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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

CIVIL TECHNOLOGY FACULTY

DEPARTMENT OF WOOD TECHNOLOGY

INVESTIGATING THE QUALITY OF CHARCOAL PRODUCED FROM *ACACIA SEYAL* WOOD AROUND DIRE DAWA CITY ADMINISTRATION

By

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A THESIS SUBMITTED TO THE DEPARTMENT OF WOOD SCIENCE TECHNOLOGY IN PATIRAL FULFILLMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF SCINCE IN WOOD SCIENCE TECHNOLOGY AND MANAGEMENT

Advisor Dr. Sisay Feleke

ADDIS ABABA, ETHIOPIA

2025

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A THESIS SUBMITTED TO DEPARTMENT OF WOOD SCIENCE TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN WOOD SCIENCE TECHNOLOGY AND MANAGEMENT

Advisor Dr. Sisay Feleke

April 2025

ADDIS ABABA, ETHIOPIA

I. DEDICATION

I dedicate this work to all my cherished parents, particularly to the souls of my dear mother, Dawite Mazengeya, and my beloved father, Teshome Abebe, as well as to all my brothers and sisters, for their unwavering support and love for me, my exquisite wife, and the wonderful gifts of God for my loving children. Finally, I dedicate this work to those who supported me. Ideally and financially, God rewards you abundantly.

II. DECLARATION

This is to certify that the thesis entitled "Investigating the Quality of Charcoal Produced from *Acacia seyal* around Dire Dawa, Ethiopia," submitted to the Department of Wood Science Technology in partial fulfillment of the requirements for the degree of Master of Science in Wood Science Technology and Management, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during this investigation have been duly acknowledged.

Mulugeta Teshome Abebe	______________	---/---/2025
Name of the candidate	signature	Date

III. Statement of Certification

This is to certify that Mulugeta Teshome Abebe has done a study on the topic entitled "Investigating the Quality of Charcoal Produced from *Acacia Seyal* around Dire Dawa, Ethiopia," under my supervision. This work is original and suitable for the submission in partial fulfillment of the requirement for the award of the degree of Masters in Wood Science Technology and Management (WSTM). Therefore, I confirm that the student has duly collected data, analyzed it, and written up the thesis under my supervision.

.

Sisay Feleke (PhD)	_______________	---/---/2025
Advisor's name	signature	Date

IV. Approval of Thesis for defense

The study proposal **"Investigating the Quality of Charcoal Produced from *Acacia Seyal* around Dire Dawa, Ethiopia"** has officially been verified as meeting the requirements for the Master of Wood Science and Technology concentration. Therefore, I recommend that the student has fulfilled the requirements and hence can hereby can defend the thesis at the department.

Sisay Feleke (PhD)	_______________	---/---/2025
Advisor's name	signature	Date

V. Approval Sheet

CIVIL TECHNOLOGY FACULTY DEPARTMENT OF WOOD TECHNOLOGY

This is to certify that the thesis prepared by Mulugeta Teshome Abebe **"Investigating the Quality of Charcoal Produced from *Acacia Seyal* around Dire Dawa, Ethiopia"** which is submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Wood Science Technology and Management (WSTM), complies with the regulations of the Institute and meets the standards with respect to originality and quality.

Approved by:-

Advisor

Sisay Feleke (PhD) …………………………. Signature ……………. Date…………………

Examiners:

(Internal) …………………………………… Signature ……………. Date…………………

(External) ……………………………………. Signature ……………. Date…………………

VI. ACKNOWLEDGEMENT

All glory to the Almighty God for his generosity in allowing me to be alive, for giving me limitless love, blessing, and taking care of me in my life and care in all my ways. Next, I want to address my heartfelt gratitude to my advisor, Dr. Sisay Feleke, for his quick responses and constructive guidance. Encouragement, patience, and constructive criticism throughout this study. This research work was formulated with his great support and encouragement. Really, without his kind support it would have been very difficult to finish the study.

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X. List of Acronyms and Abbreviations

FTI --------------- Federal technical and vocational education and training institute

A. seyal ---------*Acacia seyal*

ANOVA---------Analysis of variance

Km ---------------Kilometer

MC---------------Moisture content

VM---------------Volatile matter

FC----------------Fixed carbon

AC---------------Ash content

CV---------------Caloric value

S1----------------Sample 1

S2----------------Sample 2

S3----------------Sample 3

DBH--------------Diameter at Breast Height

ASTM -----------American Society for Testing Materials

HHV-------------Higher heating value

FAO--------------Food and Agriculture Organization of the United Nations

MJ/kg-------------Megajoule per kilogram

CIA --------------Charcoal-Ignition-Aiders

A. -----------------Acacia

SSA ---------------Sub-Saharan Africa

PCA----------------principal component analysis

EMK---------------Earth Mound Kiln

ASTM ------------American Society for Testing Materials

DB-----------------dry basis

WB-----------------wet basis

C ------------------Degree centigrade

D-------------------Diameter

m-------------------Meter

m^2------------------Meter square

m^3------------------Meter cube

Title: "Investigating the Quality of Charcoal Produced from *Acacia Seyal* around Dire Dawa, Ethiopia"

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XI. Abstract

The main intention of this study is evaluating the quality of charcoal produced from Acacia seyal in metallic barrel around Dire Dawa. The goal of the study is to shed light on the features and attributes of this specific charcoal while discussing possible negative effects on the environment and the economy. The research informs farmers who made their livelihoods in charcoal production and advances sustainable resource management by analyzing the manufacturing process and quality factors.

Ethiopia is one of the many developing nations whose energy sectors heavily rely on biomass charcoal. Thus, it is essential to look into the quality of charcoal made in the Ethiopian region of Dire Dawa from Acacia seyal. The purpose of the study is to evaluate the charcoal samples' ash, carbon, and calorific value in order to ascertain their overall effectiveness and suitability.

The chemical properties of charcoal produced from Acacia seyal trees, includes the moisture content percentage (MC %), ash %, volatile matter (VM %), fixed carbon (FC %), and calorific value (CV %), have a correlation of 0.550, 0.334, 0.592, -0.805, and 0.484, respectively, with respect to thickness, and the correlation of lengths is 0.550, 0.881, 0.592, -0.805, and 0.484, respectively. Based on average percentage, the maximum result recorded is MC 7.9 % Ash; 4.97% VM 86.31%; FC 27.61% and CV% 5801%, whereas the minimum MC% is 3.74 Ash% 1.60; VM% 64.30; FC% 9.90; CV% 4365. The maximum charcoal yield percentage is 38.461% whereas the minimum yield is 30% the average 33.359%.

Keywords: Acacia seyal, diameter, moisture content, density, proximate analysis.

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

More than half of the global population now lives in cities, leading to high demand for energy consumption. Urbanization will influence the type of fuels used and also the total energy consumption for different functions, and choice depends on income. Charcoal is the main cooking fuel, especially in urban areas in sub-Saharan Africa, South Asia, Latin America, and the Caribbean (Santos et al., 2017).All over the world, demand for energy has exacerbated human dependence on natural resources. According to the United Nations' Food and Agricultural Organization (FAO), more than 50% of wood from forests worldwide is used for energy production. In Europe and North America, consumption of charcoal is less conspicuous, but it is highest in Africa (Nabukalu & Gieré, 2019).Global energy demand is increasing rapidly due to increasing world population and economic growth. This increased energy use has led to various problems such as overexploitation of nonrenewable energy resources and other environmental problems such as deforestation, environmental degradation, and climate change (Tekle Asresu, 2017). Global demand for charcoal is increasing mainly due to urban population in developing countries and urban-dwellers are restricted to charcoal use because of easiness of production, access, transport, and tradition(Santos et al., 2017).Globally, more than 2.4 billion people rely on the use of wood fuel, including charcoal, for cooking, and small enterprises use fuelwood and charcoal as important energy providers(FAO, 2020).The wood energy situation in developing countries, the majority of which are in tropical regions, in Asia and Africa consumption of wood energy is declining, although consumption in Africa, remains high while in South America, where wood energy is less important, overall consumption appears to have been rising slowly (Chidumayo & Gumbo, 2013).

Energy is a basic requirement of human beings. The source of energy is categorized into renewable or non-renewable resources based on a time scale of lifespan. In many developing countries fuel-wood is still the main source of energy. Biomass fuels come in a variety of forms, both unprocessed, (wood, straw, dung, vegetable and agricultural wastes) and processed (charcoal, methane from biogas plants and landfills, logging waste and sawdust, and alcohol produced by fermentation). Biomass energy is mainly used in least developed countries (LDCs), particularly in Africa. Its contribution to the total energy uses typically ranges from 80-90% in poor countries, 55-65% in middle and 30-40% in higher income LDCs (Elrasoul, 2003). Around the world, charcoal has persisted as an energy resource and retained unequivocal dominance in the energy consumption mix of some nations many years on since modern alternatives were invented. Charcoal consumption is often linked to lack of modern alternatives but all over the world, electrified regions are still using charcoal as an energy source{Formatting Citation}.Charcoal is produced from trees grown in forests, woodlands, bush lands, grasslands, farmlands, and plantations (Odour, 2012) Global wood charcoal production has tripled over the last 50 years from 17.3 million tons in 1964 to 53.1 million tons in 2014(Doggart ,Nike and Meshack, 2017).Globally, more than 2.4 billion people rely on the use of wood fuel, including charcoal, for cooking, and small enterprises use fuelwood and charcoal as important energy providers .FAO estimates that the global production of wood charcoal was about 53.2 million tons in 2018, of which 34.2 million tons (or around 64%) were produced in Africa (AFWC, 2023).

In Africa, over 90 % of the wood taken from forests is used for fuel the majority is consumed directly as fuelwood, however, a varying but substantial amount is transformed into charcoal. More than 80 % of it is used in urban areas making charcoal the most important source of household energy in many African cities (Seidel, 2008). Charcoal consumption is often linked to a lack of modern alternatives, but all over the world, electrified regions are still using charcoal as an energy source (Nabukalu & Gieré, 2019). Charcoal plays an important role in both the energy sectors and the economies of most African countries(Van der Plas, 1995) .Ethiopia's Energy consumption is predominantly based on biomass energy sources. An overwhelming proportion (94%) of the country's energy demand is met by traditional energy sources such as fuel wood, charcoal, branches, dung cakes, and agricultural residues (Conservation, n.d.). Ethiopia is one of the sub-Saharan African (SSA) countries whose energy depends on the traditional use of biomass fuels such as wood, charcoal, agricultural residues, and animal dung (TEFERA, 2020). The Ethiopian rural household consumption of wood (including the charcoal equivalent of wood) is estimated to be 91.2 million tons per year with 4.2 million tons per year of charcoal. Total consumption of agricultural residues and dung is estimated to be 19.3 million tons per year and 20.7 million tons per year, respectively (Region, 2023). Ethiopia has huge renewable energy resource potential, which includes biomass, hydropower, wind, solar, and geothermal energy. However, except for the woody biomass (50%), agricultural residue (30%), hydropower (5%), wind (3%) and geothermal (1%) which are exploited, the available energy potential is not well developed, and is among one of the least developed in the world. The total national energy consumption of the country in 2010 was 1,300 PJ which is the lowest in Sub-Saharan Africa (Tekle Asresu, 2017)

Acacia seyal grows naturally in the clay plains of central and eastern Sudan and has been extensively managed for firewood and charcoal production in order to meet energy requirements. The species forms either pure stands of different densities (dense, medium to poor) or mixed stands associated with other tree species (Mohammed, 2011). A. seyal usually grow under different stand densities(Andualem et al., 2019). Acacia seyal is one of the strongly gregarious sub Saharan tree species with major role of fuel wood and fodder production. Acacia seyal is found in elevated areas up to 2100 m in tropical regions with a soil pH of 6-8 and grows in a mean annual rainfall of about 500- 1200 mm and high temperatures of 39-42°C (Andualem et al., 2019).

1.2. BOTANICAL DESCRIPTION

Historically, the generic name ‘Acacia’ comes from the Greek word ‘akis’, which means ‘point’ or ‘barb’. Acacia seyal belongs to the family of Fabaceae (Mimosoideae). It is a small to medium-sized tree. It grows up to 17 m tall and 60 cm in diameter at breast height. Acacia seyal is widespread in the semi-arid zone of tropical Africa from Senegal eastwards to Somalia and the Red Sea and from the Nile valley south to Zambia. Acacia seyal is usually found near riverbeds at lowland sites and near waterholes or seasonally flooded black cotton soils. Herbivores feeding on the tree may play an important role in seeds dispersal (Abdalla et al., 2014). The tree is native in: Egypt, Eritrea, Ethiopia, Ghana, Iran, Israel, Kenya, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Saudi Arabia, Senegal, Sudan, Syrian Arab Republic, Tanzania, Uganda, Yemen, Zambia, and Zimbabwe.

It is also domesticated in Afghanistan, Bangladesh, Bhutan, India, Nepal, Portugal, Sri Lanka, and US *A. seyal* produces good, dense firewood that is used widely throughout its range. The smoke is pleasantly fragrant and the wood burns rather quickly. In Chad the tree is considered to provide the best fuelwood. In Sudan it is used to make a fragrant fire over which women perfume themselves. *A. seyal* var. seyal is an important source of rural energy as both firewood and charcoal. The trees are cut at the age of 8-15 years, depending on population pressure and demand for wood. (Mimosoideae & Mimosoideae, 2009).

Similarly, in Ethiopia, charcoal and fuel wood play a dominant role in energy consumption, constituting approximately 90% of the total energy used. Ethiopia ranks as the world’s third-largest charcoal producer, with production surpassing 4.4 million tons, following Brazil and Nigeria. Due to limited access to electricity and natural gas, many Ethiopian communities heavily rely on fuel wood and charcoal. Charcoal is extensively used for cooking in households, bakeries, restaurants, and small-scale industries. The charcoal business provides income to around 1.5 million people from over 300,000 households. Eight percent of total households and thirty percent of urban households utilize charcoal for daily cooking (Tazebew et al., 2023).In Ethiopia, *Acacia seyal* is mostly known by its charcoal, fire wood use and branches used for fences. When investigating the trend of neighboring countries like Sudan, the tree produces gum, and the gum exports to India and Europe to earn income from Gum sale (Andualem et al., 2019).

Ethiopia is one of the sub-Saharan African (SSA) countries whose energy depends on the traditional use of biomass fuels such as wood, charcoal, agricultural residues, and animal dung (TEFERA, 2020). In Dire-Dawa administration, dense acacia woodland species, open shrub land, and open shrub land with *Prosopis juliflora* plantation occupy a total of 12,250 ha. In particular, the dense shrub or acacia woodland species occupy a total area of 777 ha, which is 0.58 % of the total area and is located in the Hurso, Jeldessa, Gerba-Anano and Chiri-miti kebelles. These charcoal makers are principally involved in charcoal production due to the following pull factors. **Firstly**, the close proximity of the to the city of Dire-Dawa more accessible recently **Secondly**, localities were involved in the production and sale of fuel wood and charcoal as easy means of money making to cope with the impacts of prolonged dry seasons. **Last** but not least, in the light of charcoal economy, the price of charcoal has attracted poor and landless peoples as it was sold 80-120 and 150-180 Eth Birr per sack in the study sites and Dire-Dawa city respectively. Additionally, charcoal is transported and supplied to Djibouti at a better price than to Dire-Dawa (Abay & Haylemariyam, 2018). Carbonization is a thermo-chemical process by which complex carbonaceous substances, such as wood or agricultural residues, are converted into carbon rich mass. Carbonization process is the thermochemical process that includes heating of the biomass with limited amount of oxygen under the high temperature for the preparation of solid fuel charcoal, liquid fuel as tar and gaseous fuel as combustible hydrocarbonic gas. The carbonization is a more convenient process to produce charcoal which is the energy dense, smoke free fuel and consists of a fixed carbon content of 70% or more (Esubalew, 2018).

1.3. Statements of the problem

Biomass energy is the dominant source of energy in Ethiopia. Due to the limited potential to use electricity, most people in Ethiopia, particularly in the Dire-Dawa administrative city, rely on biomass, especially charcoal. Charcoal is produced in rural areas from different tree species and transported by cars (Isuzu), camel and donkey for sale.

Inefficient methods of producing charcoal, using the earth mound technique for the production of charcoal exacerbates environmental deterioration, leading to deforestation. Because more trees must be consumed to fulfill energy demands due to the method's poor yield, local ecosystems are severely stressed, which worsens deforestation. In addition to this the method is labor-intensive production processes of digging and filling the mounds with biomass and cover-up, is a part of the traditional earth mound technique producing charcoal. For the personnel engaged in the charcoal production process, this arduous procedure not only increases inefficiencies but also presents health and safety hazards.

In order to address the inefficiency problem of charcoal production in the earth mound technique, adopting of an easy and efficient method of charcoaling method will improve the environmental degradation and deforestation in the area, and increase the charcoal yield. By exploring the complexities of this problem in great detail, this research aims to provide light on potential directions for improved procedures and results.

1.4. Objectives of the study

1.4.1. General objectives

The general objective of the study is to assess the quality of the charcoal produced in a metallic barrel from *Acacia seyal* around Dire Dawa town.

1.4.2. Specific objectives

- To assess the effect of diameter and lengths of *Acacia seyal* on produced charcoal quality
- To evaluate the quality parameters (volatile matter, moisture content, ash content, carbon content and calorific value) of the charcoal.
- To assess the yields of charcoal generated from *Acacia seyal*.

1.5. The Research questions

- How moisture is in the *Acacia seyal* charcoal in the Dire Dawa area, and how often is it used in the area to produce charcoal?
- What is the fixed carbon content and calorific value of the charcoal made from *Acacia seyal* in the Dire Dawa area, and how do these characteristics affect the charcoal's energy content and quality?
- How do the charcoal yields and general quality of *Acacia seyal* produced in the Dire Dawa area compare to other wood species that are often used to manufacture charcoal?

1.6. Significant of the study

The quality and yield of charcoal produced in traditional, earths-mound, method affected significantly due to various reasons, therefore, producing and assessing the quality of charcoal produced in metallic barrels from *Acacia seyal* around Dire Dawa town gives an insight of the method. The relevance of the study is emphasised in assessing the quality of charcoal generated from *Acacia seyal* in metallic barrels and its implications for the environment and local livelihood. The investigation provides assistance in the development of sustainable strategies for managing forests and preserving the indigenous flora of the area. The study provides insight into the efficiency of the production technique by assessing the quality characteristics of charcoal made from *Acacia seyal* in metallic barrels. It provides information on the effectiveness and feasibility of implementing metallic barrel-based production processes to local producers, decision-makers, and interested parties. Determining the output and quality of charcoal from *Acacia seyal* helps with cost, sustainability, and energy access considerations. It may result in advancements in the processes used to produce charcoal, improving energy accessibility, and lessening environmental effects.

1.7. Scope of the Study

The scope of this study is confined to the specific objectives, which encompass the examination of the moisture contents, ash content, carbon content, charcoal moisture, and volatile matter of *Acacia seyal* charcoal produced using a metallic barrel. It is important to note that the study does not encompass a comparison of other charcoal produced.

The outcomes of this study will help policy makers in pertaining to charcoal production and consumption, particularly with regards to *Acacia seyal*, and their implications for the forest resources of the region. The advantages of this research encompass comprehensive information on the quality and characteristics of the charcoal derived from *Acacia seyal*.

This study does not include tree age and carbonization temperature because the metal barrels used for carbonization is a simple and locally available material, making it difficult to estimate the temperature. Additionally, determining the age of the tree is challenging since acacia trees grow naturally in the forest rather than being planted, making it difficult to estimate their age. Furthermore, this study does not address the development of charcoal production in the Dire Dawa region, market conditions or ecological implications.

1.8. Limitations of the Study

In the financial case, the study focuses only on charcoal produced in the Dire Dawa area. The results might not be generalizable to charcoal produced in other regions. Furthermore, uncontrolled environmental conditions occurred during the production and storage of charcoal. Limited access to advanced laboratory facilities or analytical tools may lower the quality of the report.

1.9. Research gap

There might be a lack of comprehensive studies evaluating the quality parameters of charcoal produced from *Acacia seyal* using metallic barrels. Research could focus on developing standardized methods for assessing charcoal quality, including calorific value, moisture content, ash content, carbon content, volatile matter, and fixed carbon. Among different producers, production methods, and processing techniques exist understanding the factors influencing charcoal quality variability can help improve production processes and ensure consistent quality standards. This research could explore traditional versus modern charcoal production techniques, including kiln types, carbonization temperatures, and processing duration, and their effects on charcoal quality, yield, and environmental sustainability. There is a lack of more general ecological and contextual elements that might affect the quantity and quality of charcoal produced in the region. The ecological impact of production techniques and a deeper comprehension of the dynamics of charcoal production as well.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Overview of Charcoal Produced from *Acacia seyal*

A. seyal belongs to the genus Acacia Mill which is one of the largest genera within the family of Mimosaceae. The genus Acacia includes about 1200 species widely distributed in the dry land all over the world. *Acacia seyal* native ranges include Egypt, Eritrea, Ethiopia, Ghana, Iran, Israel, Kenya, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Saudi Arabia, Senegal, Sudan, Syrian Arab Republic, Tanzania, Uganda, Yemen, Republic of, Zambia and Zimbabwe. The species is used to make syrup mixed with *Balanites aegyptiaca*, fodder, apiculture, fuel, fiber, timber, gum or resin, tannin or dyestuff, and medicinal values, as well as shelter and shade (Ayalew et al., 2020). *A. seyal* trees grow up to 17 m tall in Sudan, with a flat top crown. They have a distinctive smooth, powdery bark, which varies from white to greenish-yellow or orange-red, with a green layer beneath (Ahmed, 2018). Like other acacias, *A. seyal* is widely distributed in the African savannas. The species is an important source of fuel wood, building poles, forage, commercial gums, and tannins. Additionally, *A. seyal* serves valuable ecological functions such as reducing soil erosion and acting as a defence line for desert encroachment in many parts of the Sudan (Mohammed, 2011) *Acacia seyal* grows rapidly during the seedling stage, attaining a height of 1 m in the first year. It is the most common constituent of the woodland. Mature trees are usually 7-8 m high with a diameter at breast height of between 12 and 18 cm. The tree is usually 10-12 m high and occasionally up to 17 m. Its wood is hard, and it grows slowly in the seedling stage (Adams, 1967).

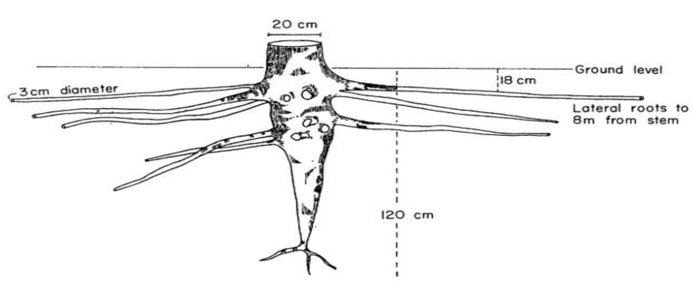


Figure 1: Root system of Acacia seyal

Acacia species are considered as the most widely distributed species in Sudan. Their uses concentrate on charcoal, firewood, fuel wood, and gum source. *Acacia seyal* has two varieties: *A.seyal var. seyal and A.seyal var.fistula*. both varieties produce gum known as *gum Talah*

(Mohamed et al., 2021). *Acacia seyal* var. seyal is considered as one of the most widely distributed tree species in Sudan, particularly in the poor rural area (Gamal, 2014).

2.2. Acacia seyal

The tree is a typical savanna acacia, widespread in semi-arid areas of Africa from Senegal to Egypt and south to Malawi and Zimbabwe. In Ethiopia, it is found in seasonally flooded black-cotton soil, in river valleys and wooded grassland of the Dry and Moist Kolla and Weyna Dega agroclimatic zones in Gonder, Gojam, Shoa, Arsi, Harerge, Ilubabor, Kefa, Sidamo, western Tigray, and western Welo regions, 500–2,100 m. It is known by different names depending on where it grows.

The species is known with different vernacular names in Ethiopia: Adiquento, Makani (Afar), Wachu (Amharic), Wocha-adi, Wacho dima Borona Oromo), Wosiya wajo, Wakko-dimo, Wajjo, Wajji, Wachu (Oromo)

2.3. Ecology

A.seyal is used for fire wood, charcoal, poles, posts, medicine (bark, gum), fodder (leaves), bee forage, shade, nitrogen fixation, soil conservation, windbreak, gum, tannin and dye (bark) (Orwa C, Mutua A , Kindt R , Jamnadass R, 2009).*Acacia seyal* is one of the drought-tolerant agroforestry tree species found in eastern and southern Africa and native trees to the Sahelian zone of Africa (Belayneh et al., 2021).

2.4. Wood density

Wood density is a key variable for the estimation of tree mass. Within individual trees, wood density differs among branches, trunk and roots and can also vary radially within the trunk as wood is added at the periphery during growth(Henry et al., 2010).Wood density is extremely variable among species, sites and between trees (Dias et al., 2018).

Acacia seyal wood air dry density and hardness strength in comparison with Milletia laurentii and Quercus rubra(Gamal, 2014).

Property	Acacia seyal	Milletia laurentii Quercus	Quercus rubra
Density (g/cm^3)	0.893	0.860	0.700
end hardness (N/mm^2)	84.03	39	60
Side hardness (N/mm^2)	51.18	24	33

2.5. Economic importance of Acacia seyal

Acacia forests are valuable sources of energy in home use activities. As the majority of Ethiopians depend on fuel wood for their local energy needs, the role of Acacia as an energy component is intense and especially high in lowland areas of the country. In addition, Acacia is essential in the production of charcoal, and the hard wood is used to meet the energy demand in home use activities. Acacia is an important wood in the production of different homemade commodities and materials. For instance, it is used for various local purposes like making (i.e. hoe and ax handles, for house construction) and in the production of exquisite furniture. Moreover, the spiny branches of African *acacias* are often used for fencing homesteads, backyards, or even farmlands to prevent the entrance of domestic and wild animals to agricultural land, thus minimizing crop losses. The lowland Acacia dominated lands are inhabited mostly by nomadic and agro-pastoral communities. These people utilize deciduous forest resources, including the perennial trees/shrubs, for their livestock feed. The narrow-leaved deciduous forests support the local economy through collecting and selling the plants as fuel wood, producing charcoal, and producing gum and resin from these plants (Mesfin et al., 2020).

2.6. Kilns

Kilns are chambers used to produce charcoal from wood through a process of pyrolysis (heating in the absence of oxygen).The function of charcoal kilns is to turn wood into charcoal. Bricks, metal, or concrete are some of the materials used to build charcoal kilns.

2.7. Types of charcoal kilns

The types of charcoal kilns, according to their characteristics, can be divided in to three categories .Fixed or permanent kilns, such as brick beehives, masonry kilns, mud beehives, furnaces, and retorts made of brick, cement, or clay. There are two important designs.

Non-permanent kilns, Earth Kiln: The simplest type of kiln is a neatly stacked pile of wood that is then completely covered with green vegetation and earth. Almost any size of wood can be carbonized in earth covered kiln as they can easily be modified in shape and size to suit the needs.

Portable kilns these are usually made of metal and have the advantage that they can be carried or rolled to the wood supply. The most popular type of portable kiln, developed by the Tropical Products Institute, U.K. consists of two interlocking cylinders surmounted by a conical roof (Saravanakumar & Haridasan, 2013).

2.8. Traditional charcoal production

In Ethiopia, charcoal is commonly produced using the traditional earth kiln method–earth mound kiln and earth pit kiln; earth mound kiln is the most frequent method with an efficiency of 10-15% .A traditional kiln has three key advantages.

1. Zero-Cost: Requires no capital investment or special tools to build.
2. Easiness: Can be built on an open piece of land near woodlots. This allows minimum effort from charcoal producers for transportation of wood for carbonization.
3. Operation: Requires no specialized technical knowledge or equipment to operate and minimum oversight (TEFERA, 2020).

2.9. Improved charcoal production

The improved earth kiln offers better carbonization, resulting in a higher yield (about 25-30 per cent compared to 20-25 per cent of traditional kilns) and a better quality of charcoal. These kilns can be rectangular, dome shaped with varying dimensions and design. They are ideal for producing high quality charcoal in large quantities and at higher efficiency (30-35 percent), and are best suited for charcoal production. These kilns are typically drum shaped and either setup vertically or horizontally based on design and capacity (TEFERA, 2020).

2.10. Carbonization

Carbonization is the process by which complex carbonaceous substances, such as wood or agricultural residues, are broken down into elemental carbon and chemical compounds by heating(Esubalew, 2018). During carbonization, the production of condensable and non-condensable gases occurs, besides the solid fraction, charcoal(Assis et al., 2016a). Carbonization is the thermochemical process includes heating of the biomass with limited amount of oxygen under the high temperature for preparation of solid fuel charcoal, liquid fuel as tar and gaseous fuel as combustible hydrocarbonic gas the carbonization is more convenient process to produce charcoal(Esubalew, 2018).

2.11. Charcoal

Wood charcoal is one of the popular materials in domestic and industrial power generation material which made from wood. Charcoal is a black substance obtained by burning wood without much air. Charcoal is the material that is converted from the wood for the purpose of stable energy making in industries. Charcoal is the lightweight black carbon and ash residue hydrocarbon produced by removing water and other volatile constituents from animal and vegetation substances. Charcoal is usually produced by slow pyrolysis, the heating of wood or other substances in the absence of oxygen which the process is called carbonization. The finished charcoal consists largely of carbon. Commercial charcoal is found in either lump, briquette, or extruded forms (Paramasivan & Premadas, 2019). Charcoal is a lightweight carbon and ash residue hydrocarbon produced by removing water and other volatile constituents from biomass resources. Charcoal is the general term for a range of carbonized materials with varying combustion and dark properties. Charcoal is produced by a process called carbonization, a process by which solid residues with increasing content of carbon are formed from organic material, usually by pyrolysis in an inert atmosphere. In the course of pyrolysis, biomass undergoes a sequence of changes and normally produces a black carbonaceous solid called charcoal, along with a mixture of gases and water. Normally, in carbonization, charcoal production is maximized in a course of slow heating rates at low temperatures during pyrolysis. Wood charcoal is mostly pure carbon, made by heating wood above 400ºC in a low oxygen situation. The process, can take days and burns off volatile compounds such as water, methane, hydrogen and tar. The factors affecting wood carbonization are - the nature of the wood, wood chemical composition, wood structure, and physical properties such as density, permeability, thermal conductivity, size, and shape, and various external conditions such as temperature, heating rate, carbonization time and pressure (Lalmuankima, n.d.2019).

2.12. Moisture content of charcoal

Fresh charcoal from an opened kiln contains very little moisture, usually less than 1%.Absorption of moisture from the humidity of the air itself is rapid and there is, with time, a gain of moisture which even without any rain wetting can bring the moisture content to about 5 to 10%, even in well-burned charcoal (Esubalew, 2018).

2.13. Charcoal Production

Charcoal is produced from wood by a complex process called carbonization. Carbonization occurs at temperatures between 450 and 600 °C in the absence of air. Under these conditions, organic vapours and gases are lost, and part of the organic substances polymerizes, all of which increase the carbon content of the product. One of the factors affecting quality as well as the yield is temperature. At relatively low temperatures around 300 °C a high yield of charcoal is obtained. But this charcoal has a high content of volatile material, which is undesirable because it produces noxious fumes during use. Temperatures around 600 °C give lower yields, but the charcoal has a low content of volatiles, making it a preferred fuel. Charcoal can be made from both hardwood and softwood. However, hardwood is usually preferred because the charcoal has higher energy content and is easier to handle (Seidel, 2008). Charcoal is a burnt wood, which lost all moisture and most volatile contents in the production process (Rotowa et al., 2019). Ethiopia is the third highest charcoal producer in the world, after Brazil and Nigeria, with an estimated amount of more than 4.4 million tons of charcoal. According to the Ethiopian forest action program, fuel wood, including charcoal, contributes 66% and 62% of the energy consumption in rural and urban areas, respectively (Tazebew & Addisu, 2023)

2.14. Relevant Physiochemical Properties

Charcoal is an odorless, tasteless, fine black powder or black porous solid material. It is typically encountered as course granules or powder. It is insoluble in water and also in organic solvents. It has low specific gravity: 0.08 to 0.5, combustion energy around 14 100 Btu/lb = 7830 cal g^{-1} = 3.28×10^5 J kg^{-1} and high boiling point 4200 ^{0}C (Abdollahi & Hosseini, 2014).

Porosity: Charcoal is highly porous, which is one of its most significant properties. Charcoal porosity is a function of charcoal true and apparent density. The porosity of charcoal will increase if the true density increases with increasing pyrolysis temperature, and the apparent density is relatively independent of pyrolysis temperature.

Density: The density of charcoal varies significantly based on the type of wood used and the production method. True density refers to the solid carbon structure, i.e. the pore walls of the charcoal particles, while apparent density includes both the solid structure and the pores within the charcoal and is alternatively termed the particle density (Somerville & Jahanshahi, 2015).

Conductivity: Charcoal is classified as a poor conductor of heat and electricity. Carbonized charcoal was used as an electrode for primary batteries. These electrodes were made from powdered charcoal or coke bonded with sugar syrup or coal tar, pressed, and carbonized (Mochidzuki et al., 2003)

Charcoal is also used as a decolorizing agent for decolorizing sugar solutions, organic preparations, and alcohol and petroleum products. Charcoal can be made from almost any lignocellulosic raw material (Chandrashekar, 2013)

Absorption Capacity: The biomass charcoal samples with large surface area, porous structure and abundant functional groups should be expected to work as excellent adsorbent to adsorb heavy metal ions and organic compounds from water (Bai et al., 2020).

2.15. Activated Charcoal

Charcoal is a fine black powder or black porous solid. it is scentless, tasteless, and insoluble in water (Ghanim & Al-Mayah, 2020). Activated charcoal (AC) is composed of carbon arranged in a quasi-graphitic form in small particle size. It is a porous and tasteless material and is distinguished from elementary carbon by the removal of all non-carbon impurities and the oxidation of the carbon surface (Thomas, 2008). Activated charcoal is an insoluble powder produced by pyrolysis of organic material at higher temperature than ordinary charcoal production. It is able to adsorb a wide variety of drugs and toxic agents onto its surface. Activated charcoal has the ability to adsorb a wide variety of substances onto its surface, but some substances, such as ethanol, iron, lithium, and cyanides, are not adsorbed in significant amounts (Neuvonen & Olkkola, 1988)

2.16. Quality wood charcoal

Quality wood charcoal as having low moisture content, relatively easy to cut, easy to handle, easy to ignite and burn with high calorific value/heating value, producing very little or no smoke without toxic fumes and neither spits nor sparks. They retain grain of the wood; it has a jet black color with shining luster; it is sonorous with a metallic ring and does not soil the finger. The *Acacia* wood species have been studied for their potential of charcoal production and gross heat of combustion. The results obtained indicated that charcoal from Acacia wood species had density ranges from 0.563 to 0.90 gcm−3, with heating value of 32.39 MJkg−1, percentage fixed carbon of 84.70% and low ash and volatile matter of 3.35% and 11.95% respectively. The results obtained were more or less close to the desirable criteria for quality charcoal. Suggested apparent density of 0.4 to 0.9 g cm^{-3} for efficiency of quality charcoal (Christiana. O, 2014). Charcoal quality can be specified and measured in various ways that are usually derived from the end use requirements; some of these ways are moisture content, volatile matter, ash content, and duration time (Challenges et al., 2018).

2.17. Chemical composition

Wood is an organic material that consists of carbon, hydrogen, oxygen, nitrogen, and a small part of mineral elements. The main components of wood are cellulose, hemicellulose, and lignin. During carbonization, the production of condensable and non-condensable gases occurs, besides the solid fraction, charcoal. Properties of the solid material are related to the interaction of these precursors. Therefore, the amount of each component and the way they are organized directly influence directly the mechanical properties of wood and, consequently, the quality of the charcoal obtained after carbonization. The main component that acts on the formation of charcoal is lignin, since it is thermally more stable than the carbohydrates of wood. mass losses for lignin do not surpass 60 % at temperatures above 600 ^{O}C. Mass losses related to hemicelluloses and celluloses are large and occur in a temperature range from 270 to 380 ^{O}C (Assis et al., 2016b).

2.18. Experimental results on five tree species

After each preferred tree species was dried for to four weeks at a temperature of 18°C to 27 ° C, the moisture content was lost by each species: O. africana 14.61%, A. nilotica 16.25%, A. etbaica 18.35%, *A. seyal* 24.34%, and A. schimperi 27.44%. The Diameter of the preferred five tree species (each three samples each) where prepared, and then their corresponding densities and the percentage of moisture, ashes, volatile matter, and fixed carbon contents

Experimental results and principal component analysis (PCA) on five tree species on their density and moisture, ash, volatile matter, and fixed carbon contents.

Species name	Diameter (cm)	Density (g/cm3)	Moisture contents (%)	Ash contents (%)	Volatile matter contents (%)	Fixed carbon contents (%)
O. africana	7.367	0.914	5.908	0.994	70.710	22.388
A. nilotica	6.400	0.857	7.030	1.971	71.495	19.503
A. etbaica	6.300	0.779	7.819	2.741	73.644	15.796
A. seyal	6.667	0.665	8.279	3.353	76.790	11.578
A. schimperi	5.800	0.553	9.927	4.445	79.673	5.954

The experimental result proved that O. africana holds the highest fixed carbon content, as seen in the Table, whereas A. schimperi holds the least fixed carbon content in it. The **densities** of the species were ranged from 0.553 g/cm^3 (Acokanthera schimperi) to 0.914 g/cm^3 (Olea africana). Olea africana proved to have the highest density. Olea africana is more likely to have a higher energy per unit volume than the other species. Olea africana is more likely to have a higher energy per unit volume than the other species the **moisture content** is a very important property that can greatly affect the burning characteristics of biomass. A just fallen tree contains 40% to 60% of hygroscopic moisture depending on the species of the tree as well as the seasons here; the samples dried up to four weeks only. The moisture content ranged from 5.908 (Olea africana) to 9.927 (Acokanthera schimperi). O. africana has also the least moisture content and is inversely correlated with the fixed carbon content as Graphed with another sample in higher volatile matter is an indicator of the least fixed carbon content and vice versa. The **fixed carbon** of a fuel indicates the percentage of carbon available for char combustion. The percentage of fixed carbon in the Table ranges from 5.955% (A.schimperi) to 22.388% (Olea africana) in the firewood samples. The general trend shows that the percentage of fixed carbon (PFC) increases as the density increases. Further, PFC decreases as the percentage of ash content, moisture content, and volatile matter, increases as observed from laboratory results shown in Table the correlation analysis of wood density, PMC, PVM, and PAC with PFC. The density (r = 0:982) is positively correlated with PFC, PMC (r = −0:873) is correlated negatively with PFC, PAC (r = −0:941) is correlated negatively with PFC, and PVM (r = −0:971) is correlated negatively with PFC. This indicates that the increment of one of the energy properties increases or decreases the other properties. The **ash content** ranges from 0.994 (Olea africana) to 4.445 (Acokanthera schimperi); the highest fixed carbon holds up the least ash content. Similar observations are found in this research. That means as the percentage of ash content increases, the percentage of fixed carbon decreases as observed in Table The high ash content of Acokanthera schimperi indicates that it has high mineral content Volatile Matter. **Volatile matter** refers to the part of a biomass material that is released as volatile gases when it is heated up to 400°C to 500°C. Volatile matter represents the components of carbon, hydrogen, and oxygen present in the biomass that when heated turn to vapour usually a mixture of short- and long-chain hydrocarbons .From the Table volatile matter is inversely proportional to the percentage of fixed carbon. That is, as volatile matter increases, the percentage of fixed carbon decreases and vice versa. O. africana has still the least PVM among other woody species in the sample(Desta & Ambaye, 2020)

Table 1: Table Laboratory analysis of *Acacia nilotica, Acacia etbaica, Acacia seyal*

Species name	PMC	PAC	PVM	PFC	CV(KG/g
	Mean±stdev	Mean±stdev	Mean±stdev	Mean±stdev	Mean±stdev
A. nilotica	4.220±0.84	3.180±0.08	28.875±0.66	63.725±0.21	31.549±0.26
A. etbaica	5.987±3.18	4.082±0.07	29.468±1.42	60.464±2.15	30.628±0.96
P. capensis	7.000±1.77	5.008±0.26	30.156±0.71	57.837±2.15	29.957±0.58
A. seyal	7.307±0.80	5.711±0.02	30.801±0.31	756.182±0.51	29.605±0.28
A.schimperi	9.773±0.20	6.031±0.05	32.585±0.83	51.611±0.67	28.633±0.05

Source (Manaye et al., 2022)

2.19. Proximate Composition of Four Acacia

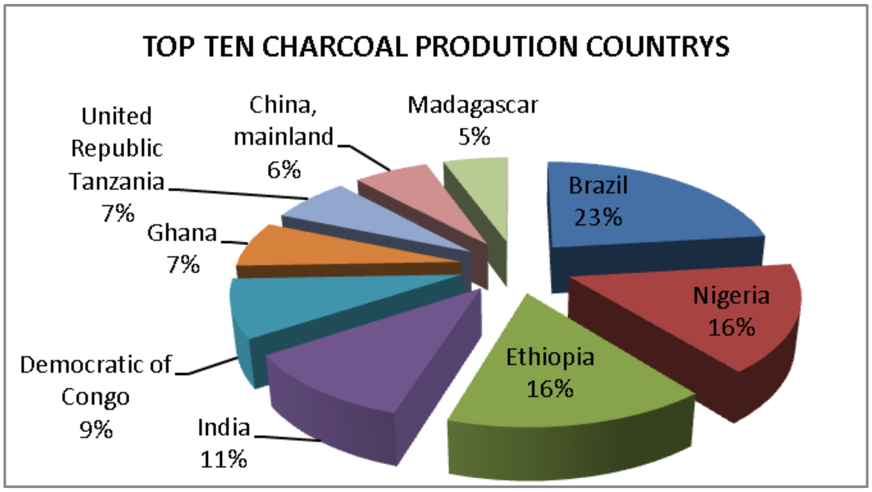
Acacia nilotica ssp. Adansonia Moisture %6.37 ±0.39, Ash % 4.40 ±0.20 Acacia nilotica ssp. Nilotica Moisture % 6.06 ±0.07, Ash % 4.45 ±0.1, Acacia seyal var. seyal Moisture % 5.94 ±0.00, Ash % 4.96 ±0.22, Acacia sieberianavar. Sieberiana Moisture % 6.28 ±0.08 , Ash % 4.02 ±0.14(Ali Mustafa & Al-Kamali, 2016).

Quality wood charcoal as having low moisture content, relatively easy to cut, easy to handle, easy to ignite and burn with high calorific value/heating value, producing very little or no smoke without toxic fumes and neither spits nor sparks. The results obtained indicated that charcoal from Acacia wood species had density ranges from 0.563 to 0.90 gcm^{-3}, with a heating value of 32.39 $MJkg^{-1}$, a percentage fixed carbon of 84.70%, and low ash and volatile matter of 3.35% and 11.95%, respectively. The results obtained were more or less close to the desirable criteria for quality charcoal. Suggested apparent density of 0.4 to 0.9 gcm^{-3} for efficiency of quality charcoal(Christiana. O, 2014).

2.20. Top Ten Countries Wood Charcoal Production Quantity

Table 2 Top Ten Countries Wood Charcoal Production (Paramasivan & Premadas, 2019)

Top Ten countries	Production Qty (tonnes)	
	Sum	Average
Brazil	42754000	6107714.29
Nigeria	29864965	4266423.57
Ethiopia	28736898	4105271.14
India	20160000	2880000.00
Democratic of Congo	16175662	2310808.86
Ghana	12743900	1820557.40
United Republic Tanzania	12667080	1809582.86
China, mainland	11739686	1677098.00
Madagascar	10181896	1454556.57
Thailand	9994603	1427800.43



Ethiopia's energy consumption is predominantly based on biomass energy sources. An overwhelming proportion (94%) of the country's energy demand is met by traditional energy sources such as fuel wood, charcoal, branches, dung cakes, and agricultural residues (Conservation, n.d.). Ethiopia has huge renewable energy resource potential, which includes biomass, hydropower, wind, solar, and geothermal energy. However, except for the woody biomass (50%), agricultural residue (30%), hydropower (5%), wind (3%) and geothermal (1%) that are exploited, the available potential is not developed (Tekle Asresu, 2017). The rural community of the Dire Dawa administrative area depends on dry land crop cultivation, livestock rearing, (mainly camels) and charcoal business for their livelihood. The vegetation formations in the vicinity of Dire Dawa city is dominantly covered by shrub and woodlands dominated by acacia species. In the last two decades, the invasive tree species, *Prosopis juliflora*, has taken over large areas in the vicinity of the city. The Dire Dawa city residents as the main household energy sources use firewood and charcoal, followed by kerosene and electricity. Charcoal supplied to the city comes mainly from the acacia dominated, free-access woodlands from localities in the vicinity of the city within a radius of about 50 km. There are, however, some trends where charcoal is transported from the Afar region. Acacia species (locally known as t'edecha) are the most preferred charcoal species. But, nowadays, due to scarcity of supply, many other indigenous tree species and some other exotic species including *Prosopis juliflora* are being used to produce charcoal. Alike most of the charcoal making technologies in different regions of the country, charcoal-making techniques in Dire Dawa are primarily based on the traditional kiln methods (earth pit or mound kilns). The field assessment showed that an estimated volume of 1200 sacks of charcoal is produced daily from the surrounding areas. People involved in charcoal production and marketing in the region are men aged 18 to 35 years. Like other regions, the charcoal business in Dire Dawa is dominated by illegal actors. Thus, it is difficult to quantify the number of producers and actors in the business as well; it varies considerably. According to information received from charcoal brokers and distributors, camels, followed by donkeys and cars, serve as the main means of charcoal transportation into the city. It is estimated that 80 to 100 camels and 100-120 donkeys, with an estimated amount of 800 sacks of charcoal, enter into the city daily (Melaku. et al.2013).

2.21. Environmental Impacts of Charcoal

Charcoal production causes deforestation and erosion (Kullane et al., 2022). Large-scale charcoal production, primarily in sub Saharan Africa, has been a growing concern due to its threat of deforestation, land degradation, and climate change impacts (Asiva Noor Rachmayani, 2015).These impacts range from the source of livelihood and economic development to physical stress and injuries, exposure to high temperature, and toxic gases, among other impacts. In addition, land degradation has reduced global crop productivity by 23% of the global land surface and as many as 100-300 million people are at risk of floods because of loss of coastal habitat and protection (Ajibola et al., 2020). The ultimate impacts of charcoal production include deforestation, degradation of grazing and browsing areas, erosion, and soil impoverishment. The most significant impacts occurring during charcoal production and usage are emissions into the air and working environment. On the global and regional scale they contribute to the global warming, while on the local scale, they may impose health risk for the workers and people living in the vicinity of the production site (JASMINE, 2014).

2.22. Charcoal supply and demand

The global charcoal market is experiencing significant growth due to various factors influencing both supply and demand dynamics. This analysis outlines the current state of the market, key drivers, constraints, and regional trends.

In Ethiopia, as demand for charcoal increases with rapid urbanization, there is pressure on forests and woodlands, most of which are poorly managed and prone to degradation (Bekele, n.d.). Ethiopia’s energy sector is the high dependence on biomass (firewood, charcoal, crop residues and animal dung)(Susanne Geissler, Dietmar Hagauer (PM), Alexander Horst, Michael Krause & Österreichische, n.d.).Charcoal production and marketing have always been almost entirely informally organized and implemented by the private sector. In the Amhara region, charcoal production and sales are permitted only if Eucalyptus or other exotic species are used. Total national consumption of wood (including charcoal equivalent of wood) is estimated to be

105.2 million tons per year, with 5.7 million tons of charcoal. Total consumption of residues and dung is 19.7 million tons per year, and 22.8 million tons per year respectively. Oromia, SNNP, and Amhara regional shares of wood (including charcoal equivalent of wood) consumption are 37 %, 25 % and 23 % respectively (GoN, 2017).

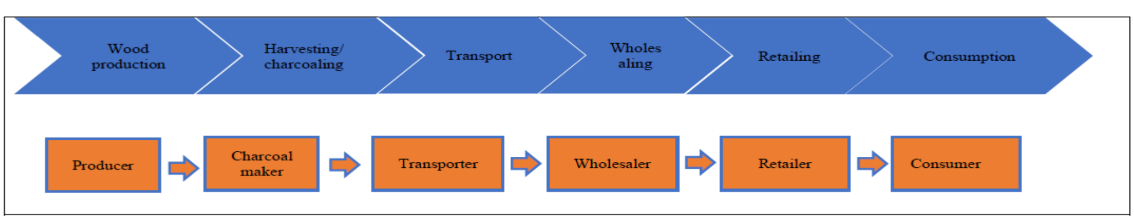
Table 3 Total National Consumption of Biomass Fuels (GoN, 2017)

REGION	Round wood tons/yr	BLT tons/yr	Charcoal as wood tons/yr	Total wood tons/yr	Total wood %	Residues tons/yr	Dung tons/yr	Charcoal tons/yr
ADDIS ABABA	684,228	-	1,060,439	1,744,667	2%	-	39,964	212,088
AFAR	830,552	-	1,195,154	2,025,706	2%	-	49,364	239,031
AMHARA	9,549,847	8,042,277	6,603,169	24,287,123	23%	3,867,504	8,221,892	1,339,000
BSG	419,308	271,709	202,893	893,911	1%	427,246	188,435	40,579
DIREDAWA	219,831	54,698	359,246	633,774	1%	39,971	29,548	71,849
GAMBELA	181,653	74,736	96,236	364,659	0%	67,069	44,966	20,735
HARARI	136,728	38,463	225,685	400,876	0%	28,108	21,501	45,137
OROMIYA	17,812,299	11,070,636	9,921,703	38,804,638	37%	7,571,451	6,261,813	1,984,341
SNNPR	15,264,304	7,185,536	3,564,630	26,014,470	25%	7,539,192	2,229,843	712,926
SOMALI	2,520,644	211,155	3,203,569	5,935,369	6%	152,929	220,755	614,467
TIGRAY	614,995	1,284,533	2,167,743	4,067,271	4%	31,256	5,511,309	433,549
TOTAL	48,234,389	28,233,742	28,600,468	105,172,465		19,724,725	22,819,390	5,713,700

2.23. The Charcoal Value Chain

The charcoal value chain starts where the tree grows, with wood harvesting to eventual consumption. It includes all the economic activities undertaken between the production and consumption systems. Many different stakeholders participate in the value chain, right from wood production, carbonization of the wood, packaging and transportation of the charcoal, retailing and distribution, and consumption (Firdausi, 2020).

The value chain approach seeks to investigate activities implemented by all actors from production to consumption, including linkage service providers, The approach aims to understand the direction of the flow of economic goods and services among different actors at different stages of engagement in the production, distribution/transportation, trading, and consumption (Ndegwa et al., 2020).



source(Ndegwa et al., 2020)

2.24. Frame work of the study

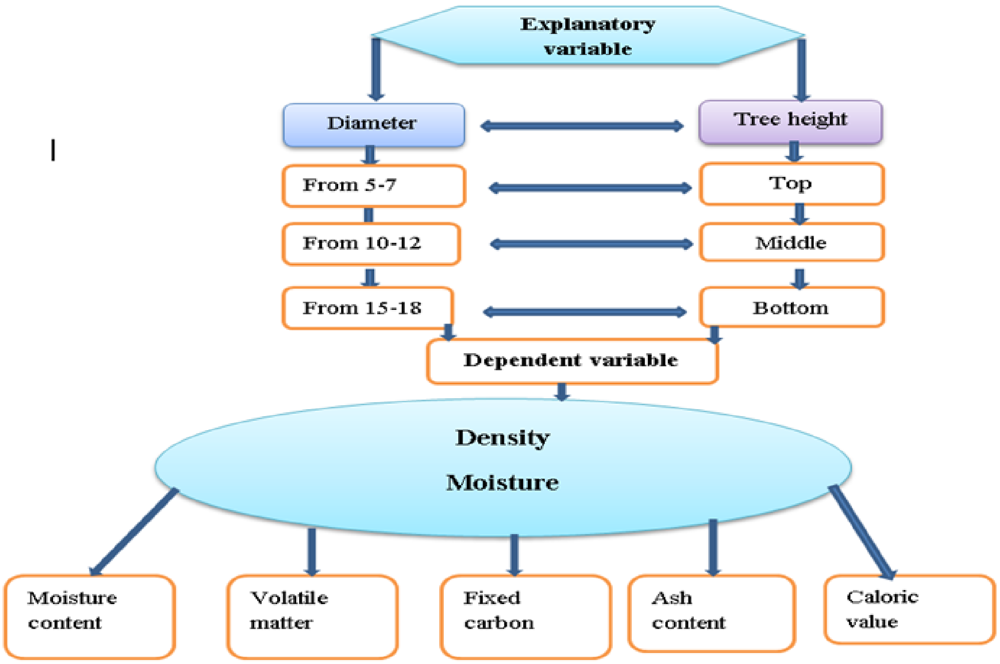


Figure 2 Frame work of the study

The frame work of the study was to evaluate the quality of charcoal made in the Dire Dawa area from *Acacia seyal*. The study can gain insight from earlier studies on land use and charcoal production in Ethiopia, including how charcoal production affects land degradation and deforestation.

CHAPTER THREE

3. Material and methods

3.1. Description of Study Area

Dire Dawa city is located about 515 km to the east of Addis Ababa. The area is found between 9° 27′ and 9° 49′ N latitude and 41° 38′ and 42° 19′ E longitude. The total area of the administration is estimated to be 128,800 ha. Dire Dawa city is situated at an altitude of 1276 m above sea level. The mean annual rainfall of the area varies from 550 mm in the lowland areas to 850 mm in mountains regions, with an average of 640 mm. The annual mean minimum and maximum temperature ranges are 14.5 and 34.6 °C, respectively (Harun et al., 2022). The climatic situation is characterized mainly by warm and semiarid climate with relatively low rainfall(Tilahun & Merkel, 2009).

The total population of the Dire Dawa Administration is 521,000. The rural area has a population of 188,000 spread over 38 rural kebeles (smallest administrative unit) while the population of Dire Dawa city is 333,000, which is subdivided into nine urban kebeles. Around Dire-Dawa City, the predominant vegetation cover types are woodland and shrub lands with a predominance of the *Acacia* species and the invasive *Prosopis juliflora* tree species. The primary sources of domestic energy source of the administration are firewood and charcoal, followed by kerosene and electricity.

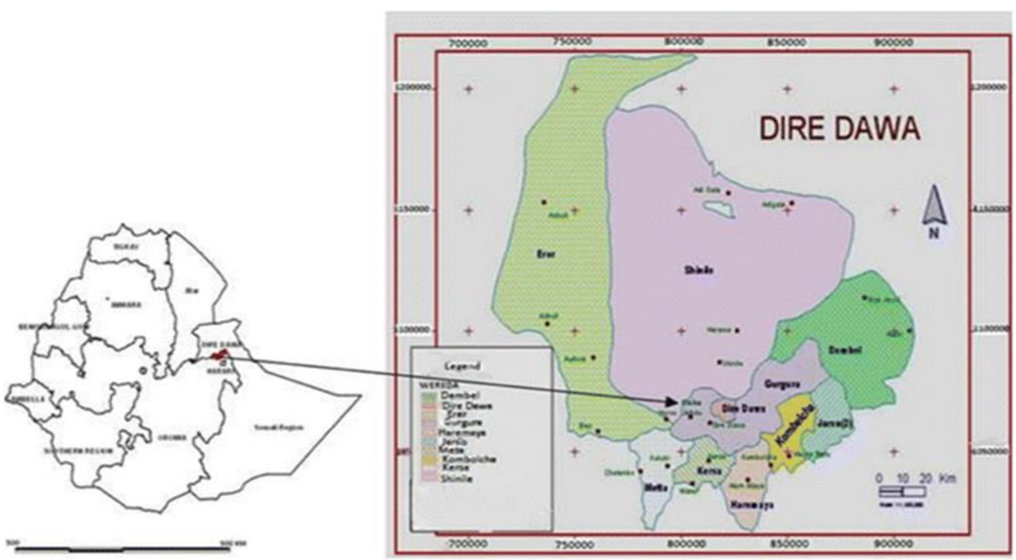


Figure 3: Map of Dire Dawa Ethiopia

The sample collection area around National Cement Factory 9°34'11.6"N 41°51'26.0"E

3.2. Sample collection methods

A total of 27 sample trees were randomly felled from three-diameter classes of 5-8, 10-13, and 15-18 that means nine tree samples from each diameter class. Then the trees were trimmed into three equal portions of the individual tree height: bottom, middle, and top parts. Regardless of the diameter class the wood samples also trimmed into three lengths of 20 cm, 25 cm and 30 cm.

Figure 4: The carbonization cycle of samples a – j

Table 4 Sample matrix of diameter class x length

Sample length	Tree diameter class based on BDH									Replication
	A			B			C			
Tree no.	1	2	3	1	2	3	1	2	3	3
20cm (D)	AD	AD	AD	BD	BD	BD	CD	CD	CD	
25cm (E)	AE	AE	AE	BE	BE	BE	CE	CE	CE	
30 cm (F)	AF	AF	AF	BF	BF	BF	CF	CF	CF	

Note- The total number of trees (9 trees) were used for one replication in the experiment

Where –Lt Total length of tree

A, B, and C are different in diameter class based on DBH of the selected tees

D, E, and F - length of carbonized samples.

3.3. Instruments used in the study

- Axe and hand saw were used for cutting, and a tape ruler, caliper, and table saw machine were used for measurements and trimming to the desired lengths.

- Hot Air Oven (DHG-9076A, China) for the determination of the moisture content of the samples and the produced charcoal.
- Electronic Balance (model FA2104, China) -to measure the mass of objects.
- Stopwatch – for monitoring of the carbonization process.
- Desiccator a sealed container used in laboratories for storing moisture-sensitive materials.

3.4. Determination of density

Disk samples with a size of 5cm thickness from each diameter class was trimmed and immediately the volume was measured using water displacement method. The dry weight of each specimen was obtained after drying in an oven at a temperature of 105 ± 2 ^{0}C until constant weight is recorded. The basic density of the sample calculated with the bellow formula

$$\text{Basic density} = \frac{\text{Oven dry weight of sample (kg)}}{\text{Green volume of sample } (m^3)} \text{x100}$$

The volume of sample disks were determined by water diss-placement method which is a simple and reliable measurement for irregularly shaped samples. A container capable of holding the sample was filled with a known volume of water and placed on a digital balance of precision 0.001 g. The balance was then tarred (the reading should be zero). The oven-dried *A.seyal* wood specimens were carefully sunk in the water (Desta & Ambaye, 2020).

Measuring the weights of specimen water displacement method

Figure 5 The process of measuring the density through water displacement methods

3.5. Moisture content of *Acacia seyal*

Moisture content (MC) is the weight of water contained in the wood compared to the wood's oven-dry weight. A change in the size of a piece of lumber is related to the amount of water it absorbs or loses. (Watano, 2006). The moisture content of the samples was determined by drying 5 g of the ground gum sample to constant mass at 105 °C using a hot air oven (Memmert

Oven). Dried samples were cooled in a desiccator before weighing. Moisture content was expressed as % of mass loss from the original mass according(Awad et al., 2024).

$$Moisture\ content, \% = \frac{Initial\ weight - dry\ weight}{Initial\ weight} x100\%$$

3.2. Carbonization process

The carbonization of the wood material was performed in a metallic barrel. The metallic barrels having two distinct sizes, varying in both length and diameter, for sample charring and cover as inlet air controller. The larger barrel measures 100 cm in length and has a diameter of 65 cm, while the smaller barrel is 60 cm long with a diameter of 54 cm.

The barrel was filled with air-dried, weighed *A. seyal* wood samples. The samples inserted into the barrel during carbonization vary in both length and diameter. Their lengths are 20 cm, 25 and 30 cm, while their diameters 5-8, 10-13, and 15-18. Each sample was inserted into barrel sequentially, step by step, followed by ignition of the wood. The ignited wood samples left to burn until it changes the color of the smoke from black to light grey/white. Following the color change, the barrel was closed with larger barrel in order to regulate the inlet air. Due to the high temperature of carbonization and limited access of air in the system, thermally degraded the wood components leave the barrel as volatile compounds leaving behind carbon rich black solid material, which is called charcoal. At the end of carbonization (after 36 hours), the smoke amount drastically decreases and starts to cool.

3.3. Determination of charcoal yields

Charcoal yields describe how much charcoal made from a specific quantity of *Acacia seyal* wood sample. Each treatment samples weight was recorded before carbonization, and then at the end of carbonization the cooled charcoal was again weighed.

$$\boldsymbol{Charcoal\ yield, \% = weight\ of\ charcoal \div total\ weight\ of\ wood. 100}$$

$$Percentage\ of\ charcoal\ yield = \frac{Output}{Total\ input} x100 \text{ ---------------------------------3}$$

This means

$$Charcoal\ yield\ (\%) = \frac{weight\ of\ charcoal}{Weight\ of\ Acacia\ seyal\ wood\ used\ for\ carbonization} x100\ \%$$

3.4. Characterization of the charcoal

3.4.1. Determination of Moisture Content of charcoal

Percentage of the moisture content (MC) determined using the standard method of the American Society for Testing Materials (ASTM D1762-84) on the basis of a dry biomass by weighing the charcoal sample (W1). One gram of sample put in a drying hot air oven (DHG-9076A, China) at 105 °C for 3 hrs., then each sample drawn from the oven and cooled in a desiccator for 30 min before weighing and repeated drying and weight measurements of the sample every 60 minutes until the constant weight (a difference of 0.005) obtained (W2). Then, percentage moisture content is determined following equation (Sisay. et al., 2020).

$$PMC = \frac{W1-W2}{W1} x100\% \quad \text{-------------} (1)$$

Where,

W1 = Initial weight of sample before drying

W2 = Final weight of sample after drying

PMC = Percentage Moisture Content

Oven dry Digital balance

Figure 6 Oven dry and Digital balance (model FA2104, china)

3.4.2. Determination of Volatile Matter (VM)

To determine the VM, 2 g of crushed oven dried charcoal sample (A) put in a crucible and inserted in the furnace. Muffle furnace FA2101, China at a temperature of 950 ^{0}C for 6 minutes, then the left residue (B) weighed. The VM determined with the formula.

$$\text{PVM} = \frac{\text{A}-\text{B}}{\text{B}} \text{x } 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where,

- A is the weight of the oven-dried sample and
- B is the weight of sample after 6 minute in the furnace at 950 0C,

3.4.3. Determination Ash content (AC)

The AC determined by heating one gram of the pulverized sample in the furnace at a temperature of 750 °C for 3 hours and weighed after cooling in a desiccator to obtain the weight of ash. The PAC determined using the following equation:

$$\text{AC} = \frac{\text{B}}{\text{D}} \text{x } 100 \text{ ----------------------(3)}$$

Where,

D= the weight of ash and

B= the weight of oven dried sample

3.4.4. Determination of Fixed Carbon (FC)

The percentage of fixed carbon (PFC) calculated by subtracting the sum of percentage volatile matter (PVM) and Percentage ash content (PAC) and percentage moisture content (PMC) from 100 % as shown in the following equation.

$Fixed\ carbon(FC) = 100 - (\text{AC} + \text{MC} + \text{VM})$---------------------- (4)

3.4.5. Determination of Caloric/ Higher Heating value (HHV)

The caloric value (CV) of the produced charcoal sample was determined using an Oxygen bomb calorimeter in accordance with the (ASTM D1762-84) standard method. The oxygen bomb Calorimeter (XRY-1A, BIOBASE BIODUSTRY SHANDONG Co, LTD, China) first calibrated using a standard sample of benzoic acid whose known calorific value is 6.32 kcal/g. Two grams of the charcoal samples were placed in the crucibles, and the bomb calorimeter operated according to the instructions. The maximum deflection obtained in the galvanometer was converted to the energy value of the sample material by comparing the rise in galvanometer deflection with that obtained when a sample of known calorific value of benzoic acid is combusted.

Figure 7 Bomb calorimeter

3.5. Experimental design and data analysis

The charcoal quality of *A.seyal* study followed a Complete Randomized Design (CRD) with two factors (tree position X sample length) each with three levels of treatments. The mean comparison of data was analyzed using Design Expert version13.

The collected data were analyzed by using the statistical packages of Microsoft Excel and Design Expert Windows, and ANOVA was employed to compare the mean difference at 95% level of confidence.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

The results and analysis of the data are covered in this chapter. The data analysis is in line with the particular goals, which included examining, interpreting, and drawing conclusions from patterns. In particular, the study aimed to assess the quality of charcoal made from *Acacia seyal* species.

4.1. Characterization of the Acacia seyal wood

The average moisture content of *A.seyal* for all diameter classes was the highest 15.02%, while the average MC varies significantly, where the lowest MC was 12.48% from the sample with the highest diameter (Table 4). The relative low moisture content in larger diameter of Acacia sample ascribed to the increase in the formation of large heartwood which is low in moisture content.

Table 5 Weight of nine samples before and after oven drying

No	Sample cut sizes(length & diameter in (mm))	Weight in gram		Moisture content (%)
		Before drying (W)	After drying (W_1)	$(W-W_1)/w$ X 100
1	5 *50	93.54	79.63	14.870
2	5*110	195.7	163.96	16.218
3	5*115	281.12	232.87	17.163
4	5* 120	616.80	517.07	16.168
5	5* 122	634.78	534.21	15.843
6	5*130	683.26	575.52	15.768
7	5* 150	982.46	849.41	13.542
8	5* 180	1774.09	1541.27	13.123
9	5*200	2014.98	1763.55	12.478
Mean		808.53	695.28	15.02
Max		2014.98	1763.55	17.163
Min		93.54	79.63	12.478

The *Acacia seyal* sample collected from Edditi around the Dire Dawa Administrative areas of woodland have a broad range density 757 kg/m^3 to 960 kg/m^3 with an average density of 857 kg/m^3 (Table 6). The density value of this study is in the range and good agreement for *Acacia* *seyal* (Gamal, 2014) but slightly higher than the report of (Desta & Ambaye, 2020). The wood density of the Acacia tree varies in tree diameter with the wood with larger diameter exhibited higher density.

Table 6. The density of the *Acacia seyal* wood of samples

NO.	Sample code	Sample sizes (cm)	Mass (gm.)	Volume (cm^3)	Density(gm / cm^3))
	S1	50	150	190	0.789
	S2	69	250	330	0.757
	S 3	82	350	440	0.795
	S 4	115	750	880	0.852
	S 5	120	760	860	0.883
	S 6	122	850	1000	0.85
	S 7	146	1200	1280	0.937
	S 8	200	2150	2410	0.892
	S 9	218	2450	2550	0.960
Mean		**50**	**150**	**190**	**0.857**

Table 7: Experimental results and principal component analysis (PCA) on five tree species (Desta & Ambaye, 2020).

Species name	Diameter (cm)	Density (g/cm3)	5.908	Ash Contents (%)	Volatile matter Contents (%)	Fixed carbon Contents (%)
O. africana	7.367	0.914	7.030	0.994	70.710	22.388
A. nilotica	6.400	0.857	7.819	1.971	71.495	19.503
A. etbaica	6.300	0.779	8.279	2.741	73.644	15.796
A. seyal	6.667	0.665	9.927	3.353	76.790	11.578
A. schimperi	5.800	0.553	9.927[a]	4.445	79.673	5.954

4.2. Charcoal yield

The kiln efficiency and the charcoal quality depend on several factors, including the kiln type, the arrangement of the wood logs, the wood species, the moisture content of wood and the management of the carbonization process. In the following the most important ones are described and an overview about the values used is provided (Gmünder, 2014).

The charcoal yield of *A.seyal* ranged from 32.12%-34.15%, neither the tree position not the thickness of the sample affected the charcoal yield. At relatively low temperatures around 300 °C relatively a high yield of charcoal is obtained. This charcoal has a high content of volatile material, which is undesirable because it produces noxious fumes during use. Temperatures around 600 °C give lower yields but the charcoal has a low content of volatiles making it a preferred fuel (Seidel, 2008). But charcoal producers generally prefer the higher yield. The charcoal yield decreases as the temperature increases. This indicates that charcoal producers take care to control the temperature to increase the yield and quality. 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.

4.3. Physico-chemical properties of *A.seyal* charcoal

The physicochemical properties of the charcoal products were determined by employing the standard test methods and analyzed properly. The proximate analysis of the charcoal products involves the determination of moisture content of charcoal product (%), 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 9.

4.3.1. Moisture content

Moisture content is a very important property which can greatly affect the burning characteristics of biomass (Desta & Ambaye, 2020). The effect of tree position and length of *Acacia seyal* showed a significant statistical difference ranging from 3.74%-7.9% with an average value of 5.642%. The charcoal from the bottom position of the tree has the highest moisture content of 6.54% and the top portion with the lowest moisture content 4.9%, and also the moisture content of the charcoal also affected by the length of the raw material where a charcoal prepared from largest length has the highest moisture content while the other two lengths have no a statistically significant difference (Table 8). 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*.

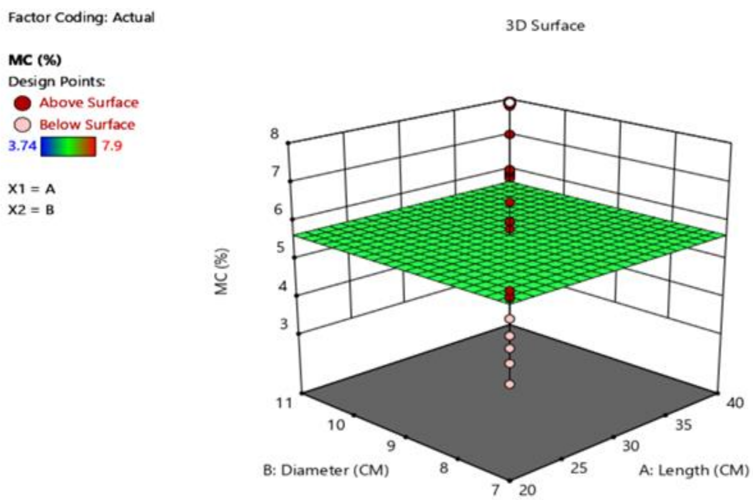


Figure 8:3D surface graph of moisture content

The 3D surface plot shows the relationship between two independent variables (A: Length and B: Diameter) on the X and Y axes, and their effect on the dependent variable, MC% (Moisture Content), on the Z-axis. Below is the detailed explanation:

- **Yellow** indicates regions of **low moisture content** (near 3.74%).
- **Red** indicates regions of **high moisture content** (near 7.9%).
- The **green grid** represents intermediate values.

Table 8. The MC% of charcoal of *Acacia seyal*

variable	Experiments									
	Replication	S_1 = 20*7	S_2 = 30*9	S_3 = 40*11	S_4 = 20*7	S_5 = 30*9	S_6 = 40*11	S_7= 20*7	S_8= 30*9	S_9= 40*11
1.MC%	1	3.74	4.8	5.6	5.78	4.6	5.9	5.95	5.98	7
	2	4.24	5.2	5.77	4.9	5	5.95	5.8	6	7.8
	3	4.6	4.4	5.9	5.3	5.8	5.99	5.96	6.5	7.9
mean		4.193	4.8	5.757	5.327	5.133	5.947	5.903	6.16	7.57
maximum		7.9								
minimum		3.74								

4.3.2. Volatile matter

Slower ignition and combustion rates and longer burn-out times. During combustion, the volatile matter liberates heat in the process. Volatiles are of key interest in assessing a coal's reactivity and ignitability. Volatile matter is the combustible part of the fuel. So, a material characterized by a high content of volatile matter is easier to ignite and requires less energy for this process. However, fuels with higher VMC emit less heat because a significant part of the mass is released with volatiles to the atmosphere, and the coke (char) residue is the main source of heat/energy (Process & Acorns, 2020). Charcoal produced from 40 cm length of the Acacia wood has the maximum percentage of volatile matter with the value of 75.37% (Table 8). The VM of the charcoal prepared from the smallest length showed a statistically significant difference ($p \leq 0.000$) from a charcoal made from 30 cm and 40 cm raw material. The low amount of VM in the charcoal made from the smallest raw material is due to the complete treatment of carbonization temperature forced the degraded wood components to leave the material. When, computing along with tree position, statistically significant difference in VM with the value of 73.4% for top, 75.03% for middle and 70.75% for bottom portions (Table 8). The presence of such high VM in the produced charcoal would be a result of incomplete combustion during the carbonization process or the nature of the *Acacia seyal* wood during the carbonization process able to form some tar products.

4.3.3. Ash content

Percentage ash content was calculated as a proportion of the dried weight of the ash residue in furnace to the oven-dried weight of charcoal specimen(Christiana. O, 2014). Low ash content offers higher heating value for briquettes but high ash content results in dust emissions that lead to air pollution. High ash content lower calorific value which affects combustion volume and efficiency(INEGBEDİON, 2022). High ash content of a plant part makes it less desirable as fuel, whereas high extractive content adds to its desirability. Again, the heat content, which is a very important factor affecting utilization of any material as a fuel, is affected by the proportion of extractives present in it. Extractives raised the higher heating values of the biomass samples (Demirbas, 2002). In other words, ash is the inorganic oxide residue remaining after the water and organic matter have been removed at high temperature of the muffle furnace capable of maintaining temperatures of between 500 and 600 °C in the presence of oxygen. The charcoal made from the different lengths and tree portions of the *A.seyal* wood show a statistically significant difference where a charcoal made from the bottom portion of the tree has high AC than the other position of the trees. The decrease in the amount of ash content in the biomass increases the quality of fuel (Kimbonguila et al., 2019).

Moisture in biomass generally decreases its heating value. Ash and extractive content are the other two important parameters directly affecting the heating value. The high content of ash in charcoal from long size material attributed to the incomplete carbonization process and an accumulation of this inorganic materials throughout the growth life time of the tree.

4.3.4. Fixed carbon

Fixed carbon is a major quality measuring parameter that determines the energy behaviors in the production it is well known that low moisture content, ash and volatile matter content indicate presence of high amount of fixed carbon that results in quality charcoal and vice-versa. Conversely, a low fixed carbon in charcoal could cause many problems like associated with ignition, irregular combustion and slagging (Mengistu et al., 2025). Fixed carbon is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles (Ozbayoglu & East, 2018). The fixed carbon of a fuel indicates the percentage of carbon available for char combustion. It is not equal to the total amount of carbon in the fuel since a significant amount is released as hydrocarbons in the volatile (Desta, 2020).

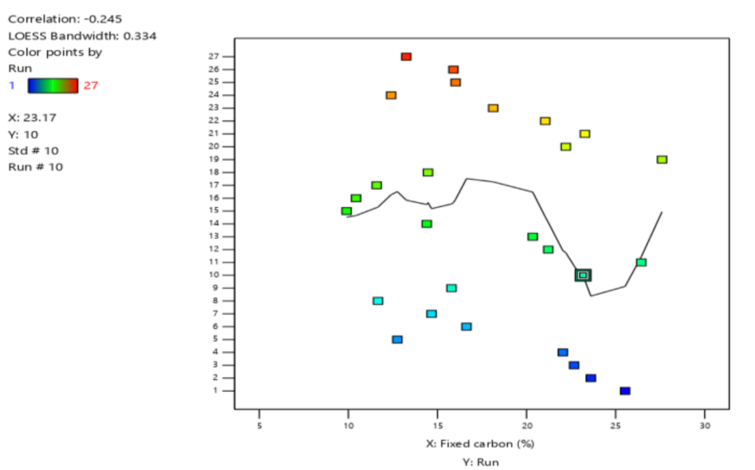


Figure 9: Scatter diagram of the FC data

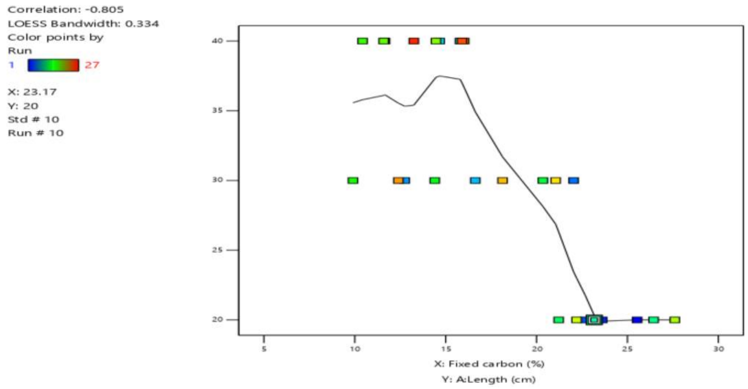


Figure 10: Relation of FC % and Length

The scatter plot graph illustrates a strong negative correlation between the fixed carbon percentage and the deviation from a reference point. The x-axis represents the deviation from the reference point in coded units, while the y-axis shows the fixed carbon percentage.

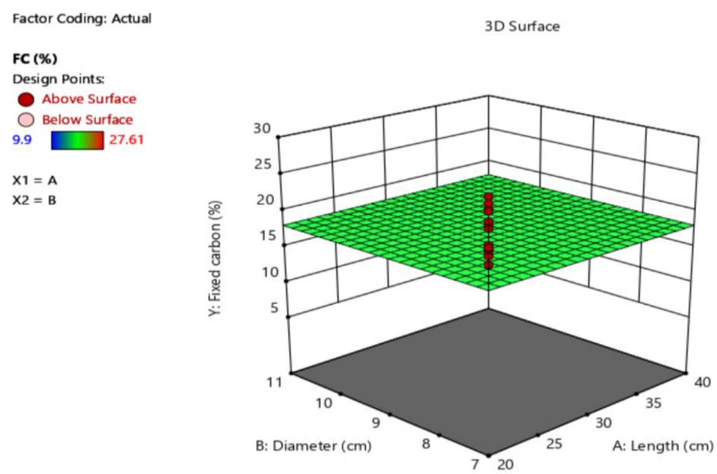


Figure 11: 3D surface of FC graph

The 3D surface plot graph represents the relationship between fixed carbon (FC) and the independent variables. The highest Fixed Carbon 27.61% was observed at the charcoal produced from smaller length**.**

4.3.5. Heat value

The calorific value of briquette determines the amount of heat energy present in the material. The calorific value was determined in line with the moisture content, ash content, and volatile matter on the briquettes. The calorific value (kJ/kg) of the samples under test was calculated from the temperature rise of the briquettes when burnt and its heat capacity (Sisay. et al., 2020).Calorific value is the most important combustion property for determining the suitability of a material as fuel(Rapheal et al., 2018). The standards measure of the energy content of a fuel is its heating value (HV), sometimes called the calorific value or heat of combustion. In fact, there are multiple values for the HV, depending on whether it measures the enthalpy of combustion, the internal energy of combustion, and whether for a fuel containing hydrogen, product water is accounted for in the vapor phase or the condensed (liquid) phase (Demirbas, 2002).

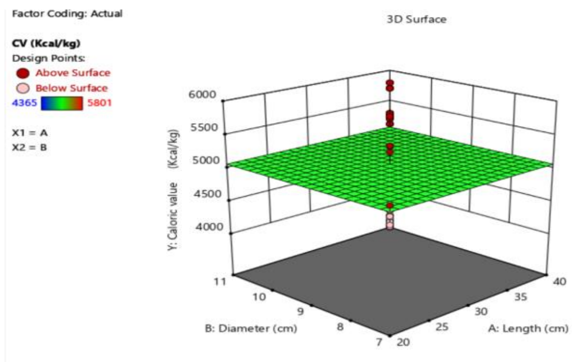


Figure 12:Contour and 3D surface graph of CV

The 3D surface plot illustrates the relationship between caloric value (CV) and two parameters: length (A) and diameter (B). The lowest value: **4365 Kcal/kg** (blue/green shades).

Highest value: **5801 Kcal/kg** (red shades).

The highest caloric value (CV = 5801 Kcal/kg) is observed at the upper bounds of both parameters. The lowest caloric value (CV = 4365 Kcal/kg) occurs at the lower bounds of both parameters. The caloric value increases as the length and diameter increase, implying a positive correlation.

Table 9: The main effects of tree positions and lengths on the physicochemical properties

The main effects of tree positions and lengths on the physicochemical properties of the charcoal produced from *Acacia seyal*;

Treatment					**Mean Square**	
(Length)	**Charcoal Yield (%)**	**MC (%)**	**VM (%)**	**FC (%)**	**Ash (%)**	**CV (Cal/g)**
20 cm	32.99	5.14	68.48	23.97	2.40	4956.33
30 cm	33.35	5.36	75.32	16.41	3.52	4891.22
40 cm	33.74	6.42	75.37	13.75	4.56	5364.44
$LSD_{0.05}$	0.32	0.53	3.18	3.07	0.69	187

By Tree Portion (TP)

Treatment (TP)	Charcoal Yield (%)	MC (%)	VM (%)	FC (%)	Ash (%)	CV (Cal/g)
Top	32.12	4.92	73.40	18.37	3.32	5026.56
Middle	33.80	5.47	75.03	16.89	3.29	5065.33
Bottom	34.15	6.54	70.75	18.87	3.88	5120.11
$LSD_{0.05}$	0.32	0.53	3.18	3.07	0.69	187

CHAPTER FIFE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this research, I have pointed out that charcoal produced using barrel methods especially from the bottom section of the tree yields a superior product with higher calorific value (5120 kcal/kg), lower moisture content, and reduced volatile matter. This production technique is simple, time-efficient, cost-effective, and minimizes waste, making it an ideal approach for communities around the city. Given the abundance of acacia trees in the region, it is crucial to prioritize their use in sustainable charcoal production. Additionally, since the overall charcoal output in Dire Dawa remains quite low, it is important for local authorities to place greater focus on developing this sector. Furthermore, promoting the planting of high-caloric value tree species in the area will help ensure a more productive and sustainable supply of quality charcoal.

5.2. Recommend

Dire Dawa city administration it is a city with a collection of all ethnicities, so it is a city with a large population, so the energy consumption is very high after electricity charcoal consumption. It is possible to produce enough charcoal in a modern way by providing technical support for them this contributes to manage deforestation, erosion, and soil impoverishment around the city.

The benefits may get

- Reduce the woodland degradation rate
- Increases the economic benefits of the residents.
- Improves health (reduces air pollution).
- Ensures sufficient charcoal production, so it changes the way of life of the society; therefore, it needs a lot of attention.
- Reduction of energy wastage while producing the charcoal.
- Awareness creation on modern kiln system production of charcoal.

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Annex 1. Charcoal Yield data

	Sizes of sample (Length * diameter in cm)								
size	5 *50	5*110	5*115	5* 120	5* 122	5*130	5* 150	5* 180	5*200
code	S1	S2	S3	S4	S5	S6	S7	S8	S9
S1	93.54	195.7	281.12	616.80	634.78	683.26	982.46	1774.09	2014.98
S2	93.73	195.30	281.35	616.96	634.85	683.35	982.61	1774.25	2015.8
S3	93.96	195.85	281.75	617.10	634.96	683.55	982.80	1774.45	2015.12
Mean of S1-S3	93.54	195.3	281.12	616.8	634.78	683.26	982.46	1774.09	2014.98
initial mass	93.54	195.7	281.12	616.80	634.78	683.26	982.46	1774.09	2014.98
Oven dry mass	79.63	163.96	232.87	517.07	534.21	575.52	849.41	1541.27	1763.55
MC%	14.870	16.218	17.163	16.168	15.843	15.768	13.542	13.123	12.478
	S1	S2	S3	S4	S5	S6	S7	S8	S9
mass of FC	23.938	23.94	17.14	14.042	23.61	14.9	12.163	24.365	17.19
mass of wood	93.54	195.7	281.12	616.80	634.78	683.26	982.46	1774.09	2014.98
charcoal yield	0.316	0.32	0.322	0.332	0.341	0.339	0.344	0.333	0.330
charcoal yield%	31.637	32.494	32.242	33.279	34.181	33.944	34.047	33.370	33.098

Annex 2. Proximate analysis data of charcoal from *Acacia seyal* results

Tree position	length (cm)	Charcoal yield	MC (%)	AC (%)	VM (%)	FC (%)	CV(KCal /Kg)
top-1	20	30	3.74	2.575	68.15	25.535	4864
	20	31.578	4.24	2.01	70.14	23.61	4966
	20	33.333	4.6	2.23	70.50	22.67	4878
top-2	30	30.405	4.8	2.85	70.31	22.04	5021
	30	32.727	5.2	3.21	78.84	12.75	4365
	30	34.351	4.40	3.57	75.4	16.63	5345
top-3	40	31.111	5.60	4.23	75.5	14.67	5122
	40	32.490	5.77	4.6	77.965	11.665	5801
	40	33.125	5.90	4.56	73.75	15.79	4877
middle -1	20	32.727	5.78	1.6	69.45	23.17	4936
	20	31	4.9	2.16	66.5	26.44	4875
	20	36.111	5.3	2.27	71.21	21.22	5023
middle-2	30	35	4.60	2.4	72.65	20.35	4365
	30	33.333	5	3.78	76.82	14.4	5345
	30	34.210	5.8	3.99	86.31	9.9	4824
middle -3	40	32.5	5.90	4.01	79.66	10.43	5301
	40	33.333	5.95	4.63	77.83	11.59	5709
	40	36	5.99	4.74	74.8	14.47	5210
bottom-1	20	32.857	5.95	2.14	64.3	27.61	5156
	20	35	5.8	3.155	68.84	22.205	4897
	20	34.285	5.96	3.5	67.26	23.28	5012
bottom-2	30	31.111	5.98	3.8	69.17	21.05	4678
	30	34	6	3.97	70.905	18.13	4824
	30	35	6.5	4.07	77.43	12.4	5254
bottom-3	40	32.352	7	4.6	72.38	16.02	5301
	40	34.285	7.8	4.8	71.5	15.9	5709
	40	38.461	7.9	4.9	74.94	13.25	5250

Abbreviation

MC=Moisture Content, VM= volatile matter content, FC= Fixed Carbon Content, AC=Ash Content and CV= Calorific Value

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Annex 3. Summary of Results

The detailed analysis provides insights into the variability and averages of key properties in Acacia seyal trees based on sample lengths and diameters across different sections of the tree

Property	Low Value (Minimum)	High Value (Maximum)	Average Value
Moisture Content (MC)	3 .74%	7 .90%	5.642 %
Ash Content (AC)	1 .60%	4 .80%	3.312%
Volatile Matter (VM)	64 .30%	86 .31%	70.280%
Fixed Carbon (FC)	9 .90%	27 .61%	17.552%
Calorific Value (CV)	4365 KCal/Kg	5801 KCal/Kg	4,876.222 Kcal/Kg

The above table summarizes the ranges of key parameters—Moisture Content (MC), Ash Content (AC), Volatile Matter (VM), Fixed Carbon (FC), and Caloric Value (CV)—from the laboratory results. It includes the minimum and maximum values for each parameter