
Ash content	Species type	4	2.27	0.57	0.73	0.5745	0.015	0.747409
	Tree part	4	101.87	25.47	32.80	< 0.0001	0.663	
	Interaction	16	10.72	0.67	0.86	0.6118	0.07	

3.3. Fuel value index

The fuel-wood energy content can be determined by the fuel value index of the tree species [47]. The wood density and calorific value are directly related to the fuel value index of the tree, while the moisture content and ash content are inversely related to the fuel value index [48].

3.3.1. Wood density and calorific value

The amount of wood in a unit, per volume of wood, is referred to as the wood density. The fundamental wood density is the ratio of the dry weight to the green volume of the specified wood. More wood content in a given volume indicates a high density [49]. The density of wood varies based on the tree's growing environment, species, and tree area assessed for density computation. Branches often have lesser wood density than the tree stem. Trees that grow quickly have a low density. Wood density is higher in older, slower-growing trees [50]. In the present study, the wood density at stem parts was higher than the density in the branch and leaf "Table 3". The mean wood density of the *E. globulus* was the best of the other selected trees' and followed by *E. saligna, and E. viminalis* was the smallest of all tree species "Table 1". The calorific value of *E. saligna* was 19.1 MJ/kg, the highest, whereas the smallest was *E. camaldulensis*, and it was only 17.8 MJ/kg "Table 1". The calorific values of the tree decreases from the bottom of the tree to the leaf of the tree "Table 3". The higher wood density, competitive values of calorific value coupled with the high above-ground biomass and fuel value index of eucalyptus trees at 7 ages indicates that they are a viable option for fuel-wood for rural household energy security [51]. The fuel quality of *E. globulus* was good as the wood density of this species was higher than that of the others, and the present study is in line with the study done earlier [52, 53]. The statistical ANOVA indicated that the effects of tree part and species type on the wood density were considered in the experiment at a ($p \leq 0.05$) significant level "Table 2". The species type and interaction effect on the wood density were insignificant. The effect of tree part on the wood density was significant at ($p < 0.0001$). The variation or effects of the independent variables (species type, tree part, and interaction) account 77% of the variance in the number of cases studied. From the R^2 value (77%), the species type effect accounts only 4% of the total variance, with the tree part effect accounting for 62% and the interaction accounting for 11% "Table 2". The wood density of the tree species was approximately proportional to each other. There was no variance or very minor differences in the wood density of the selected tree species. The wood density varied greatly across the tree parts, and this had an impact on the fuel quality of the trees table 3. It increases at the bottom of the tree, resulting in a significant shift in the variances in fuel value index across the tree parts.

The standard calorific value uses to categorize species as best fuel-wood ranges from 4000-5000 Kcal g^{-1} [54]. However, the age of the species has its effects on the calorific value, as mentioned earlier [55]. Accordingly, the determined calorific value was ranged in the standard value, and there was a significant difference among the species. The present study showed that *E. saligna* and *E. viminalis* had a higher calorific value than the other species. Based on the variance analysis, the effect species type on calorific value was significant at the $p \leq 0.0001$ level, while the effect of tree part on calorific value was significant at ($p \leq 0.002$) "Table 2". The calorific value difference between the selected tree species was high. Along the tree part, it increases from bottom of the tree to the leaf of the tree "Table 3". Very high calorific values of the trees were observed in the leaves. The present study is similar to the previous study obtained by M. Ngangyo-Heya *et al.* [56]. The interaction effect was insignificant at ($p \leq 0.05$). Collectively, the variation or effects of the independent variables (species type, tree part, and interaction) account 55.14% of the variance in the number of cases studied. From the R^2 value (55.14%), the species type effect accounts 27.33% of the total variance, with the tree part effect accounting for 18.2% and the interaction only accounting for 9.6% "Table 2".

3.3.2. Moisture content and ash content

The study showed that *E. grandis* and *E. Viminalis* had a high amount of moisture content. *E. globulus* had the lowest moisture content table 1. The average ash content was obtained, and *E. camaldulensis* had the highest value followed by *E. globulus*. *E. grandis*, and *E. saligna* had a low amount of ash content "Table 1".

Table 3. Mean comparison of selected trees based on tree part.

Tree part	Species type	Mean ± Standard Deviation					
		Moisture_content (%)	Ash_content (%)	Calorific_value (MJ/kg)	Wood_density (g/cm^3)	Volatile_mater (%)	Fixed_carbon (%)
Bottom	E. saligna	9.14 ± 0.82	2.30 ± 0.87	18.40 ± 1.06	0.63 ± 0.08	74.25 ± 1.53	14.33 ± 0.91
	E. globulus	9.49 ± 0.49	1.67 ± 0.76	18.00 ± 0.30	0.56 ± 0.02	74.77 ± 1.74	14.10 ± 0.53
	E. viminalis	10.01 ± 0.27	0.93 ± 0.15	18.87 ± 0.78	0.58 ± 0.02	73.86 ± 0.23	15.27 ± 0.21
	E. grandis	8.59 ± 0.57	1.67 ± 0.67	18.00 ± 0.52	0.58 ± 0.06	74.98 ± 1.91	14.73 ± 1.27
	E. camaldulensis	8.79 ± 1.25	1.80 ± 1.57	17.90 ± 0.26	0.59 ± 0.01	74.40 ± 1.52	15.00 ± 0.75
	Total	9.20 ± 0.83	1.67 ± 0.90	18.23 ± 0.67	0.59 ± 0.04	74.45 ± 1.34	14.69 ± 0.82
Medium	E. saligna	9.04 ± 1.27	1.27 ± 0.47	18.83 ± 0.75	0.58 ± 0.02	75.55 ± 0.90	14.20 ± 0.92
	E. globulus	9.61 ± 0.48	1.40 ± 1.08	17.97 ± 0.75	0.60 ± 0.06	74.60 ± 2.32	14.43 ± 0.87
	E. viminalis	11.23 ± 0.81	1.17 ± 0.83	18.50 ± 0.10	0.55 ± 0.02	73.57 ± 0.16	14.03 ± 1.16
	E. grandis	10.43 ± 0.67	1.40 ± 0.26	17.70 ± 0.30	0.59 ± 0.01	74.61 ± 0.74	13.57 ± 0.32
	E. camaldulensis	9.56 ± 0.52	1.33 ± 0.64	17.47 ± 0.46	0.58 ± 0.01	74.67 ± 0.23	14.43 ± 0.65
	Total	9.98 ± 1.05	1.31 ± 0.61	18.09 ± 0.69	0.58 ± 0.03	74.60 ± 1.18	14.13 ± 0.78
Top	E. saligna	9.60 ± 0.67	0.43 ± 0.15	18.77 ± 1.18	0.59 ± 0.00	74.30 ± 1.49	15.67 ± 2.31
	E. globulus	9.49 ± 0.31	1.57 ± 0.91	18.00 ± 0.69	0.60 ± 0.05	74.08 ± 1.43	14.87 ± 0.31
	E. viminalis	10.34 ± 0.59	1.17 ± 0.93	18.70 ± 0.66	0.56 ± 0.03	73.63 ± 1.57	14.87 ± 0.15
	E. grandis	13.60 ± 5.86	0.80 ± 0.10	18.70 ± 0.66	0.60 ± 0.02	74.03 ± 0.51	11.60 ± 6.15
	E. camaldulensis	9.60 ± 0.31	0.83 ± 0.67	17.73 ± 0.49	0.58 ± 0.01	74.32 ± 0.30	15.23 ± 0.23
	Total	10.53 ± 2.77	0.96 ± 0.68	18.38 ± 0.79	0.59 ± 0.03	74.07 ± 1.04	14.45 ± 2.91
Branch	E. saligna	8.88 ± 0.33	2.50 ± 1.14	19.07 ± 0.61	0.65 ± 0.01	71.47 ± 0.92	17.17 ± 0.51
	E. globulus	8.59 ± 0.80	2.97 ± 0.97	18.60 ± 0.85	0.67 ± 0.04	72.08 ± 1.50	16.40 ± 1.47
	E. viminalis	8.66 ± 1.02	2.70 ± 0.53	18.93 ± 0.31	0.63 ± 0.00	71.34 ± 0.78	17.33 ± 0.81
	E. grandis	9.28 ± 0.53	2.57 ± 0.06	18.50 ± 0.56	0.68 ± 0.02	70.49 ± 0.57	17.67 ± 0.85
	E. camaldulensis	9.52 ± 0.47	3.33 ± 0.35	17.73 ± 0.55	0.64 ± 0.02	69.15 ± 0.85	17.97 ± 0.51
	Total	8.99 ± 0.68	2.81 ± 0.69	18.57 ± 0.70	0.65 ± 0.03	70.91 ± 1.33	17.31 ± 0.94
Leaf	E. saligna	9.20 ± 0.65	3.60 ± 1.25	20.37 ± 0.40	0.69 ± 0.05	69.96 ± 2.33	17.27 ± 0.67
	E. globulus	8.29 ± 0.50	3.53 ± 0.64	18.30 ± 1.06	0.72 ± 0.06	72.75 ± 1.34	15.40 ± 1.11
	E. viminalis	8.24 ± 0.32	4.63 ± 0.70	19.37 ± 0.98	0.68 ± 0.04	71.30 ± 0.61	15.83 ± 0.81
	E. grandis	8.49 ± 0.73	3.80 ± 1.14	19.57 ± 0.47	0.64 ± 0.02	69.45 ± 1.11	18.27 ± 1.17
	E. camaldulensis	8.95 ± 0.37	5.20 ± 2.01	18.23 ± 1.54	0.72 ± 0.04	69.94 ± 0.75	15.90 ± 1.08
	Total	8.64 ± 0.60	4.15 ± 1.25	19.17 ± 1.18	0.69 ± 0.05	70.68 ± 1.70	16.53 ± 1.39

The ash content in the wood is used in evaluating the fuel-wood characteristics, which is generally considered to be a negative parameter [57]. The high ash content of a plant part makes it less desirable as a fuel since a considerable part of volume cannot be converted into energy [54]. An ideal fuel-wood species should have a high calorific value coupled with a high wood density and a low ash content [58]. The effect of tree part and species type on the moisture content was considered in the experiment at a ($p \leq 0.05$) significant level "Table 2". The effect of species type and interaction effect on the moisture content was insignificant at ($p \leq 0.05$), whereas the effect of tree parts was significant at ($p \leq 0.002$). Collectively, the variation of the independent variables (species type and tree part) account 49.7% of the variance in the number of cases studied. From the R^2 value (49.7%), the species type effect accounts 5.7% of the total variance, with the tree part effect account 19.81% and the interaction only shared 24.14% "Table 2". The same as the moisture content, ANOVA was considered in the experiment at a ($p \leq 0.05$) significant level to analyze the effect of tree parts and species type on the ash content "Table 2". Accordingly, the effect of species type and interaction effect on the ash content were insignificant at ($p \leq 0.05$), while the effect of tree parts on the ash content was significant at ($p \leq 0.0001$). Collectively, the variation or effects of the independent variables (species type, tree part, and interaction) account 74.74% of the variance in the number of cases studied. From the R^2 value (74.74%), the species type effect accounts only 1.5% of the total variance, with the tree part effect account 66.3% and the interaction shared 7% “Table 2”. The ash content decreases from bottom of the tree to leaf of the tree “Table 3”. The collective result of wood density, calorific value, ash content, and moisture content combined, and the fuel value index was obtained in this study. Accordingly, the fuel value index of *E. saligna* was 276.34 followed by *E. globulus*, which was 228.192. These two species had a higher fuel value index. *E. grandis* and *E. camaldulensis* had a lower fuel value index “Figure 3”. The study obtained by S. Ojelel *et al.*[47] and Desta and Ambaye [48] supports the present study and in line with the research outputs.

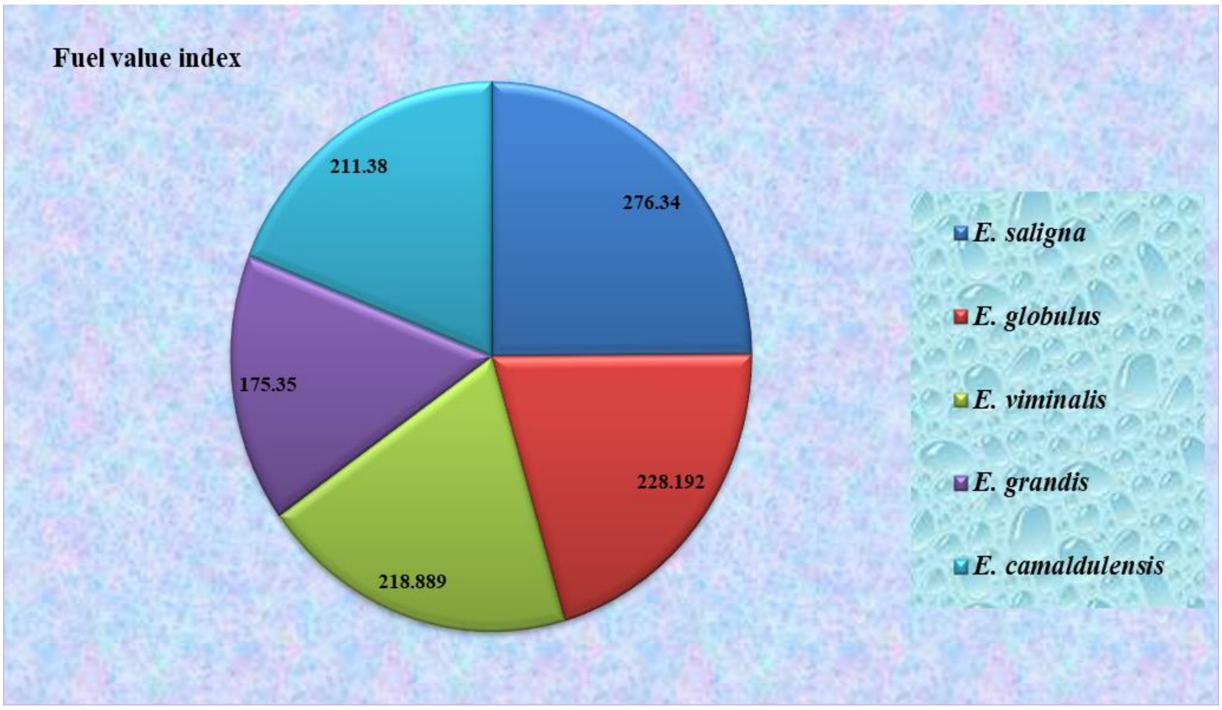

Figure 3. Fuel value index of selected trees.

The fuel value index is an important parameter for identifying new and reinforcing the traditionally used tree species as quality fuel-wood [59]. The fuel value index depends upon the caloric value, wood density, moisture content, and ash content of wood, which is an important parameter for screening desirable fuelwood species [4, 57]. Statistically, the effect of species type and the interaction effect on the fuel value index was considered in the experiment at ($p \leq 0.05$) significant level “Table 2”. The species type and interaction effect was insignificant. The effect of tree part on the fuel value index was significant at ($p \leq 0.0001$). The present study is in line with the previous study, as revealed in [59, 4, 57, 60]. Collectively, the variation or effects of the independent variables (species type, tree part, and interaction) account 26.1% of the variance in the number of cases studied (species types, 23%, tree part 2%, and interaction 1.1% “Table 2”).

4. Conclusion

In this investigation, a biomass potential and the fuel characteristics of the selected tree species were studied. The above-ground biomass varied from 13.96 kg to 87.47 kg $Tree^{-1}$, and the carbon content varied from 6.03 kg to 37.86 kg $Tree^{-1}$. The above-ground biomass significantly varied among the species. *E. globulus* had the highest above-ground biomass, volume, and basal area, while *E. camaldulensis* had the lowest value. Accordingly, the descending order for the above-ground biomass measurement was *E. globulus*, *E. viminalis*, *E. saligna*, *E. grandis, and E. camaldulensis*, respectively. This was the same as the carbon content of these tree species. The fuel value index of tree species ranged from 175.35 to 276.34 $Tree^{-1}$, and significantly varied among the species. *E. saligna* had the highest fuel value index, while *E. grandis* had the lowest value. The descending order for the fuel value index test was *E. saligna*, *E. globulus*, *E. viminalis*, *E.*

camaldulensis, and *E. grandis*, respectively. *Eucalyptus globulus*, *E. viminalis*, and *Eucalyptus saligna* were the most appropriate tree species for the studied area based on the tree fuel quality test.

5. Recommendations

In the highland area of Ethiopia, the Eucalyptus species are dominating and highly used for the fuel-wood purpose. Based on the present study done on the tree biomass potential and fuel characteristics, *E. globulus, E. viminalis, and E. saligna* were the most performed trees on the highland areas of the country; hence, the researchers recommend wide planting of these tree species to solve the fuel-wood scarcity in the highland areas.

6. Nomenclature

ANOVA	Analysis of Variance
DF	Degree of Freedom
GML	Generalized Linear Model
R^2	Coefficient of Determination
SS	Sum of squares
$Tree^{-1}$	Per tree

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