



FACULTY OF CIVIL TECHNOLOGY
DEPARTEMENT OF WOOD TECHNOLOGY

Preparation and characterization of charcoal made from
Acacia brevispica of different diameter classes in Gilgel
Beles.

North West of Ethiopia

By:

Yeshalem Sintayehu

ID.NO / 306/14

A Thesis Submitted to the Faculty of Civil Technology for the Partial
Fulfillment of the Requirements for the Masters of Science in Wood
Technology

Advisor: Dr. Sisay Feleke

Co-advisor: Moti Nebyu (Msc.)

August 2024

Addis Ababa, Ethiopia

FEDERAL TECHNICAL AND VOCATIONAL EDUCATION AND
TRAINING INSTITUTE
SCHOOL OF GRADUATE STUDIES

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Wood Technology

Yeshalem Sintayehu

Advisor

Sisay Feleke (PhD)

Addis Ababa, Ethiopia

July 2024

APPROVAL SHEET I

This is to certify that the thesis entitled “Preparation and Characterization of Charcoal Made from

Acacia brevispica of different around Gilgel Beles.Area”, submitted in partial fulfillment of the requirement for the degree of master’s specialization in Wood Science and Technology, by Yeshalem Sintayhu carried out under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Dr. Sisay Feleke.

Name of Major Advisor

Signature

Date

DECLARATION

I, Yeshalem Sintayhu, hereby declare that this thesis is my original work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree to the Federal Technical and Vocational Education and Training Institute. This thesis report could be deposited at the Federal Technical and Vocational Training Institute library to be made available to readers, under the rules of the library. I declare this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

Yeshalem Sintayhu

Signature

Date

ACKNOWLEDGEMENTS

Primarily, I want to express my gratitude to almighty God for the most compassionate and benevolent, without whom I would not have been able to begin and complete my study, as well as all other duties in my life, at this time. Besides, I express my gratitude to my advisers Dr. Sisay Feleke, for providing me with constructive counsel and assistance throughout the process of developing the proposal to the final write-up of this study. I would like to thank my co-adviser Mr. Moti Kanisa for providing me constructive counsel and assistance throughout the process of developing the proposal to the final write-up of this study. I would like to send my acknowledgment to Dangure local police Office workers for their contribution and support of in the process of sample collection and production of the Charcoal from *Acacia brevispica*. I would like to thank the Ethiopian Geological Survey, Manbuk Poly Collage, I would like to express my heartfelt gratitude to my husband Melkamu Muleta, and my Children has provided me with moral support and encouragement, Finally, the last but not the least gratitude my deep thanks go to my friends Wbetu Aweke and Minchel Megestu helping me in the preparation of collecting and transporting *Acacia brevispica* throughout the study.

List of Abbreviations and Acronyms

DPH	Tree diameter class based
AS	Ash Content
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Material
CRD	Complete randomized design
CV	Calorific Value
D	Density
DF	Degree of Freedom
FC	Fixed Carbon
GLM	General Linear Model
ISO	International Organization for Standardization
LSD	Least significant difference
MC	Moisture content
MS	Mean Square
NS	Not significant
VM	Volatile Matter
TDC	Tree diameter class based
TP	Tree position
B	Bottom
M	Middle
T	Top
LT	Total length of the tree
NGOs	Non-governmental organizations

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ABSTRACT

This study's primary goal is to assess the quality of the charcoal made from Acacia brevispica in the Gilgel Beles area produced in barrel. The study's objective is to clarify the characteristics and properties of the charcoal while talking about any potential advantages and drawbacks for the economy. By examining the production process and quality parameters, the research promotes sustainable resource management and provides valuable information to farmers who rely on charcoal production for their livelihood. A total of 9 Acacia brevispica of three Diameter A total of 9 Acacia brevispica of three Diameter classes were used for this study. A total of 9 Acacia brevispica of three Diames were used for this study. Each collected trees were divided in to three equal length and left over to natural drying for three weeks in open air. The carbonization process was performed in a barrel, burning/igniting for 2h until it changes the smoke colour emitted during burning then followed by blocking air with inverted another barrel left for 18h. The charcoal produced in this process had yield of 52-60%. The study has a treatment are wood density, moisture content, volatile matter, fixed carbon, Calorific value and Ash content. The data was analyzed by using General Linear Model of Multivariate Analysis (Two-way ANOVA) using SPSS version 26 where mean comparison made at $p \leq 0.05$ significant levels. There was a significant ($P < 0.05$) variation in Acacia brevispica density and moisture content in solaconditionamongdiameterandportion.

Key words: Acacia brevispica, diameter, carbonization, density, barrel, calorific value

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the Study

Currently, fossil fuels are the world's dominant energy source, making up around 80% (IEA, 2009). The fossil fuel price fluctuations, instability around the fossil fuel producing countries, depletion of the fossil fuel reserves becoming a global problem. The gradual rise of global warming and air pollution is also exacerbating the power deficiency throughout the world. Therefore scientists around the globe looking for potential source of sustainable energy, one of which is the renewable energy sources (Goldemberg J. , 2007). Renewable energy sources are more environmentally friendly and are thus better candidates for use in achieving some measures of technological development under a sustainable environment both in developed and developing nations. The contribution of forest resources to the livelihoods for the woodland communities has received greater attention during the last decade (Angelsen, A. et al , 2014). The benefits include both timber and non timber forest products such as construction materials, fuel wood, gum & resin and materials for charcoal production (Smith, H.et.al, 2017). Charcoal is a key contributor to the livelihoods of woodland communities and is widely used in urban and rural households for cooking because of its high heat value and smokeless characteristics (Schure, J., et.al , 2013). Charcoal producers in lowland areas use the free access raw materials collected from natural forests or other sources and turn them into marketable commodities in high demand (Tassie, K., et.al, 2021). About 230,000 tons of charcoal is being used per year for domestic purposes in Ethiopia. Charcoal, among the main products of woodland forests, is a critical source of energy in Africa; where close to 80% of the population uses it as the basic resource for cooking and heating .Studies indicated that about 90% of the Ethiopian energy comes from biomass of which charcoal is part of it (Yonas, A., et.al , 2013). Charcoal production provides a significant portion of urban and rural households' energy needs and is also a source of livelihood for 10,000 rural households in the country. In Ethiopia, charcoal is generally produced from the resources in the woodlands in traditional method of production (Duchoslav, J., et.al, 2019).Charcoal is mainly produced from communal lands, and its production is more traditional (using traditional earth kiln technology).The aim of this study specifically focused on the assessment of good charcoal production based on different tree diameter classes and tree height position providing that charcoal have several advantages over fuel

wood in terms of convenience in use, cleanliness, greater heat intensity and quality fuel characteristics, requirement of relatively smaller space for storage and transportation (Yaman, S., et.a, 200). Moreover, charcoal is relatively easy to ignite and can burn uniformly, with little smoke, little ash and preferred by women for easy break into the proper size for cooking. While being aware of the possible negative effects of charcoal production on the environment, few environmental policies awareness creation by the NGOs and the office of quality charcoal production management, attempted to intervene on the part of stakeholders. As a result, this study will motivate to assess the quality of charcoal production in the Gilgel Beles district produced in a metallic barrel. The result of this study contributes to the improvement of production system to intervene by the government and other development practitioners toward quality charcoal production.

1.2 Statement of the Problem

Ethiopia, as the country's renewable energy sector is still in its infancy stage, charcoal, among the main products of woodland forests, is a critical source of energy in the country; urban and pre urban areas of the country where close to 80% of the population uses it as the basic resource for cooking and heating. However, poorly controlled charcoal production practices accelerate the forest degradation of the woodland potential. The declining availability of fuel wood, coupled with population growth, the ever-rising prices of kerosene and cooking gas in Ethiopia, is creating a human and environmental crisis such as deforestation, desertification, soil erosion, ozone depletion etc. The charcoal production system is more unsustainable, low quality environmental problems, low charcoal yield, and traditional and rudimentary production. Charcoal production supports the majority of the livelihoods of rural households and provides a significant portion of urban households' energy demand in the country. This study tries to highlight how charcoal is produced efficiently and improved charcoaling method in order the negative effect of the production mechanism.

1.3 Objectives

1.3.1 General Objective

The general objective of the study was characterization of charcoal made from *Acacia brevispica* of quality charcoal manufacturing from different tree diameter classes in Gilgel Beles.

1.3.2 Specific Objectives

- To produce charcoal from different tree diameter classes and identify the effect and interaction effect the factors on charcoal yield and quality.
- To determine charcoal yield on carbonization of the selected species,
- To study the energy performance of carbonized wood charcoal production with regard to tree diameter classes,
- To estimate the efficiency of carbonization method.

1.4 Scopes and limitation of the study

The scope of this study is limited to the produce of charcoal from different tree diameter classes based on DBH regarding with tree portions / lower (Bottom), center (Medium) and upper (Top) of single species from Gilgel Beles area. The study sample collection was not replicated in area due to the budget and time constraints. This study used air-dried sample measurement of moisture content.

1.5 Significance of the study

Ethiopia has abundant biomass energy sources with lowest rates of access of community to modern energy. These biomass sources are mostly (>80%) used in traditional forms as firewood and charcoal. Preparation of charcoal from the abundant biomass sources such as forest biomass is one of the alternatives to make biomass energy more efficient and productive as an alternative source of energy supply. This study entails to showcase the option of alternative source of bioenergy production method by preparing charcoal from the selected tree species using locally available materials like ordinary barrel. This study also could show the use of bio economy of the forest resources biomass an economic, social and environmental benefits, especially which helps to raise the living condition of the urban and rural society's and also contribute the county's economic advancement.

CHAPTER TWO

2 LITERATURE REVIEW

2.1. Forest Biomass Energy

Ethiopia is one of the top 10 countries in Africa with the highest shares of biomass fuels in their total energy consumption. (AFREC, 2022) Biomass fuels in Ethiopia accounted for about 86% of the total energy consumption compared to the average 51% in Africa (IEA, 2022). Fuel wood consumption is one of the major causes of unsustainable utilization of biomass resources in Ethiopia (Moges, 2010). Today, at least, one-third of fuel wood comes from unsustainable extraction in forests and woodlands (MoFECC, 2017). Forests biomasses are a source of energy through the conversion of woody biomass into convenient solid, liquid or gaseous fuels to provide energy for industrial, commercial or domestic use. Over the course of the last 30 years, assessments of fuel wood consumption, both firewood and charcoal, in developing countries have changed substantially (O keefeet.al, 1985). Ethiopia is one of the most severely deforested countries in sub- Saharan Africa, particularly in forest degradation which resulted in soil erosion and degradation of agricultural and grazing lands. The decline in overall stability and productivity of the country's natural resource is the result of complex and interrelated series of processes that were triggered by the loss of forest cover in critical watershed (Kokou, K et.al, 2009). Even though, the charcoal is of good quality when part of the wood used is fresh, the excessive exploitation of the forest resources for energy purposes puts an important pressure on the ecosystems and leads consequently to serious environmental and biodiversity degradation. The impact of population growth on forest degradation and forest resource consumption is direct since needs of energy and other forest product services are essentially proportional to population size. (FAO, 2000). To cover energy needs, most households in Ethiopia resort to freely gathered biomass fuels. More than 85% of Ethiopian population lives in rural areas. The vast majority of the rural and urban populations are dependent on the traditional fuels wood, and in shortage cases the cow dung and crop residues burned for energy purpose otherwise to be used as organic soil enrichment. Therefore, charcoal is more advantageous and much preferred fuel wood than firewood due to being of lighter weight, less bulky, low in indoor air pollution and more compact, thereby easier to store indefinitely and cheaper to transport (Tinsae, B et.al , 2012). Biomass fuels like charcoal represent the case where energy

consumption is strongly linked with the economy (agriculture, households, services, and health) and the environment (soil nutrients, forest, air quality, and climate change). These linkages are of special interest in countries like Ethiopia where biomass is the main energy source (MoWIE, 2019). The consumption (figure 1) and productions (Figure 2) of charcoal in Ethiopia shows an increasing trend (AFREC, 2015)

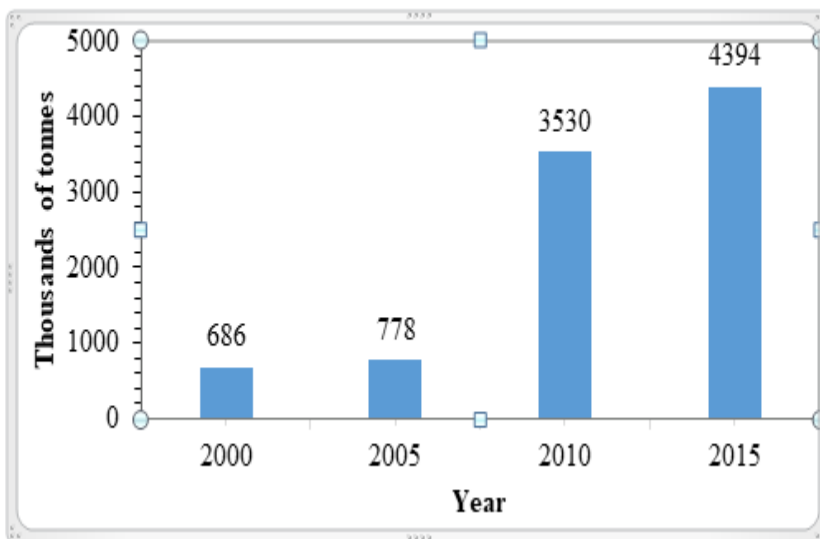
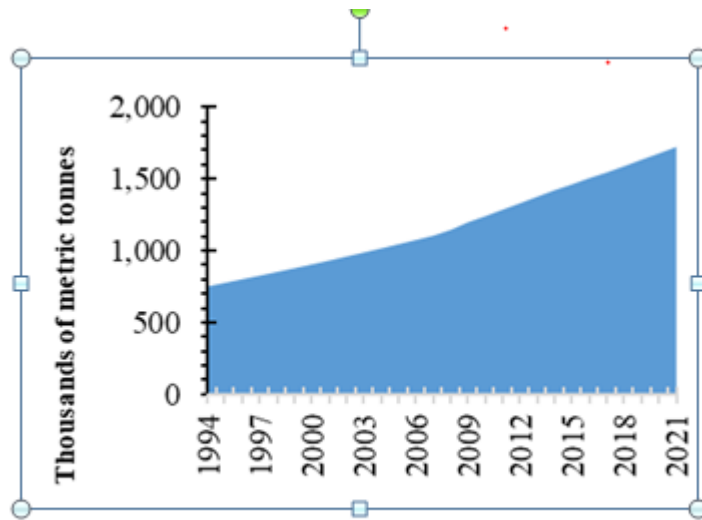


Figure 2. 1. Charcoal a) final energy consumption, b) production in Ethiopia

2.2. Morphology, ecology and management of *Senegalia brevispica*

Acacia senegalia brevispica was formerly known as *Acacia brevispica*. It was reclassified after molecular phylogenetic studies resulted in the transfer of many *Acacia* species into the genera *Vachellia*, *Senegalia*, *Mariosousa* and *Acaciella*, with Australian species remaining the *Acacia* genus *Acacia senegalia brevispica* (L) Willd (family: Leguminosae, Mimosoidea) is a promising multipurpose tree species in arid and semi-arid areas of Ethiopia with various socioeconomic and ecological benefits. (Kyalangalilwa et al, 2013).

Senegalia brevispica was reclassified after molecular phylogenetic studies resulted in the transfer of many acacia species into the genera *Vachellia*, *Senegalia*, *Mariosousa* and *Acaciella*, with Australian species remaining the *Acacia* genus (Kyalangalilwa, B et.al, 2011). In this document for easy of communication the *Acacia brevispica* naming maintained. It is more often a shrub, forming thickets, or scrambling over other plants. However, sometimes it grows to a slender tree to 7 m. Its bark is light grey–pale brown; young stems are green, hairy, and often zigzag. The thorns are characteristically small, single prickles, mostly hooked and scattered along the stems. The leaves are compound with 5–20 pairs of pinnae and leaf stalk to 10 cm. The flowers are fragrant, yellow-white in round heads on branching stalks to 10 cm. The shrub is very noticeable when in flower over large areas. The fruits are elongated pods containing 7,000–9,000 seeds per kg, usually straight to 15 cm, rough brown, and thin. The seeds inside are visible and easily split on the tree (Bekele-Tesemma, 2007). It is used for firewood, charcoal, fodder and live fence. *A. brespica* is commonly grown in dry as well as semi-humid parts of Africa, from Ethiopia and Sudan south to South Africa. It is found forming thickets together with other shrubs and trees in bush land. It grows well in Moist and Dry Kolla and Weyna Dega agroclimatic zones from 400–2,000 ma.s.l. *Acacia brevispica* (L) Willd (family: Leguminosae, Mimosoidea) is a promising multipurpose tree species in arid and semi-arid areas of Ethiopia with various socioeconomic and ecological benefits (Azene, Bet.al, 1993).The species is highly valued for its production of gum *Acacia* from trunks, branches and twigs. In addition to gum, a *brevispica* trees improve soil fertility and are widely used to control desertification. The tree also provides fuel wood, local construction materials, and livestock fodder from leaves and pods. It is highly suitable for agroforestry systems, for its nitrogen fixing ability in combination with agricultural crops (Consulter, 1991).In Ethiopia, natural stands of *Acacia brevispica* are found in the

Acacia-Commiphora woodlands in the western, southern and southeastern lowlands and Acacia woodlands in the rift valley region (Azene, A., et.al , 1993).

2.3. Charcoal Quality

Most acacia species are preferred by the community for charcoal productions as they produce good quality charcoal (Mekonnen, 2020).Charcoal will go further if it is used efficiently and if its quality is optimal for the particular end use. Charcoal quality can be specified and measured in various ways, which are usually derived from the end-use requirements; some of these ways are moisture content, volatile matter, ash content, and burning time. The least demanding market for charcoal quality wise for domestic purpose. Consumer's preference for quality charcoal is that the weight of the charcoal is also a determinant of its quality. Quite often, good charcoals are usually heavy, while the bad ones are likely to be very light and brittle. Charcoal of satisfactory market quality can be made in kilns of any size or type when suitable coaling temperature and time conditions are present.

2.3.1. Moisture content

The moisture content of wood fuels depends on the time of harvesting, the location, the kind, and the length of storage, as well as the processing of fire wood into wood fuel (charcoal production). Moisture content affects the calorific value, combustion temperature; exhaust therefore drying of the wood drying prior to carbonization will remove the process drawbacks. Since the pressure of the steam created when the wood is burned weakens and/or splits the resulting charcoal, wood with a moisture content of 10% or more has a significant susceptibility for internal and/or exterior use. Because of its impact on heating value, moisture is one of the difficulties that restrict the use of wood as fuel (Wamukonya, L et.al , 1995). All tree species have a fresh moisture level below 65%. When burning biomass, some of the energy is needed to turn water into vapor, which lowers the amount of energy available for heating (Gaafar, M *et.al* 2005).

2.3.2. Wood density

Acacia brevispica is known for its relatively high wood density compared to other acacia species. The average wood density of *Acacia brevispica* ranges from 700 kg/m³ to 900 kg/m³, depending on factors such as geographical location and growth conditions.

Density of wood varies greatly between various wood species and type of diameter classes, tree age, tree portion, geographical location, soil type etc. The most common species for use as fuel wood are between 650 and 750 kg/m³. It is crucial to keep track of how the overall moisture affects the density of the wood (Bekele, 2021). The grade of the charcoal declines with weight and water content. High-density characteristics make *A. brevispica* an excellent for firewood. Higher basic density is important parameters to fuel wood characteristics, trees with the highest density can generate large energy per unit volume (Groves, 1989). Increased density is important for the final quality of the charcoal, but it is necessary to observe alterations on the anatomic aspects of the wood, which are important for the field drying and carbonization process.

2.3.3. Wood Ash

Ash content is one of the important factors which directly affect the heating value of firewood (Groves, 1989). The ash content of good quality charcoal should not exceed 5% which is consistently calculated on a dry basis, which refers to the solid waste product left over after thorough combustion. Some agricultural residues can have substantially greater total ash levels than fuel wood, which typically has a total ash content of roughly 1%. This has an impact on the energy value of the biofuels because the materials that make up the ashes often have little energy value. A biomass fuel with 1% total ash has 3% more energy than dry wood fuels with 4% total ash (Friedl, 2005). In general, the higher amount of ash in biomass fuel wood makes it less charcoal quality.

2.3.4. Volatile Mater

Volatile matter is another factor governing the ignition and flame stability, the reactivity and burnout of chars, and the amount of unburned carbon in the fly ash (FAO, 2004). Volatile matter (VM) is the percentage loss in mass, adjusted for moisture, when charcoal is heated out of contact with air under standard conditions. When more volatile matters are in the mix, it liquid causes high reactivity during the pyrolysis process, resulting in increased production of biofuels. In general, the higher amount of volatile mater in biomass fuel wood makes it poor charcoal quality (Mohiodin, 2013).

2.3.5. Caloric Value and Carbon content

Calorific value is a measure of the amount of energy produced from a unit weight of charcoal when it is fully combusted in oxygen. The energy (calorific) value is used to determine the energy contents of biomass. The elements occurred in charcoal such as moisture content, ash content and elemental composition primarily affects the energy (calorific) value the fixed carbon content of charcoal ranges from a low of about 50% to a high or around 95%. The carbon content is usually estimated as a "difference"; all the other constituents are deducted from 100 as percentages and the remainder is assumed to be the percent of "pure" or "fixed" carbon. The fixed carbon content is the most important constituent in metallurgy since it is the fixed carbon which is responsible for reducing the iron oxides of the iron ore to produce metal. It is further reported that a lower moisture content, ash and volatile matter content determine a higher fixed carbon that resulted in a quality charcoal vice-versa. The determination of fixed carbon is vital for assessing biomass materials because it represents a large portion of the biomass that must be burnt in the solid state. As the percentage of fixed carbon increases, it indicates the high quality of charcoal is produced (Mencarelli *et al.*2022).

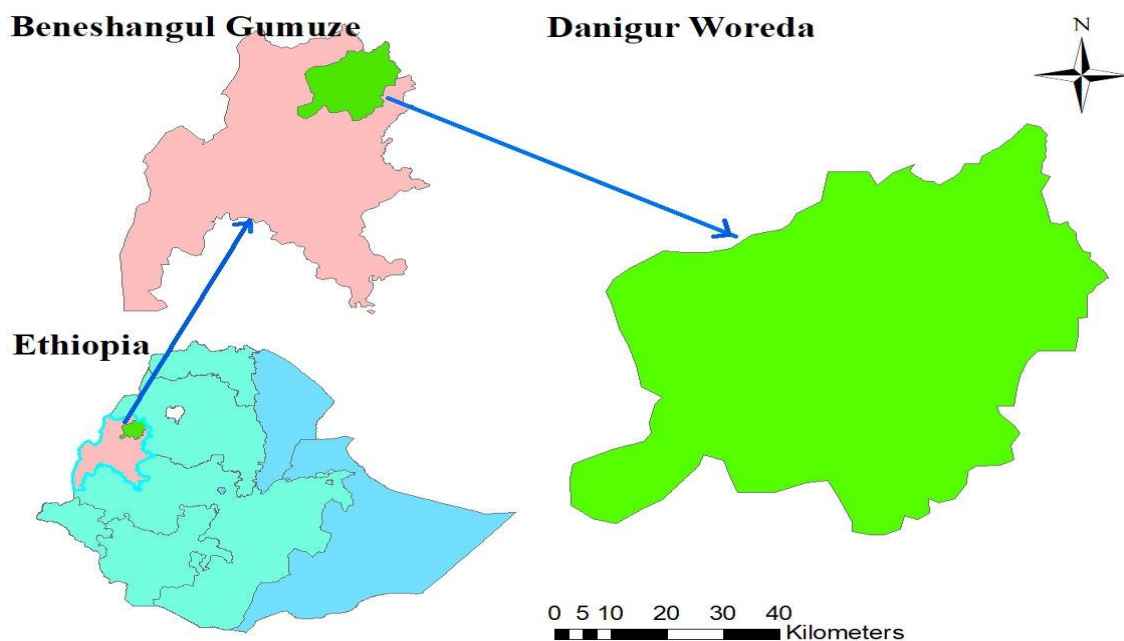
2.4. Conceptual frame work on the study

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Site

The study was conducted around Gilgel Beles watershed is the sub-watershed of upper Tana Beles River basin, located in north-western of Abay River basin and situated in Metekel Zone of Benishangul-Gumuz region of northwest of Ethiopia. Metekel zone is situated at distance of 546 km from Addis Ababa north-west direction. The geographical location of the town is approximately 11°10' to 11° 15' 28" N Latitude and 36° 16' 50"E to 36° 46' 9" E Longitude. The study area is located 94.8 km away from Metekel Town. Gilgel Beles River flows from northeast to west passing through Gilgel Beles town. The watershed has an altitude range from 956-2500m above sea level with a total area coverage 770 km² (Nega, T.et.al , 2021).



figuer 3. 1Map of the study area Sources: Researchers.

3.2. Sample Collection and Preparation

A total of nine *Acacia brevispica* (L) Willd trees in three diameter classes (5 to 8 cm; 8 to 10 cm and 10 to 13 cm), were randomly selected from the natural woodlands around Gilgel Beles. After the tree cut down, the logs were cut into three equal portions lower (bottom), center (medium) and upper (top) parts with length approximately one third of the total length of the tree.

Table 3. 1. Sample selection procedure based on tree portion and tree diameter class

Tree position	Tree diameter class based on DBH									remark
	ADC-1			BDC-2			CDC-3			
Top	1/3 of L_t (TA)			1/3 of L_t (TB)			1/3 of L_t (TC)			
Medium	1/3 of L_t (MA)			1/3 of L_t (MB)			1/3 of L_t (MC)			
Bottom	1/3 of L_t (BA)			1/3 of L_t (BB)			1/3 of L_t (BC)			
Replication	1	2	3	1	2	3	1	2	3	

Noted! The total of nine numbers of trees was used for one replication in the experiment

Where:-

L_t : - Total length of the tree

T: - Top position of the tree

M: - Medium position of the tree

B: - Bottom position of the tree, and

DC-1, DC-2, and DC-3 - are different diameter class (DBH)



3.3. Green wood drying and cutting processes

Acacia brevispica (L) collected wood was allowed to dry under the natural condition solar drying method for a period of two to three weeks to an average moisture content

rich between 13 % to 17 %. Next, the dry wood was cut into 20 cm length to the size of the barrel kiln for charcoal production.

3.4. Carbonization and charcoal production from the selected species

Charcoal is produced in Earth kiln system around the *Gilgel Beles* town with no capital investment and special equipment requirement (only hand tools like hoes, rakes, shovels, buckets and ladders etc. were used during the experimental work). In this study, I used barrel than the usual charcoal appropriately sized logs with different diameter class (5 to 8 cm; 8 to 10 cm and 10 to 13 cm) were prepared accordingly to the experimental setup weighing 1,420g for 5 to 8 cm DBH top, middle 3,550 g weight, bottom 4,755 g from 8-10 cm DBH top 2,545 g from g, middle 3,790g, bottom 8,890g and from 10-13cm DBH top portion weighing 4,450 g, middle 8,655 g and bottom 12,540 g weight of dry wood was subjected to barrel kiln for the carbonization processes. The processes of wood carbonization into charcoal have been observed by monitoring the change in smoke color from the carbonization barrel chimneys and natural outlets. The color transitioned to light blue, indicating the completion of carbonization (Pennise, 2001). Charcoaling of the *Acacia* species in the barrel takes on average. (18h). After the completion of the carbonization processes, the unburned wood and the charcoal product were collected separately put in the sack and weighed using a balance the wood to charcoal conversion efficiency of the barrel kiln during each batch carbonization processed.



figuer 3. 3. Carbonization and charcoal production from *Acacia brevispica*

3.5. Determination of Moisture Content

The moisture content (MC) on a dry basis has been determined using the standard method (ASTM, 2017)The weight of green wood sample was subjected to solar drying method until its mass reached a constant weight. Then MC before carbonization process of the sample calculated using the following formula.

$$MC(\%) = \frac{W_1 - W_2}{W_1} \times 100 \text{ --- Equation 3.1}$$

Where: W_1 is the initial weight, W_2 is the weight after drying, and MC is the moisture content.



figure 3. 4. Air drying the sample and measuring the weight of specimens

3.6. Determination of density

The density determination performed in accordance with the sample preparation of carbonization left over to natural drying and 18 days air drying prepared from the middle portion of the second internode at the bottom, middle, and top portions of all diameter categories with 3 cm thickness disk. The volume was measured at fresh level using water displacement method by immersing sample cut of 30 mm thickness disk from the middle part of the culm portion internodes in two-third filled graduated beaker with distilled water. The dry weight of each specimen was obtained after drying in oven at a temperature 103 ± 2 °C until constant weight record. The basic density of the samples calculated as follows.

$$\text{Basic density} = \frac{\text{dry weight of sample (kg)}}{\text{grean volume of sample (m}^3\text{)}} \text{Equation 3.2}$$



figure 3. 5. Measuring the volume and sundry mass of the samples

3.7. Determination of charcoal yield

The yield of producing charcoal has been computed based on the air dry biomass (DB) using the following formula (ASTM, 2017).

$$\text{Charcoal yield} = \left(\frac{\text{CM}}{\text{BM}} \right) * 100 \text{ --- Equation 3.3}$$

Where: CM: - Mass of charcoal produced and BM: - Mass of air dried woody biomass input

3.8. Determine the efficiency of barrel mound kiln

The wood-to-charcoal conversion efficiency of the barrel kilns was calculated following the method (FAO., 1997). The method holds significant importance as it takes into account crucial factors such as the moisture content of the wood, unburned wood, and the total energy utilized to achieve conversion yields. The wood to charcoal conversion efficiency of the barrel kilns in this charcoal production study system has been computed based on the mass of air dry wood (MDW), mass of charcoal (MC), and mass of unburned wood (MUW) using the following formula.

$$\text{NE} = (\text{MC}/(\text{MDW} + \text{MUW} + \text{BO})) * 100 \text{ --- Equation 3.4}$$

Where: NE= Net efficiency of the kiln, MC = mass of charcoal, MDW = mass of dry wood, MUW = mass of unburned wood, and BO = is the total energy used to obtain conversion yields (initial burnings).

3.9. The Proximate Analysis of the *Acacia brevispica* Charcoal

3.9.1. Moisture Content Determination:

The moisture content (MC) of the charcoal was assessed following the established protocol (ASTM, 2017). A pulverized charcoal sample weighing 1 g was subjected to oven-drying at 105°C for 2 hours until its mass reached a constant value. The MC of the sample was then calculated using the formula:

$$MC(\%) = \frac{W_1 - W_2}{W_1} \times 100 \dots\dots\dots (1)$$

Where, W1- represents the initial sample weight, W2- is the weight after drying, and MC is the moisture content.

3.9.2. Volatile Matter Determination:

The volatile matter (VM) was determined as per (ASTM, 2018). A 1 g sample of pulverized charcoal was taken and heated at 950°C for 6 minutes, subsequently cooled in a desiccator, and weighed until a consistent mass was achieved. The VM was calculated using the equation:

$$VM(\%) = \frac{W_1 - W_2}{W_1} \times 100 \dots\dots\dots (2)$$

Where, VM - stands for volatile matter, W1 is the original sample weight, and W2 is the weight after cooling.

3.9.3. Ash Content Determination:

The ash content (ASH) was assessed following the (ASTM, D3174-1 2018) standard. To determine the ash weight, 1 g of moisture-free pulverized charcoal sample was heated at 550°C for 4 hours and weighed after cooling in a desiccator.

$$ASH(\%) = \frac{W_2}{W_1} \times 100 \dots\dots\dots (3)$$

Where, W2 signifies the weight of cooled ash, and W1 is the initial weight of the dry sample

3.9.4. Determination of Fixed Carbon:

The fixed carbon (FC) was computed by subtracting the sum of VM, ASH, and MC from 100, using the equation:

$$FC = 100\% - (ASH + MC + VM) \dots\dots\dots (4)$$

3.10. The Ultimate Analysis of *Acacia brevispica* Charcoal production (Placeholder1)

3.10.1. Calorific Value Determination:

The calorific value (CV) of the produced charcoal was determined employing a Parr Oxygen bomb calorimeter, adhering to the (ASTM, 2019) standard. The bomb calorimeter was calibrated using a standard sample of benzoic acid with a known calorific value of 26.4 MJ/kg. Two gramme sample of pulverized charcoal was placed in the crucible, and the bomb calorimeter was operated following the standard procedure.

3.5. Data Analysis

The gathered data were subjected to statistical analysis using SPSS software (Version 9) and Microsoft Excel (2016). This experiment has been performed following a completely randomized design (CRD) with a total of two Diameter class and tree portion each with three levels of treatments in three replications. The Least Significant Difference (LSD) at the significance level of $P < 0.001$ was employed to compare means that exhibited significant disparities.

figure 3. 6. Experimental design

CHAPTER FOUR

4. Result and Discussions

The *Acacia brevispica* sample collected from the woodlands around Gilgel Beles area have a broad range density 610 kg/m³ to 960 kg/m³ with an average density of 780 kg/m³ (Table 4.1). The density value of this study is in the range and good agreement for *A.brevispica* in Tigray region (Mengeteab et al 2018). The wood density of the Acacia tree statically varies in tree diameter and along the tree position. the wood with larger diameter exhibited higher density and it was statically significant difference between the *Acacia brevispica* sample collected from the woodlands around Gilgel Beles area have a broad range density 610 kg/m³ to 960 kg/m³ with an average density of 780 kg/m³ (Table 4.1). The density value of this study is in the range and good agreement for *A.brevispica* in Tigray region (Mengeteab et al 2018). The wood density of the Acacia tree statically varies in tree diameter and along the tree position. The wood with larger diameter exhibited higher density and it was statically significant difference between the density of each diameter classes. Similarly, there was a significant difference in density along the tree position where the largest density was recorded in bottom part of the tree. Overall the density difference of 163.3 kg/m³ between the bottom and top portion of the wood. The Tukey HSD comparison test showed that the wood sample from 10-13 cm DBH has significant difference from the 8-10 cm and 5-8 cm DBH *Acacia brevispica* wood. The results of the percentage of green wood moisture content (MC_{wood}) experimental analysis have showed that maximum MC_{wood} (16.4%) was recorded for the charcoal produced from 5-8 cm tree diameter classes and minimum MC_{wood} (14.4%) was recorded for the charcoal produced from 10-13 cm tree diameter classes (Table4. 2). In addition, the tree position has a significant effect on the amount of MC_{wood} in the charcoal product ($P < 0.001$). The maximum MC_{wood} (16.41 %) was recorded samples from top tree position and a relatively lower MC_{wood} (14.43 %) was observed on bottom tree position (Table 4.2). In general, a lower percentage of MC_{wood} in the carbonization process of the wood to charcoal products enhances the yield, increase retort efficiency, fuel quality (calorific value) (Chaney *et al*, 2010).

4.1. Proximate and ultimate analysis of charcoal

The physicochemical properties of the charcoal products were determined by employing

The standard test methods and the results were elaborated properly. The proximate analysis of the charcoal products involves the determination of moisture content of green wood and charcoal product (%), moisture content of charcoal (%), volatile matter (%), ash content (%), and fixed carbon (%), whereas, the ultimate analysis includes the determination of calorific value (cal/g). The results of the analysis of variance (ANOVA) for the proximate and ultimate analysis of the produced charcoal with the main and interaction effects of experimental variables are presented in Table 4.1. The main effects have been observed and hence, tree diameter classes have a significant effect ($p < 0.001$) on the green wood moisture content, density, wood-to-charcoal conversion efficiency, charcoal yield, and ash content. Whereas trees diameter classes has an insignificant effect on charcoal moisture content, volatile mater, fixed carbon and calorific value. On the other hand, the main effects of tree position were observed and had a significant effect ($p < 0.001$) on the green wood moisture content, density, wood-to-charcoal conversion efficiency and charcoal significant effect on charcoal moisture content, volatile mater, fixed carbon, ash content and calorific value.

Table 4. 1. Average data of *Acacia brevispica* wood and physicochemical properties of the charcoal.

Treatment	<i>Acacia brevispica</i> DBH	Portions of the DBH			
		Top	Middle	Bottom	Mean
Density (kg/m ³)	5-8 cm	0.62	0.76	0.83	0.73 ^b
	8-10 cm	0.66	0.79	0.87	0.77 ^b
	10-13 cm	0.80	0.88	0.96	0.88 ^a
	Mean	0.69 ^c	0.81 ^b	0.86 ^a	
Moisture content in dry condition (%)	5-8 cm	17.33	16.34	15.56	16.41a
	8-10 cm	16.34	15.34	14.29	15.33b
	10-13 cm	15.61	14.26	13.43	14.43a
	Mean	16.42 ^a	15.31 ^a	14.42 ^a	
Charcoal Yield (CY) (%)	5-8 cm	35.13	21.72	22.72	26.52 ^{ab}
	8-10 cm	20.11	21.38	21.93	21.14 ^b
	10-13 cm	31.10	27.21	34.64	31.65 ^a
	Mean	28.88 ^a	23.43 ^a	26.43 ^a	
(NE %)	5-8 cm	31.13	20.14	20.98	24.0
	8-10 cm	18.32	20.30	21.36	20.0

	10-13 cm	30.04	20.24	33.57	27.95
	Mean	26.49	20.22	25.30	
MCcharcoal (%)	5-8 cm	6.18	5.8	5.9	5.96
	8-10 cm	6.13	5.45	5.35	5.64
	10-13 cm	5.75	6.09	5.10	5.64
	Mean	5.93	5.81	5.45	
VM%	5-8 cm	26.34	26.12	27.45	26.63
	8-10 cm	27.80	26.61	26.12	26.84
	10-13 cm	30.84	27.24	30.27	29.45
	Mean	28.32	26.65	27.94	
(FC%)	5-8 cm	62.56	63.34	63.95	63.28
	8-10 cm	62.51	63.11	64.32	63.31
	10-13 cm	61.11	63.55	66.61	63.75
	Mean	62.06	63.33	64.96	
(AS%)	5-8 cm	4.30	4.10	4.06	4.15
	8-10 cm	4.08	4.56	4.21	4.28
	10-13 cm	3.3	3.35	3.08	3.24
	Mean	3.89	4.00	3.77	
CV (Cal/gm)	5-8 cm	6806.20	7038.24	6699.27	6847.90
	8-10 cm	6815.36	6758.11	6961.27	6844.91
	10-13 cm	6791.88	6871.46	6919.41	6860.
	Mean	6804.48	6889.27	6859.98	

Table 4. 2. Analysis of Variance (ANOVA) for the proximate analysis, calorific value of the produced charcoal from *Acacia brevispica*;

Source of Variation	D F	Mean Square								
		MC _{wood} (%)	D (kg/m ³)	NE	CY (%)	MC _{charcoal} (%)	VM (%)	FC (%)	AS (%)	CV (Cal/gm)
TDC	2	8.33**	0.08***	185** *	186** *	0.34	22	4.92	3.24* *	27638
TP	2	9.02***	0.03** *	52**	65**	0.72	6.9	7.28	0.24	54564

TDC*TP	4	0.54	0.01*	71***	70***	0.35	4.06	4.06	0.2	18569
CV (%)		2.12	6.16	0.88	11.14	9.35	11.61	11.6	17.72	2.74
R-Square		0.95	0.85	10.46	0.85	0.41	0.29	0.29	0.47	0.27

- Significant at $p < 0.05$; ** - Significant at $p < 0.001$; *** - Significant at $p < 0.01$; R - regression coefficient.

4.1.1. Charcoal moisture content

The effect of TDC of *Acacia brevispica* showed highly significant difference but statistical similarities of $MC_{charcoa}$ were recorded on diameter class of 5-8 cm with the value of top portion maximum 6.29% and minimum value of recorded on 10-13 cm with the value of 4.77%, respectively (Table 4.1). Moreover, computing along TP, highly significant variation observed between the top 6.02% and bottom tree portions made charcoals, while the charcoal made from the middle portion (5.83%) didn't show a statistical significance difference either to the top or bottom part made charcoal (Table 4. 3). These values were in agreement with earlier experimental results reported by (Sisay. et al., 2020) found in the average moisture content 5.60% for the study of production and characterization of charcoal briquette from *Oxytenanthera abyssinica*, *Arundinaria alpina*, *Acacia melifera* and *Prosopis juliflora*.

4.1.2. Volatile matter (VM)

Volatile matter is one of the factors governing ignition and combustion processes because the presence of volatile matters makes easier to ignite, generally have better flame stability and improved carbon burn out, and lower NOx emissions (Gulan, 2018). Charcoal produced from 8-10 cm tree diameter classes has the maximum percentage of volatile matter with the value of 26.84% and followed statistically similar VM in charcoal produced from 5-8 (26.63%) and 10-13 cm tree diameter classes with the value of 29.45% (Table 4. 2). When, computing along with tree position, statistically significant difference in VM with the value of 28.33% for top, 26.66% for middle and 27.95% for bottom portions (Table 4. 3). The presence of low VM in the produced charcoal enhances its combustion tendency in which a heterogeneous smokeless and flameless burning process takes place within the porous fuel or burning (De Souza et al, 2004). These values were in agreement with earlier experimental results reported by (Fikremariam. et al, 2020) found in the VM in the range 26.06% to 29.19% for the study of production and

characterization of briquettes from carbonized *Cupressus lusitanica* sawdust with different organic binders.

4.1.3. Fixed carbon (FC)

Fixed carbon (FC) is a measure of the solid combustible material in solid fuel after the expulsion of VM; moisture content and ash; its content is used as an estimate of the amount of coke obtained on carbonization (Diezet al, 2002). In other words, FC is the major quality measuring parameter that determines the energy behaviors in the production of DBB (Gomez et.al, 1995). When explained in the same way, FC in the dry bio carbon for use in metallurgical processes and it is an important factor for measuring the non-volatile carbon remaining after a sample is heated at 900 °C for a period of 10 minutes in woody biomass (ASTM, 2013). The results show that the main effects of FC on charcoal making from different DBH from *Acacia brevispica* was insignificant. The effect of DBH and TP on the charcoal FC statistically insignificant, however variation in either of the factors DBH or TP exist. This indicates that the FC content doesn't depend on the biological nature of the input material, biomass; rather it is affected by the carbonization processes (Table 4.2.) Moreover, computing along with TP on FC presented statistically not significant differences with the value of 61.93% for top TP, 62.87% for medium TP and also 63.73% for bottom TP. These values were approached to earlier experimental results reported by (Imeh et.al, 2017) the FC value in the range 75.96% to 87.2% for the studies of production and characterization of biomass briquettes from tannery solid waste.

4.1.4. Ash content (AC)

The percentage of ash content (AC) is the proportion of the non-combustible components of biomass materials and it has a significant impact on the combustibility of fuels (i.e., woody charcoal) derived from the biomass (Mitchual et al, 2014). The higher ash content in the fuel induces the higher emissions of dust particles the so-called particulate matters (PM) and the lower calorific value of the biomass briquette (Li et.al , 2000). In other words, ash is the inorganic oxide residue remaining after the water and organic matter have been removed at high temperature muffle furnace capable of maintaining temperatures of between 500 and 600 °C in the presence of oxygen. The diameter class and tree portion of the *A.brevispica* didn't show a statistically significant difference. However, the ash content of the charcoal produced from different TDC and TP showed different values of ash were recorded on 5-8 cm DBH with the value of 4.15% and 8-10

cm DBH with the value of 4.38%, while minimum value was recorded on 10-13 cm DBH with the value of 3.78%, respectively. (Table 4. 2). The decrease in the amount of ash content in the biomass increases the quality of fuel (Imeh et al, 2007). In general, a lower percentage of ash content in the woody charcoal products enhances the fuel quality (calorific value) and the ignition characteristics of the charcoal (Chaney et al, 2010). Thus, the obtained values indicated that ash content in the experiment showed that the produced charcoal from *Acacia brevispia* with 5-8 cm and 8-10 cm DBH exhibits better fuel characteristics or fuel quality than the charcoal produced with 10-13 cm DBH. The high content of ash in charcoal from large diameter input material attributed to the accumulation of this inorganic material throughout the growth life time of the tree.

4.1.5. Calorific value (CV)

Calorific value, sometimes called heating value or heat of combustion, is a standard that measures the total energy content produced in the form of heat when a substance is combusted completely with air or oxygen (Bhuiya et al, 2008). The main effects of TDC and PT on CV of specified tree sample have shown statistically insignificant difference values were observed on 5-8 cm DBH, 8-10 cm DBH and 10-13 cm DBH with the value of 6948 cal/gm., 6845 cal/gm. and 6861 cal/gm., respectively (Table 4.2). When, computing along within TP. statistically not significant difference CV were observed with the value of 6804 cal/gm. for top TP, 6889 cal/gm. for medium TP and 6950 cal/gm. for bottom TP. These values were found to be superior/much better results with earlier experimental results.is found in the ranging interval between 4214.068 cal/g to 4973.58 cal/g. in accordance to (Heuzé,V *et.al* 2019). Therefore, woody charcoal product from *Acacia brevispia* were of high heating value that is adequate and can be used for domestic cooking, heating space, and small-scale industrial applications as an alternative energy source to firewood.

Table 4. 3.The main effects of tree diameter class based on DBH and tree position on the physicochemical properties of the charcoal produced from *Acacia brevispia*;

Treatment	Mean Square					
	MC _{wood} (%)	MC _{charcoal} (%)	VM (%)	FC (%)	AS (%)	CV (Cal/gm)
TDC						
5-8 cm	16.41 ^a	5.8 ^a	26.63 ^a	63.23 ^a	4.15 ^a	6948 ^a
8-10 cm	15.32 ^b	5.45 ^a	26.84 ^a	63.31 ^a	4.38 ^a	6845 ^a

10-13 cm	14.43 ^c	5.64 ^a	26.63 ^a	61.99 ^a	3.15 ^a	6861 ^a
LSD_{0.05}	0.32	0.53	3.17	3.08	0.69	187
TP						
Top	16.42 ^a	6.02 ^a	28.33 ^a	61.93 ^a	3.89 ^a	6804 ^a
Medium	15.31 ^b	5.81 ^{ab}	26.66 ^a	62.87 ^a	4.1 ^a	6889 ^a
Bottom	14.42 ^c	5.46 ^b	27.95 ^a	63.73 ^a	3.78 ^a	6950 ^a
LSD_{0.05}	0.32	0.53	3.18	3.07	0.69	187

Means that do not share a letter are significantly different at $P < 0.05$

4.2. Interaction effects of tree diameter classes and tree position on proximate and ultimate analysis

In this study, the experimental analysis revealed that the interaction effects have been observed that, highly significantly affected the green wood moisture content, the green wood density, wood-to-charcoal conversion efficiency and charcoal yield at $P < 0.0001$. But not significant effect on the moisture content of the produced charcoal, volatile mater, fixed carbon, ash content and caloric value at the level of probability, $P < 0.05$ (Table 4.2).

4.2.1. Wood moisture content

The effect of the moisture content between the tree DBH and portion has shown significant value at $P = < 0.001$ shown (Table 4.1), with the corresponding average moisture content of 5-8 DBH (16.14%), DBH 8-10 (15.53 %) and DBH 10-13 (14.43%) respectively. Regarding the portion of top, it has been shown that statistically significantly different higher values of moisture contents were recorded as 16.14 % for DBH5-8, (15.53 %), DBH 8-10 and (14.43%) for DBH 10-13 (Table 3). Moreover, a relatively higher value of moisture contents were also obtained from samples of DBH5-8 moisture content is an indispensable property that can enormously influence the burning characteristics of the charcoal produced from considerable biomass. In addition to the previous work by (Michael *et al.*, 2022), moisture content is one of the indicators of the quality of the charcoal to be used; the lower the moisture content, the higher the quality of charcoal.

4.2.2. Density green wood (D)

In this study, the interaction effects of TDC and TP on physical characteristics of the green wood density of *Acacia brevispica* were presented in Table 4.3. There was a significant difference at the level of probability, $P < 0.05$ among DBH groups and along TP. The highest (960 kg/m³) density were obtained in 10-13 cm DBH at bottom, the

lowest density (660 kg/m³) was recorded in sample from 8-10 cm DBH respectively (Table 4.4). These values were found to be superior/much better results with earlier experimental results reported the density of woody material increases as more vascular bundles packed into a smaller region, resulting in a decrease in the overall air volume. Similarly (Siam et al , 2019). found that the densities of *B. vulgaris* species to vary with age and along the culm length; density values ranged from 709.63 kg/m³ to 937.95 kg/m³, and increasing from the basal portion of the culm to the top.

4.2.3. Wood-to-charcoal conversion efficiency (NE)

The efficiency of charcoal production is dependent on many factors, such as kiln type and composition, kiln covering material, carbonization time and temperature moisture content, species, wood density, the arrangement of the wood inside the kiln, the skill and experience of the producer, and even the climatic conditions (Chaposaet.al , 2002). In this study, the interaction effect between TDC and TP on the wood-to-charcoal conversion efficiency of different tree diameter classes for making charcoal from *Acacia brevispica* had a significant effect ($p < 0.001$). The statistical analysis revealed significantly ($p < 0.001$) higher and statistically similar charcoal conversion efficiency at 10-13 cm DBH classes with the value of 30.04% (top) and 33.02% (bottom), followed by 5-8 cm DBH classes with the value of 31.13% (top). Minimum percentage of wood-to-charcoal efficiency was observed on the charcoal product made from medium and bottom tree position with the value of 15.08% and 16.16% at tree diameter classes 5-8 cm DBH. In general, when the three DBH classes were compared transversely, the highest wood-to-charcoal conversion was obtained from 10-13 cm DBH with the average value 28.40% and the lowest value wood-to-charcoal conversion was obtained from 5-8 cm DBH with the average value 19.53% (Table 4.4). Furthermore, computing along within different tree diameter classes, highly significant value of NE was recorded on 10-13 cm DBH with the average value of 28.40%, which is maximum 31.23% than 5-8 cm DBH (19.53%) and 21.31% than 8-10 cm DBH (22.35). Therefore, Charcoal can be readily produced from wood with no capital investment in equipment through the use of traditional earth mound kilns and it is important to learn methods for maximizing the efficiency of its potential (Kayham2013).

4.2.4. Determination of charcoal yield (CY)

The interaction effects of the TDC and TP on the percentage of charcoal yield (CY) in the charcoal products in this study showed a significant variation at the level of probability,

($p < 0.0001$). The maximum and statistically uniform CY was found in the charcoal product from 10-13 cm DBH with the value of 34.64% (bottom) and 31.10% (top). Minimum percentage of CY was observed on the charcoal product made from medium and bottom tree position with the value of 15.08% and 17.01% at tree diameter classes 5-8 cm DBH. In general, when the three DBH classes were compared transversely, the highest CY was obtained from 10-13 cm DBH with the average value 29.42% and the lowest CY was obtained from 5-8 cm DBH with the average value 20.19% (Table 4.4). Furthermore, computing along within different tree diameter classes, highly significant value of CY was recorded on 10-13 cm DBH with the average value of 29.42%, which is maximum 31.23% than 5-8 cm DBH (20.19%) and 19.37% than 8-10 cm DBH (23.72). Generally, charcoal producers should be known, high yield of charcoal is obtained at low temperatures around 300°C with a high content of volatile material. Temperatures around 600°C give lower yields with a low content of volatiles which makes it a preferred fuel (Seide, 2008).but charcoal producers generally prefer the higher yield. The charcoal yield decreases as the temperature increases (Konwer, et.al, 2009). This indicates that charcoal producers take care to control the temperature to increase the yield.

Table 4. 4.Physicochemical properties of the charcoal produced from *Acacia brevispia* charcoal

Treatment		Mean value		
TDC	TP	Density (kg/m ³)	NE (%)	CY (%)
5-8 cm	Top	0.62 ^e	31.13 ^b	35.13 ^{ab}
	Medium	0.76 ^d	20.14 ^e	21.75 ^d
	Bottom	0.83 ^b	20.98 ^e	22.72 ^d
8-10 cm	Top	0.66 ^e	18.3 ^d	20.11 ^c
	Medium	0.79 ^d	20.30 ^b	21.38 ^b
	Bottom	0.87 ^e	21.36 ^d	21.93 ^{cd}
10-13 cm	Top	0.80 ^{bc}	30.04 ^a	31.10 ^a
	Medium	0.92 ^{ab}	20.25 ^{bc}	27.21 ^{bc}
	Bottom	0.96 ^a	33.57 ^a	34.6 ^a
LSD_{0.05}		0.05	2.43	2.71

Values followed by the same letters under the same column are Statistically non-significant at level of probability, $P < 0.05$

4.2.5. The proximate analysis and calorific value for the green wood from *Acacia brevispica*

The results of the T-test analysis on the proximate and ultimate analysis between the green wood and charcoal product analyzed experimental variables are presented in Table (4.5). The effect of green wood and charcoal product on the parameter considered in the experiment, vis. percentage of moisture content, volatile matter, fixed carbon The values of fixed carbon, ash content, moisture content, volatile matter and calorific value are presented in Table 4.5. The highest percentage of fixed carbon (18.64%) was recorded at the 5-8 of DBH tree, while the lowest (16.36%) was concentrated at DBH 10-13 of *Acacia brevispica* (Ajith.J. *et.al*, 2021). Moreover, there was decreasing trends of fixed carbon both from the younger to the matured DBH parts. Furthermore, the highest percentage of ash content (4.25%). were found in DBH of 10-13 cm of the *Acacia brevispica*, whereas the lowest (2.52%) was found in 5-8 cm DBH *Acacia brevispica* tree. Furthermore, the highest calorific value (4127.72 cal/g) was found on 5-8 cm DBH *Acacia brevispica* whereas the lowest (4025.39 cal/g) was concentrated at the of DBH 1-13 cm *Acacia brevispica* (ASTM, 2019). Furthermore, the highest percentage of volatile matter (72.70%) was found on 8-10 cm of the wood, whereas the lowest (70.28%) 5-8 cm of DBH *Acacia brevispica* (Zelalem.G, 2017). The other one the highest moisture content (8.23) was found in 5-8 cm of DBH whereas the lowest (7.60%) was found on 8-10 cm wood sample of *Acacia brevispica* tree (Serguy.P. *et.al*, 2021).

Table4. 5.Proximate analysis and calorific value of *Acacia brevispica* wood

DBH	Treatment	Values
5-8	MC, %	8.23
	VM, %	70.28
	AC, %	2.85
	FC,%	18.64
	CV (cal/gm)	4127.72
8-10	MC %	7.92
	VM %	72.70
	AC %	2.52
	FC %	16.86
	CV (cal/gm) %	4045.94
10-13	MC %	7.60
	VM %	71.80
	AC %	4.25
	FC %	16.36
	CV (cal/gm) %	4025.39

CHAPTER FIVE

5.1. Conclusion

The gradual increase in human population and depletion of non-renewable energy resources has necessitated the exploration of sustainable, renewable, and environmentally friendly energy sources. Biomass energy is one of the potential energy resources worldwide. Green wood charcoal can be produced from various biomass sources such as woody biomass, agricultural residues and other wastes. Despite high biomass potential resources, all over the world, biomass energy in developing countries like Ethiopia is still insufficient. Therefore, charcoal production is one of the main livelihood options for the community in the dry afro-montane woodlands of Metekel Zone of Benishangul-Gumuz region of northwest of Ethiopia. The domestic use of wood charcoal in low-income families (i.e., for rural and urban households) provides great opportunities for employment and income generation and it provides a clean domestic cooking and heating as an alternative, renewable, and sustainable energy source that could be further developed and implemented at large scale. It is also helpful and contributes to the economic revaluation of green wood (forest biomasses) and wood wastes from wood processing industries. The most relevant findings in the present study were the production of environmentally friendly biomass energy (i.e. wood charcoal) from *Acacia brevispica* tree and characterization (i.e. proximate and ultimate analysis) of the corresponding products. The findings of the present study have indicated that the wood charcoal product tree diameter classes and tree position of *Acacia brevispica* have shown that with a higher calorific value, maximum wood-to-charcoal conversion and charcoal yield, less moisture content, and high levels of fixed carbon, were found on the studies are respectively 10-13 cm DBH, 8-10 cm DBH and 5-8 cm DBH at bottom portion of *Acacia brevispica* and met quality specifications required in international acceptable range. It could be concluded that woody charcoal products made from 10-13 cm DBH at bottom portion of the tree carbonized *Acacia brevispica* tree has been found to be better (good quality) than 8-10 cm DBH and 5-8 cm DBH classes. In addition, there was a little variation in the fuel quality of woody charcoal products made from 8-10 cm DBH at different tree portion (i.e. top, medium and bottom) indicating relatively lower energy content than woody charcoal products made from 5-8 cm DBH. The use of easily available and cheap barrel can increase the charcoal yield compared to the traditional earth mound charcoaling methods. Therefore, the production of sustainable energy sources from biomass forest

products provides great opportunities to achieve sustainable growth and development in economic, social, and environmental welfare.

5.2. Recommendation

Based on the findings of this study although, the production of sustainable energy sources from biomass forest products provides great opportunities to achieve sustainable growth and development in economic, social, and environmental welfare. Further studies should be carried out on the

1. Improving wood-to-charcoal conversion method connected to the type of kilns
2. Understanding and control of the carbonization process.
3. Optimum drying and preparing the wood for carbonization, screening, storage and transport to warehouse or distribution point are also required through consideration.

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Appendix

Table 7.1 appendix of the field and laboratory data



GEOLOGICAL INSTITUTE OF ETHIOPIA

Doc. Number:
GLD/F5.10.2

Version No: 1

Geochemical Laboratory Desk

Page 1 of 1

Document Title:- Hydrocarbon Analysis Report

Effective date:

Nov. 2022

Customer Name:- Yeshalem Sintayehu Gedetew

Issue Date:- 27/06/2024

Sample type:- Coal

Request No:- GLD/RN/1425/24

Sample Preparation:- 60 Mesh

Report No:- GLD/TR/3487/24

Date Submitted:- 19/05/2024

Number of Sample: Twenty Seven (27)


Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash), Calories & Sulfur.

Method of analysis:- Proximate Analysis, Adiabatic Calorie Metter and Gravimetric Method.

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Weight of Sample
DB H-10-13-T2-b	4.65	30.81	61.09	3.45	6853.66	200
DB H-10-13-T2-M	5.59	27.07	63.90	3.44	7136.50	200
DB H-10-13-T1-T	7.09	26.89	62.41	3.61	6802.59	180
DB H-10-13-T1-N	7.05	25.96	58.02	8.97	6631.90	150
DB H-10-13-T1-S	5.37	28.56	62.71	3.36	7034.73	200
DB H-10-13-T2-T	5.38	32.18	59.42	3.02	6518.75	250
DB H-10-13-T3-B	5.27	31.45	60.84	2.44	6869.83	200
DB H-10-13-T3-T	4.77	33.46	58.50	3.27	7054.30	150
DB H-10-13-T3-M	5.64	28.69	62.72	2.95	6845.97	150
DB H-5-8-T3-M	6.00	23.89	65.46	4.65	6885.93	200
DB H-5-8-T3-T	6.02	25.30	63.05	5.63	6685.44	250
DB H-5-8-T2-B	5.80	24.83	65.26	4.12	7035.04	150
DB H-5-8-T2-M	5.55	23.66	67.33	3.46	7257.10	180
DB H-5-8-T2-T	6.29	26.95	62.81	3.96	6838.01	200
DB H-8-10-T1-T	6.16	24.51	64.62	4.71	6672.60	150
DB H-8-10-T1-M	5.60	27.39	63.31	3.70	6807.59	200
DB H-8-10-T1-B	5.63	23.49	66.91	3.98	7193.72	180
DB H-8-10-T2-M	4.99	25.98	63.99	5.03	6676.85	150
DB H-8-10-T2-B	5.20	28.20	62.40	4.19	6876.85	200

Geochemical Laboratory Desk

Page 1

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1 of 1
Document Title:	Hydrocarbon Analysis Report	Effective date:	Nov. 2022

BB	H-8-10-T2-T	5.04	35.42	55.87	3.67	6641.28	200
BB	H-8-10-T3-M	5.67	26.45	62.04	5.84	6789.88	180
BB	H-8-10-T3-B	5.23	26.67	63.65	4.45	6813.25	150
BB	H-8-10-T3-T	5.94	23.18	67.02	3.85	7132.20	200
BB	H-5-8-T1-B	5.95	30.72	59.75	3.58	7033.14	200
BB	H-5-8-T1-M	5.95	30.82	59.05	4.18	6971.70	180
BB	H-5-8-T1-T	6.23	26.76	63.68	3.32	6895.05	120
BB	H-5-8-T3-B	6.04	26.81	62.66	4.48	6929.62	100

Note: - This result represent only for the sample submitted to the laboratory.

Analysts
Bethelhem Tefera
Tizita Zemene
Yirgalem Abraham
Desalew Bitew
Bane Abera

Approved By

Alemnesh Abate



	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1 of 1
Document Title:-	Hydrocarbon Analysis Report	Effective date:	Nov. 2022

Customer Name:- Yeshalem Sintayehu Gedetew

Issue Date:- 01/07/2024

Sample type:- Coal

Request No:- GLD/RN/1461/24

Sample Preparation:- 60 Mesh

Report No:- GLD/TR/3488/24

Date Submitted:- 10/06/2024

Number of Sample: Three(3)

Elements to be determined:- (Moisture, Volatile matter, Fixed carbon and Ash), Calories & Sulfur.

Method of analysis:- Proximate Analysis, Adiabatic Calorie Metter and Gravimetric Method.

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Weight of Sample
<u>DB</u> BH-5-8	8.23	70.28	18.64	2.85	4127.72	105gm
<u>DB</u> BH-8-10	7.92	72.70	16.86	2.52	4045.94	115gm
<u>DB</u> H-10-13	7.60	71.80	16.36	4.25	4025.39	120gm

Note: - This result represent only for the sample submitted to the laboratory.

Analysts

Bethelhem Tefera

Tizita Zemene

Yirgalem Abraham

Desalew Bitew

Bane Abera

Approved By

Alemnesh Abate

