PRODUCTION AND CHARACTERIZATION OF FUEL BRIQUETTE FROM MANGO (MANGIFERA INDICA) RESIDUE FOR DIVERSIFICATION OF HOUSEHOLD ENERGY SOURCES .

M.Sc. THESIS

BY

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APPROVAL SHEET

As thesis research advisors, we here by certify that we have read and evaluated this thesis work prepared entitled: **Production and Characterization of Fuel Briquette from MANGO (Mangifera Indica) Residue for Diversification of Household Energy Sources;** under our guidance, by **Solomon Mekonnen.** We recommend that it can be submitted as fulfilling the thesis requirements.

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ABSTRACT

Ethiopia's energy consumption predominantly depends on traditional biomass. The objectives of this study were to produce fuel briquette from Mango seed and mango peel waste generated from Addis Ababa city as well as to evaluate the fuel quality of the briquettes produced. The samples of mango waste collected and after air dried samples were carbonized using Philippine drum kiln model then the carbonized sample were crushed to powder and mixed with a (15 %) clay soil binder and converted to briquettes by using a beehive pressing briquette machine. Proximate analysis were carried out using ASTM procedures. Briquettes produced from carbonized mango seed, mango peel, and a mixture of carbonized seed and peel fixed carbon content and calorific value were 46.03 ± 0.80 %, 34.28 ± 0.74 %, 42.98 ± 0.49 %, and 5,588.33 ± 319.72 Cal/gm, 4,961.78 ± 274.77 Cal/gm, 5,473.15 ± 347.70 Cal/gm, respectively, and through conversion of estimated total amount of wet Mango residues were on average 22,638,912kg/yr. from Mango seed, Mango peel, and a mixture of carbonized seed with carbonized peel annually the city could produce about 44.670,16.490,and 66.060 MJ of energy . In addition to this, based on their calorific value and energy potential can substitute1,450.3ton,535.4ton and 2,144.8 tone of wood charcoal or 8.702 ton,3,212 ton and 12,868.8 ton of fuel wood substitution per year respectively. Because of that substitution 4,785 ton, 1,767 ton and 7,077.8ton of CO_2 that release to the environment reduce due to the produced a mango seed and mango peel briquette. Mango seed and peel fuel briquettes had total CO emissions of 842 ppm (0.08%) and 923 ppm (0.09%) respectively minimize air pollution. Concluded that the fuel briquette produced from mango waste have high potential as an alternative a source of energy, helps to reduced CO_2 emission by reducing the deforestation rate, reduces pollution and provides sound mango waste management option .

Keywords: Binder; Mango seed; Mango peel; Deforestation

List of Acronyms and abbreviation

AC	Ash Content
ASAE	American Society for Testing and Materials
BD	Bulk Density
BTG	Biomass Technology Group
Cal/gm.	Calorie per gram
CH_4	Methane
CO	Carbon Monoxide
CO2	Carbon Dioxide
EEA	Ethiopian Energy Authority
FCC	Fixed Carbon Content
FAO	Food and Agriculture organization
GHG	Greenhouse gas
Kg/hr	kilogram per hour
Kg/m^3	Kilogram per cubic meter
Kpa	kilopascal
LPG	liquid petroleum gas
MC	Moisture Content
MJ/kg	Mega Joules per Kilogram
MW	Mega Watt
MWIE	Minister of Water, Irrigation, and Electricity
NGOs	Non-governmental organizations
PJ	Pico joule
PM	Particular Matter
VM	Volatile Matter
°C	Degree Celsius
%	Percent

1. Introduction

1.1 Back ground

Currently global energy demand is increasing rapidly due to increasing world population and economic growth. 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 (Klimenko and Tereshin, 2010; UNEP, 2013;). The growing concerns of environment protection, energy security, over exploitation and rising price of fossil fuels, there is growing interest in renewable energy development such as hydro, wind, solar, geothermal and bio-energy (EEA, 2008) . In Africa, the search for fire wood is left to children and women who walk long distances hence reducing the time they put in agricultural production and other house hold activities. It results into low production, low incomes and household food insecurity(Kagere, 2012).

Ethiopia's energy consumption predominantly depends on traditional biomass such as firewood, agro-residues, dung, and charcoal. Traditional biomass supplies more than 92.4% of the total energy demand in the country while the remainder is supplied by oil products, hydro and geothermal (MWIE, 2014).

Our country has huge renewable energy resource potential which includes biomass, hydropower, wind, solar, and geothermal energy. However, except the woody biomass (50%), agricultural residue (30%), hydropower (5%), wind (3%) and geothermal (1%) which are exploited, the available potential is not developed. The country's energy sector is among one of the least developed in the world. The total national energy consumption of the country in 2010 was

1,300PJ which is the lowest from Sub-Saharan Africa (MWIE (2013),) . Despite significant adoption of commercial energy in Ethiopia during last few decades, biomass continues to dominate energy supply in rural and traditional sectors. Biomass energy constitutes wood fuels (including charcoal, and wood wastes), crop residues (such as coffee husk, bagasse, rice husk and crop stalks) and animal dung (including biogas). Ethiopia's energy system is characterized mainly by biomass fuel supply, which covers 85% of the energy consumption, with households being the greatest energy consumers (Ahmed 2006).

The increase in population overtime, and the consequent agricultural expansion accompanied by resettlement have resulted in increasing energy demand and a scarcity of woody biomass; these factors coupled with the rise in oil price have caused great destruction of forests in developing countries (Mulugeta L, et .al 2007). Fossil fuels are the leading sources of fuel energy, since they generate a large amount of energy from a minimal quantity, have high heating power and good quality combustion character(Riddell, et al.,2018). Briquetting is the process of converting agricultural waste into a uniformly shaped block of coal that are easy to use, convey and store(Raju et al. 2014) . Fossil fuel is not a renewable source of energy. Aside from being non-renewable, its usage can cause air pollution by releasing toxic air pollutants and carbon dioxide (CO2), which is the most important human- produced climate-altering greenhouse gas. Its health impacts especially in children include mortality and neurodevelopmental problems. There are already existing solutions through a shift from fossil fuels to clean energy (Azri et al. 2017). Mango (Magnifera indica) is a perennial crop of the family Anacardiaceae. It is grown practically all over tropical and sub-tropical regions of the world. Mangoes are among the common fruits that are consumed by many people and also used in juice production from their extractions in agro-processing industries in Ethiopia. And during their processing and raw consumption, seeds and peelings generated as waste are not utilized. They are disposed off and left to decompose or dried and burnt in a loose form which results into air pollution(Aina et al., 2009). However, the declining fuel wood and charcoal sources and rising prices of electricity, kerosene and LPG cooking gas calls for seeking alternative energy sources for both domestic and industrial use(Hamish, 2012).

Addis Ababa city generate solid waste with rate of 0.4kg/head/day from almost 4 million people and generates 23.1 tons of fruit and vegetable daily. Wastes of fruit and vegetable in Addis Ababa dumped in open field that hold huge energy potential with a quantity of wastes from fruit that avoided in the city is very huge near to 164.51 tons/day that affect the environment adversely and cause public health problem because of open dumping disposal, therefore suitable waste management system is required like waste reduction, reuse and recycle that actually reduce solid waste accumulation(Dagnew et al,2013). The main goal of this research that conduct in Addis Ababa is reuse the solid waste from mango seed and mango peel by converting the waste to fuel briquette.

This dense dependence on biomass energy in urban communities is unlikely to change in the near future. In addition to that Addis Ababa has been facing serious solid waste management problem where the waste seen scattered in different parts of the town and has no proper disposal site resulting in the emission of GHGs, health problem and lack the view of the city. So the government and the community have the responsibility to reduce such kinds of disaster.

Therefore, the main objective of this paper is to produce alternative solid fuels that can be used as a substitute fuel wood or other fuels from mango residues, to determine the quality of charcoal briquette obtained from mango residues, to evaluate the challenge of mango residues charcoal briquette production.

1.2 Statement of the Problem

Two of the major energy issues today are that of energy security and environmental implication of fossil fuel consumption .The population of Ethiopia depends on biomass for everyday energy needs. Fuel wood accounts for around 78% of the total energy demand in Ethiopia.Forest resourc es in Ethiopia have experienced so much pressure due to increasing need for wood and wood products. Nearly half the world’s population, almost all in developing countries, like Ethiopia, cooks using biomass solid fuels, predominantly wood. A serious solid waste management problem where the waste scattered in different parts of the town and has no proper disposal site resulting in the emission of GHG, health problem and lack the view of the city. On the other hand, there are also problems on the use of alternative energy source on the city. Even if the city has access to electricity, there is a problem on electricity interruption this is the challenge for the government and the community. The community also prefers to cook local food, coffee ceremon y etc. on charcoal than electricity. To solve the above-mentioned problem it is important to use alternative energy sources such as the biogas, liquid petroleum gas (LPG), ethanol and gel -fuel technologies. It is though evident that none of these latter alternatives can compete with the biom ass briquette, in terms of the low capital investment that is required to use it. In general, organic waste briquette is useful for sustainable development.

Briquetting from organic waste have several benefits to the community and environment. Therefore, the community, NGOs and Government gave attention to it as one ways of alternative energy and waste management in different parts of the country.

1.3 Objective

1.3.1 General Objective

The general objective of this research is to produce briquette from mango seeds and mango peel residue and its implications for the substitution of fuelwood, consequently to facilitate alternative energy of the country.

1.3.2 Specific Objectives

The specific objectives of the research were to:-

- Estimate its fuel quality through proximate analysis and combustion test
- Produce fuel briquette from mango residues
- Compare fuel briquette made from mango residues biomass with other similar source of energy and charcoal quality standards
- Determine the bulk density and calorific value of the briquette produced from mango residues.

1.4 Significance of the study

This study has massive significance that ranges from the global scale to the national. In view of the continuous global call to conserve the environment against the ever growing demand and supply of wood fuel with its ascending environmental threats, research of this kind is very crucial in achieving results that would inform the on-going discourse. The current efforts in combating global climate change are traceable to environmental imbalances.

The study could contribute to the identification and formulation of global strategies, plans and programmes of action for the conservation and sustainable exploitation of biological diversity. Biomass energy use like briquette technology has its own contribution for the expansion of renewable energy and it has dual purpose. The first one is used as alternative energy and secondly for the waste utilization and converting organic wastes into essential material like fuel briquette production give as many other multi socio-economic benefits like clean energy, improves deforestation (WEC, 2016).

1.5 Scope and Limitation of the study

This research aims neither the effect nor benefits of briquettes from the mango residues towards GHG mitigation nor its economic analysis. It does not attempt the production of briquettes form other wastes that are scattered on the study area and it focus only on mango supply to the city and the role of changing mango residue to charcoal briquette location may not be exclusively bounded to the target study area, its benefit and beneficiary community may extend beyond the study area. This study does not see such extended benefits. Such issues are beyond the scope of this study work.

2. LITERATURE REVIEW

2.1 Botanical Description of mango

Mango (Mangifera indica), family Anacardiaceae, is a large, branched perennial erect tree with wide evergreen crown which attains a great height. Flowers appear in large terminal inflores cences producing fruit. The skin of the fruits may be green, yellow, or red, depending upon the variety of the fruit. The fruits have a small point at one end, known as the beak. The seed within the fruit is large and flattened. The leaves are alternately arranged, 15 to 40.6 cm in length and leathery in texture. Seedling trees live much more than 100 years where as grafted ones live only 80 years or less. Mangoes vary in shape (nearly round, oval, ovoid oblong), size and color, depen ding up on the variety.

2.2 Mango production and its importance

Mango is produced in most frost-free tropical and subtropical climates, more than 85 countries in the world cultivate mango. The total production area of mango in the world is around 3.69 million hectares. The total amount of mango production in the world was around 35 million tons by the year 2009(FAO, 2009.). Mango is one of the most widely cultivated and globally traded tropical and subtropical fruit trees in the world (Clarke, et.al, 2011). To increase the availability of this fruit throughout the year, the surplus production must be processed into a variety of value-added products (Singh et al.,2005). Approximately 50% of all tropical fruits produced worldwide are mangos. As there has been increasing demand for mangos throughout the world.

The amount of mango production in Africa during 2009 is 13.6 million tones (FAO, 2009). In Sub-Saharan Africa (SSA), growing both domesticated and wild fruit species on farms diversifies the crop production options of small-scale farmers and can bring significant health, ecological and economic revenues (Keatinge et al., 2010).

Total fruit production in Ethiopia is about 500 thousand tones. Fruits have significant importance with a potential for domestic and export markets and industrial processing in Ethiopia. The main fruits produced and exported are banana, citrus fruits, mango, avocado, papaya and grape fruits(Zeberga, 2010). In Ethiopia mango is produced mainly in-west and east of Oromia, SNNPR, Benishangul and Amhara (Desta H, 2005.) .Mango production in Ethiopia is in fluctuated conditions, because of occurrence of diseases, lack of proper management and also weather conditions(CSA, 2009).

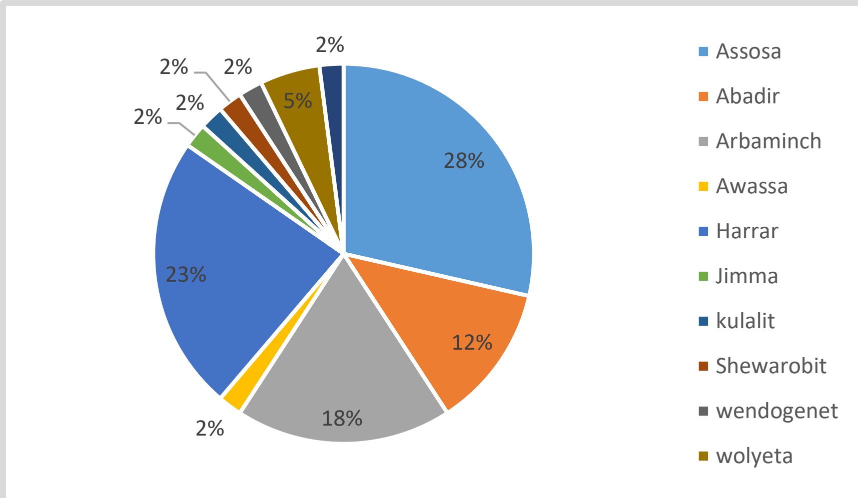
More than 47 thousand hectares of land is under fruit crops in Ethiopia. Mangoes contributed about 12.61% of the area allocated for fruit production and took up 12.78% of fruit production in comparison to other fruits growing in the country and the annual consumption of mango by the processing plant at full production capacity is 8.6 tones which is only 1.8% of the current production of mango (Elias.A 2007). However, less than 2% of the produce is exported(Joosten, 2007). But, according to CSA (2013) cropping season mangoes contributed about 14.21% of the area of land allocated for fruit production and holds 14.55% of quintals of fruits produced in the country. Therefore, the main objectives of this review is to review mango production and marketing system with their respective constraints in Ethiopia, to identify major actors along mango value chain and their respective functions along the chain, to review current status and potential opportunities of mango in Ethiopian economy. . The area coverage under mango in eastern Ethiopia has reached about 35% of the total acreage allotted for fruit production (Yeshitla, 2004). The total cultivated area for mango in Ethiopia is not more than 12, 000 hectares. The highest annual production of mango estimate in the past five years is 180,000 Mt and more area coverage is expected in the south-western and other parts of the country due to more conducive climatic and edaphic factors FAOSTAT (2010).

2.3 Mango market characteristics in Ethiopia

Market structure of mango has only a few dominant buyers. A small number of fruit wholesalers in Addis Ababa decide on the price and indirectly on the volume of supply to the Addis Ababa retail shops. They use middlemen to influence market equilibrium and farm gate prices for their own benefit. Because of poor institutional strength, producer organizations have not been able to challenge this situation(Timoteos,2009).Wholesale level in Addis Ababa, market traders dominat e the landscape and operate in ways that make it difficult for new entrants to enter the market. Addis wholesalers have strong relationships with the traders based in Assosa and these two levels of the value chain account for most of the final retail price.

2.4 Spatial market share of mango in Ethiopia

The figure below shows that market of mango in Addis Ababa from different part of the country. Based on this Assosa have high potential of mango production and market trades. On average the amount of annual mango potential in Assosa 37,731.520 kg/yr. The secondary data from the Ben ishangul Gumuz Regional State Agriculture and Natural Resource Bureau Assosa. From the total production of mango 98% for Addis Ababa market.



Source: A. Aithal and J. Wangila/ICRAF, 200

Figure2. 1: spatial market share of mango in Addis Ababa wholesale market in Ethiopia

2.3 Charcoal production from Agricultural Residue

Solid residue remaining when agro-industrial wastes, wood species, and other forms of biomass are carbonized or burned under controlled conditions in a limited space such as a kiln is called charcoal. The bulk densities of agricultural residues have naturally less than 100 kg/m^3. Because of these specific physical characteristic agricultural residues makes expensive to transport, store and use in simple combustion devices. Therefore agricultural residues are produced in large quantity and the potential use of agricultural residues for the substitution of traditionally produced commercial biomass fuel is high, the production of charcoal briquette could be accepted (BTG, 2004). To increase the amount of production of briquette charcoal and charcoal, it is recommended that not only limited to the commonly known species (raw material) like Acacia. There is a need to assess and evaluate other opportunities such as short rotation species trees like Eucalyptus and industrial process residues and other wastes.

For preparation of briquette charcoal organic material such as:- wood, straw, coconut husks and shells, rice husks, cotton stalks, coffee husks, castor husks, bagasse, sawdust, bones, and others. Among woods, usually, the hardwood species are preferred for briquette charcoal (BTG, 1999). Biomass species used for making charcoal briquette production and charcoal include from fast-growing trees like bamboo or Acacia, Mangrove, oak, Beech, Birch, Hard maple, hickory, and Prosopis. Certain tree species and agro-industrial wastes used for quality charcoal or charcoal briquette making in Ethiopia are mentioned in table 2.1. But crop residues have little alternative use for the production of charcoal.

Table2.1: Comparison of properties of biomass and biomass waste most commonly used for charcoal and fuel briquettes

Charcoal Type	Suitability for Charcoal Production	Availability of Biomass	Cost	CV(Kcal/ kg)
Cacia	Any carbonization technology can be used	Availability reduced in most countries Long period to mature. For example, Acacia nilotica takes 15 years to develop for charcoal in Sudan	Expensive	7900
Eucalyptus	Any carbonization technology can be used	Available in abundance in many countries develop in 4-5 years	Relatively inexpensive	6100
Prosopis juliflora	Any carbonization technology can be used	In African countries, Like Ethiopia, Kenya, and Sudan, it is an invasive exotic tree	Inexpensive	7150
Bamboo	Brick kiln, metal kiln or retort	Abundant in Latin America, Asia (China and India) and Africa. (More than 1 million ha is available in Ethiopia). In many African countries, it is neglected and not utilized at all	Inexpensive	6920

Cotton stalk	Metal kiln or retort	Can be freely collected since it is generally burned on-site	Freely collected	5300
Coffee husk	Improved pit kiln or retort	Can be freely collected since it is generally dumped in rivers.	Freely collected	5100
Sawdust	Improved pit kiln or retort	Can be freely collected since it is generally burned on-site.	Freely collected	4980

Source: (Yisak Seboka and Negusse Mequanint, 2006) ;(FAO, 1993)

2.3.1. Charcoal Making Process

Charcoal making process is different from country to country and the technology they use is also different. Some are being well adjusted but other less. The conversion biomass through the process of pyrolysis is charcoal making. There are four stages in the process of charcoal making depend on the temperature.

Stage 1: Drying it is an endothermic reaction that takes place at a temperature between 110-200°C. Air-dry wood contains 12-15% of absorbed water; after this stage the water completely removed.

Stage 2: Pyrolysis process is an endothermic reaction (170-300°C) known as the “pre-carbonization stage”. During this stage, some pyro ligneous liquids such as methanol and acetic acid, and a few non-condensable gases such as carbon monoxide and carbon dioxide, are produced.

Stage 3: Carbonization takes place in an exothermic reaction (250-300°C). At this stage, pyro ligneous acids and the bulk of the light tars produced in the pyrolysis process are out from the biomass.

Stage 4: The temperature is greater than 300°C. During this stage, the biomass is converted into charcoal, the fixed carbon of the charcoal is increased, and this is one of the characteristics in this stage. The charcoal does, on the other hand, still contain considerable amounts of tarry residue, together with the ash of the original biomass.

About 3-5% of the charcoal has ash content; the tarry residue may extend to about 30% by weight and the fixed carbon balance is approximately 65-70%. Additional heating increases the fixed carbon content by driving off and decomposing more of the tars. The maximum working temperatures are about 500^{o}C. At this temperature, volatile content is 10% and the fixed carbon content is approximately 85% (FAO, 1987).

2.3.2. The Efficiency of the Charcoal Production Process

Charcoal production is influenced by the following major factors:- Moisture content of the biomass (drier is better), type of kiln, size of the kiln (larger is better), type of biomass, loading of the biomass (denser is better), skill and experience, climatic conditions, temperature, oxygen supply, pressure and weight-based carbonization efficiency (based on charcoal yield) is a percentage rate expressing the ratio between the weight of the charcoal output and the weight of the air dry sample input. For instance, at 15 % moisture content the typical yield of a brick kiln is around 30%.

2.3.3. Charcoal Production Technology

Types of charcoal kiln include kiln (batch) method, earth kilns (earth mound (traditional)), improved earth mound (Casamance), pit kilns (traditional pit kiln, improved pit kiln), brick kilns, metal kilns (mark v metal kiln, drum charring units). Most commonly known charcoal kiln use for the production of briquette charcoal in Ethiopia is mark v metal kiln and drum charring units.

Mark v metal kiln: It is one of the best-known metal kilns has a main body of two cylinders joined with a slightly conical lid and top and its lid have a hole in the center which is covered except during ignition.

Drum charring units: Drum charring units are metal charcoal kilns made from 200-liter oil drums. This kind of kilns are used to carbonized fast-burning raw materials such as agro-industrial wastes (coffee husks, cotton stalks, bamboo waste, sawdust, etc.) successfully and it has the conversion efficiency on average 25%. Different types of carbonization technique can be used for charcoal production depending on the type and quantity of residue available and among others market price of wood charcoal. The drum carbonizing units and metal kilns techniques are simple, low cost and manually operated. On the other hand, there are techniques that are not suitable for small-scale production systems, they are more expensive and continuously operated charcoal production technologies and require skill manpower operators and technicians charcoal made from agricultural residue must be densified to appropriate size and shape for the purpose of household uses otherwise it is not suitable for use in household stoves and also very difficult to handle (Seboka, 2009).

Table 2.2: Comparison of carbonization methods

Carbonization Method Earth	Yield %	Duration	Capital Intensity	Labor Intensity	Cost US$
Earth pit kilns	10-15	Days	Low	High	0
Brick & steel kilns	25-30	Hours	Medium/high	Medium	50-200
Large-scale plants	30-40	Continuously	High	Low	3,000-5,000

/ retorts					

Source;(Ferguson 2012)

2.3.4. Briquetting Technologies

There are different types of briquettes technologies that are comfortable for the preparation of carbonized and non-carbonized biomass. The main briquette technologies are suitable for charcoal briquette production, different from very small to medium capacity (BTG, 2013).

Hand presses: Briquetting can be done by hand, using a simple mold and hammering the charcoal dust together. D-Lab of the MIT developed a tool that costs about 2 USD and can produce 10-12 briquettes per minute (Desta *et al.*, 2014). Hand briquettes require only a low investment but are very labor intensive.

Piston Press: It is also known as ram and die technology and it is high compaction or binder less technology, In this circumstance, the biomass is pressed into a die by a reciprocating ram with a very high pressure thereby compacting the mass to get a briquette.

Screw press: The raw material is compressed uninterruptedly by a screw through a die heated from outside, usually electrical. The hole in the screw increases the surface area of the briquette and helps efficient combustion. It produces strong briquette and it has very good burning characteristics.

To use the Screw press the raw material needs maximum 12 % moisture content and practical size should be uniform. It needs regular maintenance and is not suitable for briquetting of charcoal. They are typically used for briquetting of non-carbonized biomass. It is high compaction technology or binder less technology and the biomass is pressed in a die by a reciprocating ram at a very high pressure, the biomass is extruded continuously by a screw through a heated taper die.

Hydraulic piston press: it is different from mechanical piston press. In this case, the energy to the piston is transferred from an electric motor through a high pressure hydraulic oil system and it is light and compact. Since, of the slower press cylinder compared to that of the mechanical machine, it results in lower outputs.

Agglomerators: In several developing countries agglomeration technology applied for small-scale briquette. The charcoal is crushed to powder, binders are added, the components are mixed together, and the mix is then agglomerated. This technology involves size enlargement of a nucleus/balls of charcoal formed within a rotating cylinder. Agglomerated charcoal briquettes are created using a motor-driven agglomerator, the typical small capacity of which is 25-50 kg/hour. Agglomerated charcoal briquettes usually have diameters between 20-30 mm and they are spherical. The briquettes can be used for household cooking besides for fueling industrial furnaces. From most other briquette types Agglomerated briquettes are stronger. Agglomeration technology applied for small-scale briquette in several developing countries (BTG, 2013).

Roll press: From different types of biomass roll press is used for the production of briquette charcoal. To produce pillow-shaped briquettes a mixture of charcoal and binders are fed to the tangential pockets of two roller presses. For the smooth production of briquette, high-quality rollers with smooth surface require on which the briquettes are shaped. The current minimum available capacity of roll press is in the range of 1-4 tones/hour (BTG, 2004).

Beehive/honeycomb briquette machine: To produce uniform, high packed briquettes in a uniform mode it uses simple mechanical and electrical part and it is also cost-effective. It produces one briquette per minute and suitable for small and medium sizes. The consumer uses short time cooking or boiling in order not to waste the briquette for small-size beehive briquettes and they use large-size beehive briquettes for the purpose of longtime cooking. Normally, 2 briquettes of 500g each are produced at a time. Beehive briquettes have excellent burning qualities; the energy release is gradual and uniform, giving a blue flame. It requires special stove (beehive stove) to use the produced beehive briquette charcoal, this is the main problem. It is less well-known in Africa, but which is readily available in Vietnam, China, and Thailand. Generally, the most successful briquetting processes used in many developing countries are the agglomerated charcoal briquette and the honeycomb charcoal briquette (Seboka, 2009).

2.3.5. Common Binders used in Biomass Densification

Charcoal is a material completely missing elasticity and hence needs the addition of a sticking or agglomerating material to enable a briquette to be formed (BTG, 2013). Binders are substances, organic or inorganic, natural or synthetic, that can hold (bind) two things or something together. There are two classifications of most important binders; these are organic and inorganic binders. Organic binders include molasses, coal tar, bitumen and starch and inorganic binders like clay, cement, lime and sulfite liquor. Many of them are proposed and used to produce briquette. The binder has required the properties include produce a strong and a waterproof briquette, does not weaken the quality of the coal, does not affect the use of the coal and economically viable and environmentally acceptable (Raju *et al.*, 2014).

Table 2. 3: Overview of properties of main binders

Binder	Clay	Starch	Gum	Molasses	Wood tar/pitch
Percentage of final product	15%	4-8%	<10%	20%	<10%
Price	Low	High	Medium-high	Medium-high	Low - medium
Alternative uses	No	Food/feed	Food/feed	Food/feed	Energy
Contribute to calorific value of the briquette	No	Yes	Yes	yes	yes
Thermal treatment needed to avoid smoke	No	No	no	Preferably	yes
Increases ash content	Yes	No	no	Yes	No
Waterproof briquettes	No	No	no	After curing	After curing

Source Estimation (BTG, 2013)

2.3.6. Carbonization and Briquette Making

During direct heating of carbonization at the beginning, the raw material is balanced and note down. To protect the produce heat loss during carbonization it need to test leakage the selected kiln and then, at the bottom of the kiln there is a need to use the wire mesh grate for the purpose of heat media for the partial oxidation process and the heat flow inside the kiln become more effective. After placing the carbonize material for carbonization the selected kiln was closed (Sanger *et al.*, 2011) and there is a need to using firing material like loose glass to initially startup the firing (Quaak *et al.*, 1999).

To know the transfer of heat uninterrupted visualization is done and based on the changes observed at the exhaust essential to fix the air inlet of the kiln. The temperature of the material used inside the kiln, outside of the kiln and exhaust smoke is changed. The carbonization stage changes are observed and time is recorded. To know the selected raw material is changed into charcoal there is a need for continuous observation of the smoke color. The color of the smoke that is the blue and the light blue indicates the selected material is changed into charcoal or not. During this stage when the raw material is changed into charcoal primarily blue smoke is changed into light blue and then it became purer. Finally, the kiln needs to cool down after carbonization overnight. Then the mass of carbonized material was measured and recorded.

2.3.7. Characteristics of Briquettes

Briquettes have many advantages, this includes the net calorific value per unit volume increases during the process, it is easy to transport and store because it is a densified, and the problem of residue disposal solved during the process and the size and the quality of the produced fuel are uniforms. Before using briquettes for consumption, their moisture content (MC), volatile matter (VM), ash content (AC), fixed carbon content (FC), calorific value (CV), and bulk density (BD) must be studied and characterized (Oladeji, 2010).

2.3.7.1. Proximate Analysis

Proximate analysis is the characteristics of fuel briquette that have a close relation to combustion behavior and which is an idea of the bulk components that make up the fuel standard procedure. VM, MC, AC and FC content of the briquettes are determined by the proximate analysis

(Chaney, 2010).

Moisture Content: Moisture present in the biomass accelerates starch gelatinization, protein denaturation, and fiber solubilization processes during extrusion, pelleting, or briquetting. The initial moisture content, temperature, and pressure affect the final moisture content of the briquette. Moisture content of the raw material biomass greater than 15% result higher Moisture content in the final product (Tumuluru and Wright, 2010).

Volatile Matter: It is the charcoal elements excluding moisture, which are liberated at high temperature in the oxygen scares of air. This is generally a combination of short and long chain hydrocarbons, aromatic hydrocarbons and some sulfur. To produce a good quality briquettes the pyrolysis temperature must be optimize. Moreover, a small amount of volatile matter is necessary to produce economically acceptable briquette for the local market by giving good ignition of the combustion (Debdoubi and Colacio, 2005).

Ash Content: Ash is solid residue which is produced by the chemical breakdown of a biomass fuel. It is produced after a complete combustion and it is non-combustible inorganic residue. The thermochemical conversion process and particularly combustion are affected by the ash because it produces the chemical compound content in the ash react to form slag. The higher quality briquette has low ash amount. The Ash content of different wastes have different expected values such as for commercial fuels from 0.6% to 9.8%, energy crops from 1% to 9.6%, cereals from 1.8% to 4.8% and industrial waste from 0.4% to 22.6%. General values of ash content may appear in a range of levels below 5–20% (Maia et al., 2014).

Fixed Carbon: Briquette, which is the percentage of carbon (solid fuel) available for char combustion after volatile matter, is distilled off. It gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning (Akowuah *et al.*, 2012). Fixed carbon content of the charcoal is different from the coal ultimate carbon content that is why certain carbon is omitted in hydrocarbons with the volatile and it is also used to assess how much amount of coke will be found in a given sample of charcoal. The greater fixed carbon, the greater the amount of element existing for combustion, therefore, greater amount of heat released (Cuaresma *et al.*, 2015).

2.3.7.2. Physical Property

2.3.7.2.1 Bulk Density (BD)

For domestic and industrial use, direct burning of agricultural residues efficiency is very low. Additionally, some of the disadvantages of transportation, storage, and handling problems are also related to its use. In order to produce pellets or briquettes use densification which is one of the approaches, being actively followed worldwide towards improved and efficient utilization of agricultural and other biomass residues. Bulk Density is the most important physical property in designing the logistic system for biomass handling in addition to this; it is an important characteristic of biomass that impacts directly the cost of feedstock distributed to a bio-refinery and storage cost (Bhagwanrao and Singaravelu, 2014). But it is affected by the following factors like shape, size, particle density, moisture content, and surface characteristics. Bulk Density of the briquette was expressed as the ratio of the mass of the briquette to the volume of the briquette (Yaning *et al.*, 2012).

2.3.7.2.2 Calorific Value (CV)

The physical and chemical composition of the biomass influences the energy content. Particularly, the water and hydrogen content, the measure of the energy content of the biomass without any free water is known as "higher heating value" or "gross calorific value". In this case, the complete dry biomass still contains chemically bonded water and the water produced in chemical reactions during combustion (Rosillo-Calle *et al.*, 2012).

It is the combustion test that is the amount of heat energy released during the complete combustion of a unit mass of biomass .or it is the amount of energy per kg it gives off when burned and one of the most important characteristics of a fuel and useful for planning and control of the combustion plants this is measured with oxygen in a standardize calorimeter by using about one gram of sample and taking water as much as two litters then, before putting the samples into the instrument, 400 psi pressure oxygen is given, then 8 cm long wire length and fuse combustion heat of 4.1 Btu /cm, then finally the change in temperature (ΔT) and the heat out by burning briquettes will be calculated and recorded using installed program in a Bomb Calorimeter (S Suryaningsih *et al.*, 2017). The increasing of temperature during pyrolysis results the increasing the power CV caused by the elimination of MC, some VM and an increasing in the amount of FC thereby providing a higher energy per volume ratio (Debdoubi and Colacio, 2005).

2.3.7.3. Previous Work on Proximate and Physical Properties of Briquettes

According to Romallosa and Hornada, (2014) the growth of using biomass resource and urban wastes for briquette production is due to the increase in fuel prices. They also indicated that changing them into briquette create a chance to organize wastes and clean the environment from unwanted wastes, prevent the forest from deforestation, and decrease greenhouse gas (GHG) emission and it gives alternative energy for poor urban and rural community. This study also shows that waste materials previous which have low density to be changed in to briquette is compacted to produce higher bulk density, lower moisture content and the same shape and size making these materials simple package and store, low cost to transport, comfortable to use, and the combustion characteristics are better than the original waste material. The major steps for briquette production need four procedures, namely: preparation of materials used, mixing of the prepared materials by hand compaction of the materials using the selected molder, and finally drying the briquette to produce the end product. They also concluded that the most viable mixture to produce briquette is that paper with sawdust, the combination of paper, carbonized rice husk and sawdust and individually paper. The reason for their selections is such as production requirement and high production rate, better-produced fuel quality, rapid operating performance in terms of boiling water and cooking rice and the potential for income generation.

Other related study shows that the production of briquette from sesame stalk can have the potential to solve health problem and energy poverty at the same time it can solve deforestation. Their laboratory analyses showed that the calorific value produced from sesame stack with 15% optimal possible clay binding have 4647.75 Cal/gm. and minimum ash content, this value decrease with increasing the ratio of binding (clay) material and this value is satisfactory energy content for cooking. In addition to that the paper also shows that the main factors for the quality of briquette are ignition time, % of volatile matter, % of sulfur availability, % of fixed carbon, and % of moisture content of sesame stalk briquettes, they also compared with that time on-use biomass briquettes and they showed that for cooking and heating purpose sesame stalk briquettes is the best from the others (Gebresas *et al.*, 2015).

According to Windi *et al.* (2015), they used the method that sample household wastes are collected, the organic wastes are settled for different days in order to analyze composting then after that they pressed to reject the fluid wastes and analyze the water content and heating value and their result shows that within one day the heating value in the range of 1956.832 to 3257.24 Cal/gm. and the water content at the starting ranging 53-65% an average 1.631% moisture content. In the end product (briquettes) the calorific value increased. They also indicated that because of municipal solid waste have different material, the composition of heterogeneous mixture and size, there are a lot of briquettes process such as household waste collection, drying, binder preparation and mixing, Briquette production, Drying and packing and finally analyzing. And lastly they concluded that to get well quality briquette, it is better to put the wet briquette in windy place in order to minimize energy that is necessary for drying, the calorific value of the household waste composition must be checked whether the material has higher caloric value (such as paper, sawdust etc.) or not and the household waste should be sliced before mixing with binding to get well briquette.

They conclude that briquettes are more efficient than wood charcoal. Finally, they strongly reported that the technology has a great potential for converting waste biomass into a superior fuel for household use, in an affordable, efficient and environment-friendly manner.

Table 2.4: Comparison of wood charcoal and briquette charcoal making process

Briquette charcoal	Wood charcoal
It doesn't need digging	It need Digging
Mobile everywhere	Not mobile
It can't fire hazardous	It fire hazardous
Safe	Unsafe
Smokeless	Has Smoke
Have greater heat value	Have smaller heat value
Need Low cost	Need High cost
It Reduce deforestation	It Enhance deforestation
It burn for (2-3 hr.)	It burn for (1-2hr)

Source;(Bogale, 2009)

Generally, converting waste material into fuel briquettes are improving the fuel price, waste collection problem, prevent the forest from deforestation, decrease greenhouse gas (GHG) emission and it gives alternative energy for poor urban and rural community.

2.4. Environmental and Socio Economic Benefits of Fuel Briquette

Fuel briquettes charcoals are a smokeless fuel this is because during carbonization the smoke removes. The smoke produced from wood charcoal cause various respiratory illnesses and decreased pulmonary function (Tzanakis *et al.*, 2001). It is possible to use all degradable wastes for the production of charcoals including waste banana leaf, however, the output of the charcoal different from waste to waste. Carbonized organic matters are changed into char briquettes which are smokeless and efficient during burning. In addition, to reduce the deforestation by eliminating the need to cut down trees for fuel wood it has also another advantage to reduced smoke pollution to the environment and producing fuel briquettes from wastes increase the income, wealth of individual entrepreneurs and the country in general (Bogale, 2009).

In developing counties fuel briquette can give significant and considerable environmental and socio-economic benefit by resolving the problem of deforestation and shortage of fire wood. Therefore, the developing country like Ethiopia used their vast forest and agro residues environmentally friendly manner by generating energy (Gebrekidan and Belete, 2015).

In general, the implementation and promotion of briquette produce the following environmental, social and economic benefits:-

- It is suitable for stoves and burners because which have uniform size, shape and quality.
- It avoids health impacts by providing smokeless fuel and reduces indoor air pollution.
- It increases the net calorific values of the biomass per unit volume.
- The handling, transportation, and storage are comfortable after changing into briquette.
- The procedure minimizes the residual disposal and sanitation problems.
- It increase the burning time and reduce fuel consumption related to that solve the reliance on fuel wood and deforestation.
- The production and marketing of briquettes create profits and job opportunity.
- Briquette fuels produced from waste biomass have lower costs for the users.

Generally, the briquette fuel is the most major biomass technology contributing by civilizing domestic energy supply, increasing environmental protection and sanitation and reducing GHG emissions (Tekle, 2017).

3. MATERIALS AND EXPERIMENTAL METHODS

3.1 Description of the study area

This study were conducted in Addis Ababa which is the capital city of Ethiopia and currently includes 10 sub cities and 116 woredas the city located between 9.03^0 N latitude and between 38.74^0E longitudes.

Addis Ababa has an area of 530.14km^2 and it has cool to warm climate that influenced by the altitude and that show the temperature difference from 10^0 c up to 22^0 c depending on the elevation and wind pattern. It has 2,326 meters to 3,000 meters altitude ranges above sea level altitude ranges above sea level (Alem et al.,2010). Based on 2013 national census agency(CSA 2013) reported a total population of 3,434,000 of whom1,625,000 were male and1, 809,000 females.

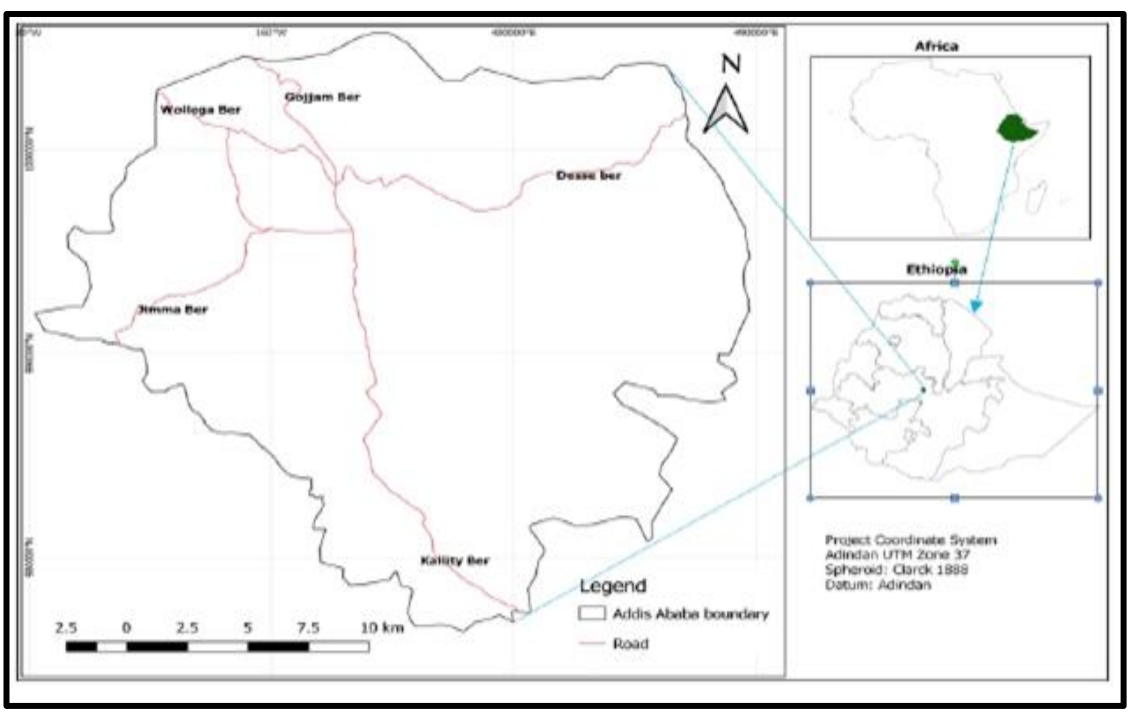


Figure 3. 1*: Map of study area (Source: Ethio, GIS)*

3.2 Conceptual framework Flow of the study

The major process includes mango residues collection up to the produced fuel briquette and laboratory work process flow chart.

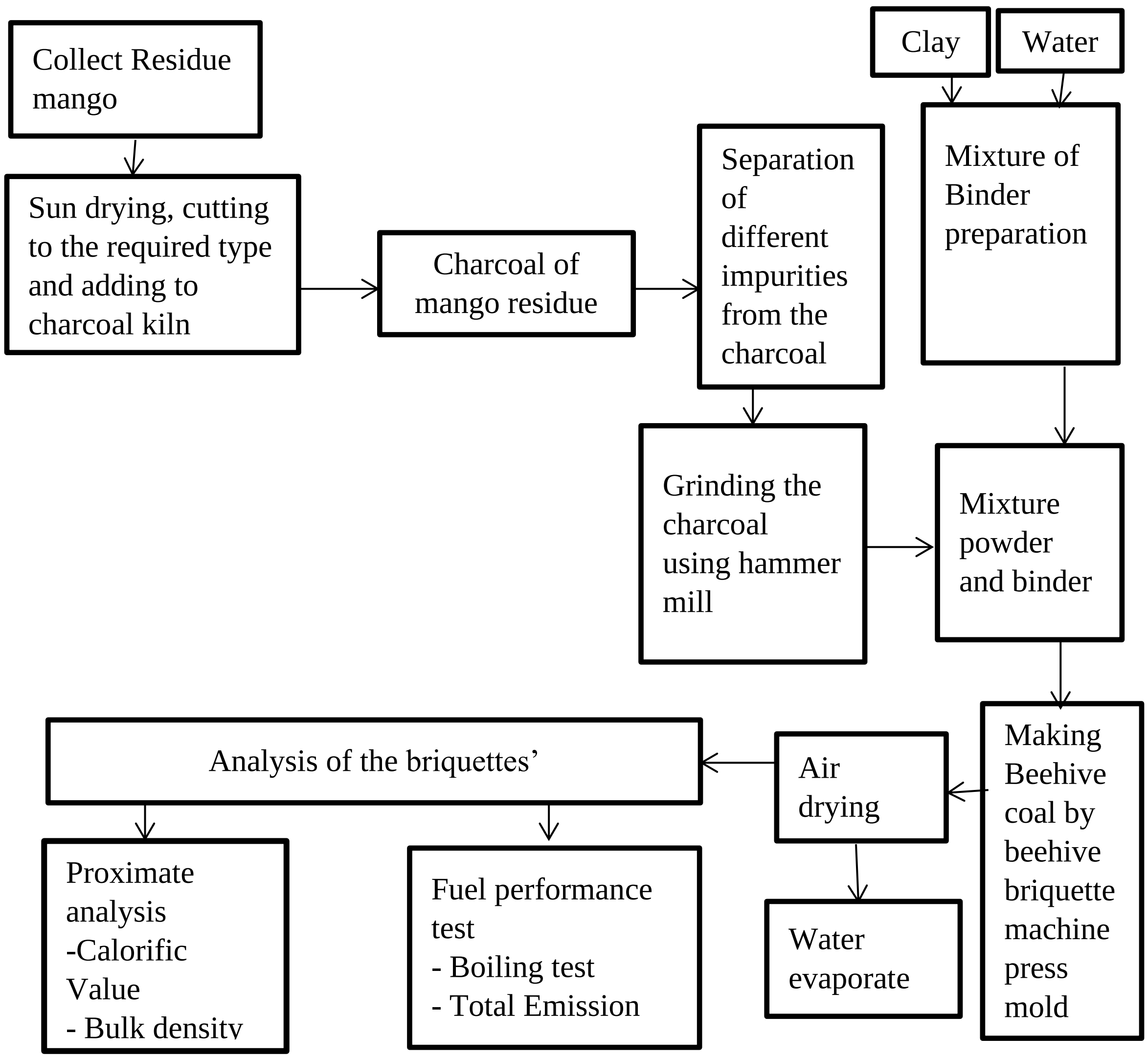


Figure3. 2: Conceptual framework of the study

3.3. Sample collection of mango seed and mango peel for carbonization process

The samples were collected randomly from Addis Ababa City Arada Sub city Atikilt Terra from mango distributer, retailer and juice houses. This sub city is selected purposely for the Sampling because Atikilt Terra found in this sub city where high exchange of fruits and vegetables including mango in the city of Addis Ababa due to this reason a lot of mango distributer, retailers and juice houses found in the sub city. Then the mango seed and mango peel samples were taken to Ministry of water, Irrigation and Energy Work shop and Laboratory (MOWIEWL) Compound and the mango seed cut in to small pieces to fit the carbonization kiln and for equal distribution of heat during sun drying and carbonization. Figure 3.3 below show that the collected mango residue.

Figure3. 3: Sample preparation for briquette production

Figure3. 4: Mango peel sample prepared for carbonization process

Figure3. 5: Mango seed sample prepared for carbonization process.

The collected mango waste are separated in to mango seed and mango peel residue then put in air on sun drying. Figure3.6 below show that the process of sample preparation from mango waste.

Figure3. 6: Mango waste, mango seed and mango peel sample for carbonization process

3.3.1. Materials

The raw materials that are used in this study are wastes of mango seed and mango peel residue, clay soil, and water will be materials used for this research.

3.3.2. Equipment

The equipment's that are use Metal kiln or Drum charring units, Oven/ incubator, electrical furnace, analytical balance, sieves, cutter and mixer, beehive briquette machine press mold, digital balance, stopwatch, crucibles, meter, desiccators, plastic basin, stove, cylindrical container, and oxygen bomb calorimeter is the equipment's we will use to characterize mango residue charcoal briquette.

3.4. Carbonization Process

Before the carbonization process begun, first weight the sun-dried mango residue (i.e. the seed and the peel part separately), to know the conversion efficiency of mango residue which had moisture content of seed residue and peel residue. The carbonization of the seed and the peel part of mango residue was carried out using the Drum kiln which was made in Ministry of water, Irrigation and Energy Work shop and Laboratory (MOWIE) workshop which accommodates 15 kg of seed and 15 kg of peel mango residue separately for one cycle. Drum kiln was selected because it is suitable for small amount of burning, easily fabricated from a local material and low cost (Sanger *et al.,* 2011). The sun-dried mango residue was compactly full into the inner drum through the opening at the top and fire for 45 minutes to 1hr according to (Bogale, 2009). The smoke color would be continuously observed to estimate the selected raw material was changed into carbonized material. The color of the smoke the blue and the light blue indicates the burning material was changed into carbonized material or not. If the raw material was changed into carbonized material primarily blue smoke was changed into light blue and then it became purer. At this time to block the air entrance, the bottom part of the drum was covered by the prepared soil, the side was covered by mud and consequently, the top side was covered by the metal cover (Emmanuel *et al.,* 2014). Finally, the kiln needs stay until cool down after carbonization and separate the carbonized material and the ash then; their weight was note as stated by (Sanger *et al.,* 2011). And the conversion efficiency of mango seed and mango peel residues into carbonized material was computed according to (Emrich, 2013), as follows:-

$$A\% = B/C*100 \quad \text{(Eq3.1)}$$

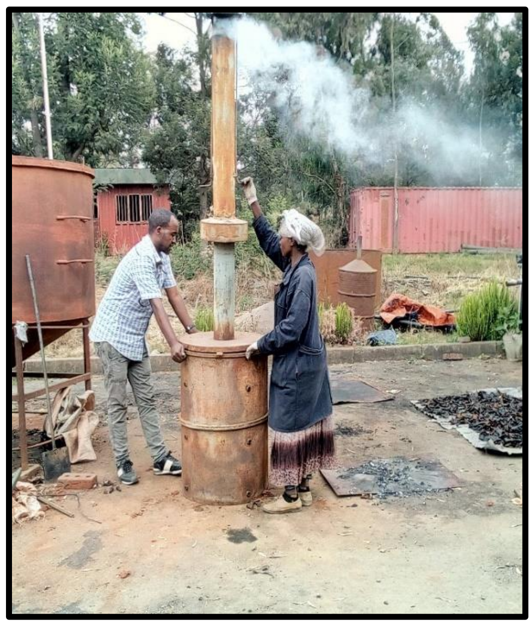
Where A=Carbonization efficiency of mango seed residue%

B= weight of carbonized mango seed residue C = weight of raw mango seed residue

$$P\% = R/S*100 \quad \text{(Eq3.2)}$$

Where P%= Carbonization efficiency of mango peel residue%

R= weight of carbonized mango peel residue S=weight of raw mango peel residue



a) Carbonization of mango peel

b) Carbonization of mango seed

Figure 3 7: During carbonization process

The carbonization process under taken by feeding the Philippine drum kiln model by measuring each sample of the mango residue. After the carbonization is completed the mass of the input will be measured it is used to calculate the carbonization efficiency carbonization model. Figure

3.8 and 3.9 below show that carbonization process product of mango peel and carbonization process product of mango seed respectively.

Figure3. 8: After carbonization process of mango peel product

Figure 3. 9: After carbonization process of mango seed

3.5. Binder Preparation and Mixing

The binder preparation and mixing Clay soil was selected as a binder because its availability, inexpensive and no alternative use and the importance of the clay soil was to act as a binder and it was added in same amounts to the samples 15%. This binder was used to increase the bonding between the carbonize mango residues. It also increases the heating time and strength of the output. Mixing of the carbonize mango residue powder with clay soil, it was done manually after carbonizing mango residue was changed to a powder using crusher; while mixing clay soil will dilute with water . (Gebresas *et al.*, 2015).

a) Clay binder b) Digital balance C) Carbonized powder

Figure3. 10: Binder preparation and carbonized powder preparation for mixing

3.6 Briquette Making

Briquetting is the process of compaction of residues into a product of higher density, it is also known as densification (Kaliyan and Morey,2008). Preparation of briquettes involves a cost effective binders that used in the process (Sugumaran.p et al,2010) and the binders were with 15% clay content (Gebresas et al.,2015) that means from the mixture of clay soil and charcoal powder the amount of clay soil was 15% of the charcoal powder.

If produced at a low cost and made conveniently accessible to consumers, briquettes could serve as compliments to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both (Wilaipon, 2008).

The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of application. Every particle of carbonized material was treated with a binder to enhance briquette sticking together and produced identical briquettes .The mixture of the clay soil (15% optimal), acting as a binder, and charcoal is then made into briquettes using beehive briquette machine press mold. Finally, the briquettes will be made dry under the sunlight for about 1-2 days (Gebresas et al., 2015).

a.) Beehive Briquette Machine

b.) During Briquettes production

Figure 3. 11: Briquette Making

Figure3. 12: Briquette produced on sun drying

3.7. Data Quality Control

During collection of the mango residue unimportant materials like wood branches, grasses, leaves, soil, sand, food waste, other fruit waste etc., were removed. After production, the briquettes were pack and kept in a dry and clean environment and subject to laboratory analysis. The laboratory analysis was done after calibration of the instrument following standard procedure of the American Society for Testing and Materials ASTM.

3.8. Laboratory Analysis

The laboratory analysis from each treatment, triplicate samples of the dry briquettes were brought to Ministry of water, Irrigation and Energy Work shop and Laboratory (MOWIE) compound for determination of moisture content (MC), Volatile matter(VM), Ash content(AC), Fixed carbon content (FC), Calorific value (CV), and Bulk Density (BD).

3.8.1. Proximate Analysis

The proximate analysis the determination of all proximate analysis was conducted using the standard test method (ASTM D1762 – 84, 2007).Figure 3.13 below show that the laboratory analysis under take using standard laboratory procedure measuring the carbonized powder preparation.

Figure3. 13: Sample preparation for laboratory analysis

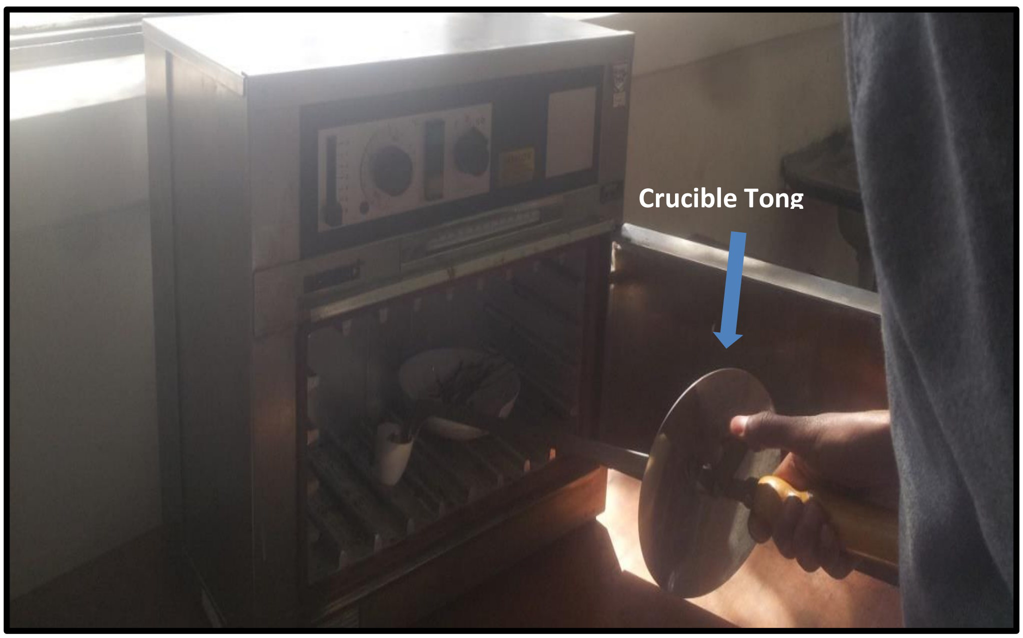


Figure3. 14: Oven, Crucibles and Crucible Tong

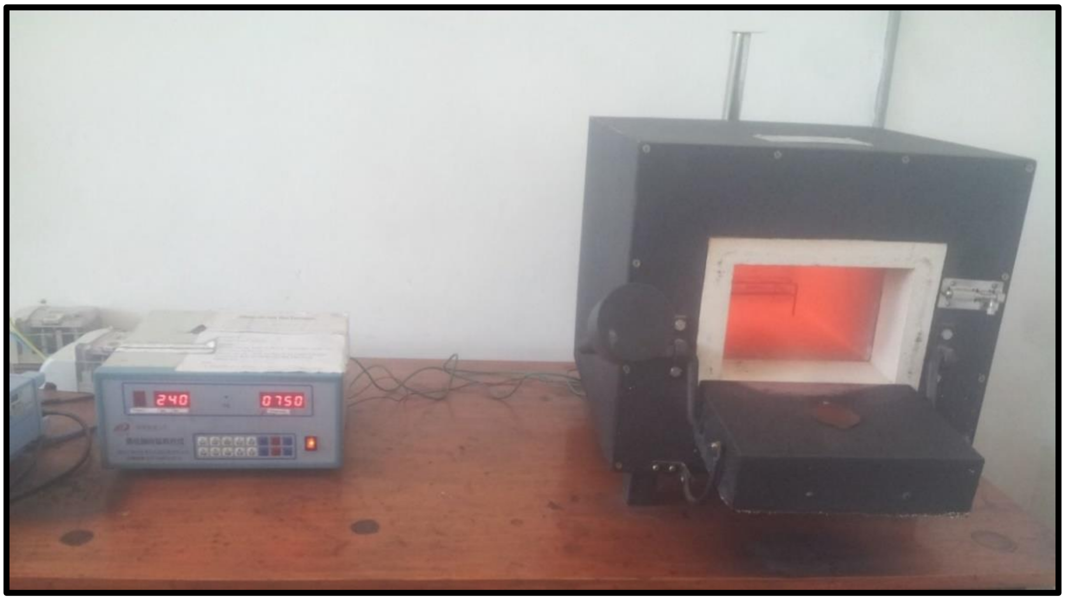


Figure3 15: Muffle Furnace

Figure 3. 16: Sample of the fragmented briquettes after removal from the furnace

Figure3. 17: Testing of combustion properties of samples

3.8.1.1 Determination of Moisture Content

The crucibles are used for the determination of Moisture Content (MC) of raw mango residue, carbonized material and the briquette produced from mango residue was began, first preheating the muffle furnace to 750^{o}C for 10 min and then cool them in a desiccator for 1h then, weighed the crucible and add 1g of sample in each crucible using the nearest 0.1 mg balance. After the above procedure placed the samples in the oven at 105^{o}C for 2h, then placed the dried samples in a desiccator for 1h and the weight was recorded. The procedure was repeated until constant mass of sample was record. The same specimen used for Volatile Matter **(**VM) and Ash Content (AC) determination. Then, the Moisture Content was calculated by the following equation.

$$MC, \% = [(W - X)/W] \times 100 \qquad \text{(Eq3.3)}$$

Where: W = grams of air-dry sample used, and X = grams of sample after drying at 105°C. MC = Moisture Content %

3.8.1.2 Determination of Volatile Matter

In this test procedure, determined the percentage of gaseous products, exclusive of moisture vapor. The VM content of raw mango residue, carbonized material and briquettes were determined by preheating the crucibles used for the moisture determination at 950^{o}C by preheating the crucibles, covers and samples in the muffle furnace door open, for two minute on the outer edge of the furnace at 300^{o}C, then heating for three minute on the edge of the furnace at 500^{o}C, then move the samples to the rear of the furnace for six minute with the muffle furnace door closed at 950^{o}C in covered crucible of specimen by lid or metal box prepared for this purpose. Finally, cool the samples in a desiccator for one hour and weight. The Volatile Matter **(**VM) was computed as follows.

$$VM, \% = [(X–Y)/W] \times 100 \quad \text{(Eq3.4)}$$

Where: VM=Volatile matter % Y = grams of sample after drying at 950^{o}C

3.8.1.3 Determination of Ash Content

The Ash Content (AC) in this sample is the approximate measure of the mineral content in the sample. In order to do this, place the lids and the uncovered crucible used for the Volatile Matter (VM) determination, and containing the sample in the muffle furnace at 750^{o}C for 6 hour. Finally, the crucibles were cool with lids in placed in a desiccator for 1 hour and then, the weight was recorded. The Ash Content (AC) was calculated as follows:

$$AS, \% = [(Y – Z)/W] \times 100 \quad \text{(Eq3.5)}$$

Where: AS= Ash Content %   Z = grams of residue at 750^{o}C

3.8.1.4 Determination of Fixed Carbon

The percentage of carbon present in a particular sample is mentioning to carbon content. During combustion the percentage of available carbon is the fixed carbon of fuel that is not equal to the total amount of carbon, because there is also a significant amount that will be released as hydrocarbons in the volatiles. According to the procedure recommended by (Weldemedhin Merete, 2014) the fixed carbon in a sample of powder briquette charcoal will be calculated as the difference between 100% and the sum of the percentage of moisture content, volatile matter content and ash content.

$$\%FCC = 100\% - (MC\% + VM\% + AC\%) \quad \text{(Eq3.6)}$$

Where:- % FCC = Percentage of Fixed carbon content,

% MC = Percentage Moisture content,

% VM = Percentage Volatile matter content,

% AC = Percentage Ash content.

3.8.2. The Physical Property of Fuel Briquette

3.8.2.1. Determination of Calorific Value

The calorific value determine energy content of a fuel. In order to measure the calorific value/ heating value of mango residue charcoal briquette, we will use Parr 6200 Calorimeter with a standard 1108 Oxygen Bomb as suggested by 6200 Calorimeter Operation manual 2010.

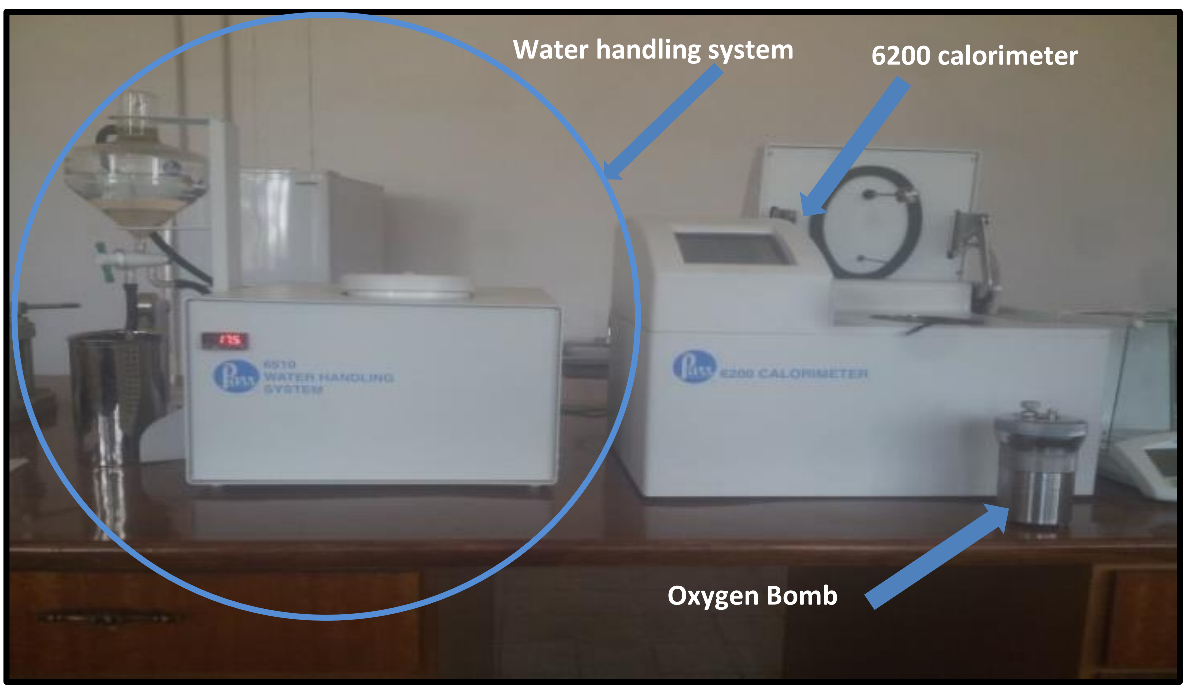


Figure3. 18: Adiabatic Oxygen Bomb Calorimeter (Parr6200)

The heating value is calculated as follows:-

$$HV = 2.326\ (147.6\ FC + 144VM\ ) \qquad \text{(Eq3.7)}$$

Where: - HV = heating value ($MJkg^{-1}$),

FC = fixed carbon and

VM = volatile matter

3.8.2.2. Determination of Bulk Density

Figure 3.19 below show that the produced briquette from mango residue calculate the bulk density by measuring mass of briquette using digital balance.

Figure3. 19: Determination of bulk density

The bulk density of the briquette was determined by taking 9 randomly selected briquettes and the weights of the produced briquettes were determined using digital balance, while the volume of the briquette was also determined by taking the average diameters and heights of the sample briquettes from two different positions using Calipers (0.1 mm precision) (Rabier *et al.*, 2006). It is calculated by $V = (\pi D^2 H)/4$).

Where, $\pi = 3.14$, D = diameter and H = height

The Bulk density refers to the weight of the material to its unit volume and it will be calculated according to (Peter Quaak, 2008).

$$BD = M/V \quad \text{(Eq3.8)}$$

Where BD = Bulk density (g/cm^3)   M = Mass of briquette V= Volume of briquette

3.8.3. Fuel Performance Test

3.8.3.1. Combustion and Water Boiling Capacity Test

The property of the produced fuel briquette such as flame color, production of dangerous spark formation, smoke and odor was check by combustion test. To distinguish the water boiling capacity or heating efficiency test one litter (1L) of water and (0.5L),(2L),of water and 500g of briquettes was used and then boiled, from this predicted the practical cooking time, efficient application or usage of the produced briquette (Abebe *et al.*, 2017). The combustion and boiling tests, for the produced briquettes, were done using Merchayae-Stove (Because “Merchaye” is an improved briquette charcoal stove has an efficiency of more than 75% and a fuel saving stove compared with traditional charcoal stoves). The stove is popular among urban dwellers and now a day such briquette charcoal and stoves have been disseminated by many micro investor / entrepreneur / and energy sake holder in urban and rural part of Ethiopia (Seboka, 2009).

In this study, the property of the produce fuel briquette such as flame color, production of dangerous spark formation, smoke and odor will be check by combustion test. To know the water boiling capacity or heating efficiency test we will use 0.5L or 1L of water and then we will boil, from this we will predict the practical cooking time, efficient application or usage of the produce briquette. It will be done using Merchayae-Stove (Yisehak, 2009).

3.8.3.2. Burning rate of briquettes

Rate of burning of a briquette were evaluated from a sample briquette combusted completely per a given period of time that recorded and calculated as follows (Jain et al., 2014).

$$R=M/T \quad \text{(Eq3.9)}$$

Where R= Rate of burning   M= Mass of briquette T= Total time taken in combustion

a) Combustion briquettes   b) Water boiling capacity test

Figure 3. 20: Combustion and Water boiling capacity test on produced briquettes

3.8.3.3 Total Emission Test

The total emission of the produced briquettes was measured using Merchayae-Stove with the produced briquettes of 500 g from mango seed and mango peel placed inside a closed standard Hood system (the hood closed on all sides except the front) it has dimensions 1000 mm width×750 mm diameter × 2820 mm height and it also had gas mixing chamber with gas analyzer connecter and a continuous measurement of CO, CO_2, O_2, NO, and NO_X was measured using Testo 330-2 L_L model multi component gas analyzer then record was took with 10 minutes interval according to Indian standard for portable solid biomass cook stove.

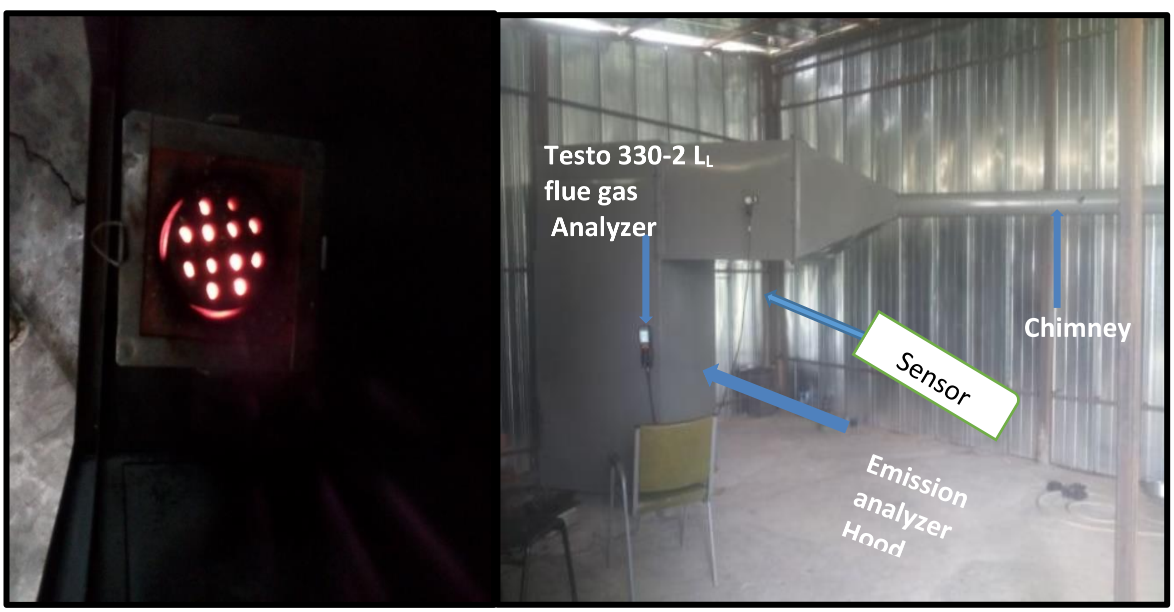


Figure 3. 21: Total emission test on produced mango residue briquettes

3.9. Potential of Mango seed and Mango peel wastes and fuel wood Substitution.

3.9.1 Potential of Mango seed and Mango peel wastes.

The Mango wastes amount was determined by taking one kilogram of Mango from randomly selected twelve Mango sellers and by estimated how much Mango Waste were found from one kilogram Mango and hence, their average was taken to determine the amount of Mango Waste. It was assumed that all Mango legally supplied to the city were fully consumed. To know the amount of fuel briquettes produced, first by taking 230 kg(125kg seed &105kg peel) wet of mango residue from the selected study area and then, how much amount of dried mango residue was found from this amount after one month sun or air dried mango waste after this the carbonization yield of the dried mango seed and peel residue was calculated by taking the average carbonization efficiency of 15 kg sun dried mango residue separately (i.e. mango seed and peel) and then, mixed this amount with 15% clay soil binder the amount of fuel briquettes produced from mango seed and peel was determined and finally, the total amount of fuel briquettes produced from the total amount of the mango waste was calculated.

3.9.2. Energy potential of Mango seed and mango peel waste

Energy potential of mango seed and mango peel waste were estimated from the calorific value that analyzed in the laboratory and from mango seed and mango peel waste potential .The annual energy potential estimated from the annual potential of mango seed and mango peel waste by considering how much energy produced from its calorific value and its annual mango waste potential.

3.9.3 Fuel wood substitution

Estimated Fuel wood substitution the conversion factors which is one(1) ton of charcoal produced from 6 m^3 fuel wood and 1 kg charcoal equivalent to 30,800 KJ energy (FAO, 1999) and amount of CO_2 reduced due to fuel wood substitute were estimated according to conversion factors (Girard, 2002).

3.10. Data Collection and Analysis

Data were collected from carbonization process, governmental organizations and laboratory analysis of briquettes it was conducted in MOWIE at Alternative Energy Development and Promotion Directorate Energy laboratory and workshop section, located at around Sea lite Miheret church Guard Shola Addis Ababa. The result were recorded, processed and analyzed using Microsoft excels. Descriptive statistics and chart graph was used to compare means and standard deviation (SD) of the result. All the analysis tests were done in triplicate (Merete *et al.*, 2014).

4. RESULTS AND DISCUSSION

4.1. Total Amount of Fuel Briquettes Produced from Mango Seed & Peel

4.1.1. Average Amount of Mango Seed &Peel from one (1) kg Mango

From the selected twelve (12) Mango Shops and Seller taken on average from 1 kg Mango 0.6 kg Mango residues were found. Table 4.1 below shows that the result of the study.

Table 4.1: Amount of Mango seed& peel from one kilogram (1kg) Mango

Trial No	Amount of Mango (kg)	Amount of Mango residues (kg)
1	1.00	0.65
2	1.00	0.62
3	1.00	0.67
4	1.00	0.64
5	1.00	0.68
6	1.00	0.59
7	1.00	0.66
8	1.00	0.71
9	1.00	0.63
10	1.00	0.70
11	1.00	0.64
12	1.00	0.60
Mean ± SD	1.00	0.6± 0.06

4.1.2. Average Amount of Mango Supply and Waste Potential from 2014-2018

According to the information provided by The Benishangul Gumuz Regional State Agriculture and Natural Resource Bureau Assosa. The potential from 2014 to 2018 total volume of mango supplied to Addis Ababa was estimated to 188,657,600 kg and the corresponding estimated wet residue potential was 113,194,560 Kg. Yet, all mango residue generated is not available.

Some part is disposed as part of the solid waste from the cities. Table 4.2 shows that yearly mango consumption from 2014-2018.

Table 4.2: The total amount of mango supply, revenue, and waste generation

Year	Mango supply (Kg)	Revenue (birr)	Mango Residue (Kg)
2014	27,881,000	780,668,000	16,728,600
2015	38,065,600	1,065,836,800	22,839,360
2016	35,651,100	998,230,800	21,390,660
2017	42,336,400	1,185,419,200	25,401,840
2018	44,723,500	1,252,258,000	26,834,100
Mean ± SD	37,731,520 ± 5,837,979	1,056,482,560 ±448,842,984	22,638,912 ± 9,394,435

4.1.3. Carbonization Yield

The conversion efficiency of raw feedstock of Mango seed residue and mango peel residue into carbonized material is 51.75% of mango seed residue and 40.00% of mango peel residue. This means from100 kg air dry mango seed residue net average carbonized mango seed residue amount is 51.75kg and from 100kg air dry mango peel residue net average carbonized mango peel residue is 40.00kg.

Table 4.3: The average results of mango residues carbonization yield by using Philippine drum kiln model.

Sample of feed stock	Treatment	Input (kg)	Output (kg)	Conversion efficiency of feedstock into carbonized material (%)
Raw Mango seed	TS1	15.00	7.81	52.06
	TS2	15.00	7.73	51.53
	TS3	15.00	7.75	51.66
	Mean ± SD	15.00	7.76 ± 0.03	51.75 ± 0.22
Raw Mango Peel	TP1	15.00	6.12	40.00
	TP2	15.00	5.58	37.20
	TP3	15.00	6.30	42.00
	Mean ± SD	15.00	4.18 ± 0.21	40.00 ± 2.04

Where TS - Treatment of seed and TP – Treatment of peel

The results in this study showed that the carbonization of the mango seed and peel residue have about 51.75% and 40.00% respectively (Table 4.3). The carbonization efficiency is relatively good comparing with yield in this study which is from Philippine drum kiln model (carbonization model) a typical yield of metal kiln at 15% moisture content is 30%. The Previous study confirmed that the carbonization efficiency can be affected with several aspects such as the moisture contents of the input sample, type of the kiln used, cooling skill, type of biomass used and weather condition. The major factors that affect the quantity and quality of fuel charcoal or fuel briquette production is the moisture content of the sun dried sample (Abebe et al., 2017).

4.1.4. Amount of Briquette Produced from the Average Amount of Mango Waste

The result Showed that from 230 kg total samples of wet mango residues, 140 kg air dried mango residues were found. This means from 100% of wet mango residue 60.9% is air dried mango residue (i.e. 79 kg air dried seed and 61 kg air dried peel) and on the other hand, on average from each 15 kg air dried mango seed and peel residues 7.76 kg and 4.18 kg of carbonized seed and peel respectively (Table 4.3). In addition to this, the mixture of 7.76 kg carbonized seed and 4.18 kg carbonized peel with the specified measured binder 15% clay soil. Therefore, from the above results, the average estimated mango supply fuel briquette recovery potential from 2014-2018 (Table 4.4).

Table 4. 4: Estimated charcoal recovery potential.

Year	2014-2018 (kg/yr.)
Mango inflow	37,731,520
Wet Mango residue generated	22,638,912
Air-dry Mango residue	12,795,906.5
Air-dry Mango Seed residue	6,656,352.7
Air-dry Mango Peel residue	6,139,554.8
Carbonized Mango residue Seed	3,182,816.1
Carbonized Mango residue Peel	1,739,540.5
Amount of briquette produced from Mango seed with specified binder 15% clay soil.	1,909,689.6
Amount of briquette produced from Mango Peel with specified binder 15% clay soil.	974,142.6
A mixture of carbonized Seed and carbonized Peel briquette with specified binder 15% clay soil.	2,883,832.2

4.2. Proximate Analysis and Physical Property

4.2.1. Proximate Analysis and Gross Calorific Value of Raw Mango Waste

Table 4.5 Showed that the testing results of the proximate analysis and gross calorific value of the raw Mango seed and peel. On average the Mango seed had MC, VM, AC, FC and a GCV of 1.74%, 74.46%, 4.14%, 19.19%and 4,560.91Cal/gm and Mango peel had MC, VM, AC, FC and GCV of 4.04%, 70.73%, 6.04%, 19.19% and 4,046.08 Cal/gm respectively.

Table 4. 5: The proximate analysis and gross calorific value of raw Mango waste.

Samples	Treatments	Proximate analysis				Calorific Value
		MC (%)	VM (%)	AC (%)	FC (%)	CV (Cal/gm)
Raw Mango seed	TS 1	1.71	72.81	4.16	19.65	5,559.90
	TS 2	1.77	73.78	4.12	19.72	3,565.93
	TS3	1.75	76.80	4.15	19.63	4,556.91
	Mean ± SD	1.74 ± 0.03	74.46±1.69	4.14 ± 0.02	19.66± 0.04	4,560.91 ± 81.40
Raw Mango peel	TP 1	4.07	70.72	6.06	17.29	4,047.08
	TP 2	4.03	70.75	7.02	21.20	3,046.09
	TP 3	4.02	70.72	5.04	19.08	5,045.07
	Mean ± SD	4.04 ± 0.02	70.73 ± 0.01	6.04 ± 0.81	19.19±1.59	4,046.08 ± 55.37

Where TS - Treatment of Seed and TP – Treatment of Peel

4.2.2. Proximate Analysis and Gross Calorific Value of Carbonized Mango Waste

The carbonized Mango seed on average had MC, VM, AC, FC, and GCV of 6.14%,30.45%,11 .16%,52.26% and 6,189.77Cal/gm and carbonized Mango peel had MC, VM, AC, FC and GCV of 6.39%, 42.48%, 8.41%, 42.72% and 5,902.40Cal/gm, respectively as shown in table 4.6.

Table 4. 6: The proximate analysis and gross calorific value of carbonized Mango residues.

Samples	Treatments	Proximate analysis				Calorific Value
		MC (%)	VM (%)	AC (%)	FC (%)	CV (Cal/gm)
Carbon-ized Mango seed	TS1	7.03	29.61	9.98	50.69	6,008.77
	TS2	5.37	30.42	11.45	54.03	6,020.79
	TS3	6.02	31.32	12.06	52.06	6,539.76
	Mea ± SD	6.14± 0.68	30.45± 0.70	11.16±1.08	52.26± 1.37	6,189.77± 247.53
Carbon-ized Mango	TP1	6.67	46.17	7.42	42.35	5,740.10
	TP2	6.38	39.93	8.71	41.96	5,956.08
	TP3	6.13	41.34	9.11	43.85	6, 011.03

peel	Mea ± SD	6.39± 0.22	42.48 ± 2.67	8.41± 0.72	42.72± 0.81	5,902.40 ± 116.93

Where TB - Treatment of seed and TL – Treatment of peel

The above result shows that the carbonized seed and peel residue had lower VM, and higher AC, MC, FC and GCV than, raw Mango seed and Peel (Table 4.5 and 4.6).

4.2.3. Proximate Analysis and Physical Properties of Fuel Briquettes

Table 4.7 showed that the results of the testing of the proximate analysis and physical properties of the briquettes made from Mango residue. Briquette made from carbonized Mango seed had a MC of 9.57%, a VM of 27.69%, an AC of 16.70%, a FC of 46.03%, a BD 0.60 g/cm3 and a GCV of 5,588.33 Cal/gm, and briquettes produced from carbonized Mango peel had a MC of 14.11%, a VM of 33.41%, an AC of 18.21%, a FC of 34.28%, a BD 0.56 g/cm3 and a GCV of 4,961.87 Cal/gm, and briquettes produced from a mixture of carbonized branch powder with carbonized leaves powder had a MC of 11.01%, VM of 28.71%, AC of 17.30%, FC of 42.98%, BD 0.54 g/cm3 and GCV of 5,473.15Cal/gm respectively.

Table4.7: The proximate analysis and physical properties of briquette made from carbonized mango waste.

Samples type	Treatments	Proximate analysis				Physical property	
		MC (%)	VM (%)	AC (%)	FC (%)	BD(g/cm^3)	CV(Cal/gm)
Briquette made from carbonized seed	T1	9.32	26.89	17.21	45.04	0.62	5,512.29
	T2	10.23	27.85	16.49	46.05	0.60	6,012.36
	T3	9.17	28.34	16.41	47.01	0.58	5,240.34
	Mean ± SD	9.57 ± 0.47	27.69 ± 0.60	16.70 ±0.36	46.03 ± 0.80	0.60 ±0.04	5588.33 ± 319.72
Briquette made from carbonized peel	T1	13.45	33.59	18.11	35.27	0.52	5,336.64
	T2	14.22	31.56	18.13	34.08	0.55	4,685.53
	T3	14.67	35.09	18.39	33.49	0.61	4,863.46
	Mean ± SD	14.11±0.50	33.41 ± 1.45	18.21 ±0.13	34.28 ± 0.74	0.56 ±0.02	4,961.87 ± 274.77
Briquette made from carbonized seed and peel	T1	10.01	29.50	17.72	42.68	0.54	5,214.23
	T2	12.01	28.92	17.08	42.59	0.52	6,003.02
	T3	11.02	27.72	17.12	43.67	0.55	5,202.21
	Mean ± SD	11.01±0.81	28.71 ± .74	17.30±0.29	42.98 ± 0.49	0.54 ±0.02	5,473.15 ± 374.70
Briquette made from eucalyptus wood	T1	9.02	22.96	12.22	58.04	0.50	5993.355
	T2	8.16	23.63	12.59	57.06	0.47	6108.146
	T3	7.18	22.84	13.20	54.11	0.49	6096.93
	Mean ± SD	8.12± 0.75	23.14 ± 0.34	12.67 ±1.70	56.07± 0.40	0.48 ± 0.01	6065.93 ± 51.55

4.2.3.1. Moisture Content

The moisture content of the raw Mango seed and Peel were 1.74% and 4.04%, respectively, and moisture content of carbonized Mango seed powder and Mango Peel powder were 6.14% and 6.39% respectively, and also moisture content of the fuel briquette produced from carbonized Mango seed, carbonized mango peel and a mixture of carbonized Mango seed and carbonized mango peel were 9.57%, 14.11%, and 11.01% moisture content respectively (Figure 4.1).

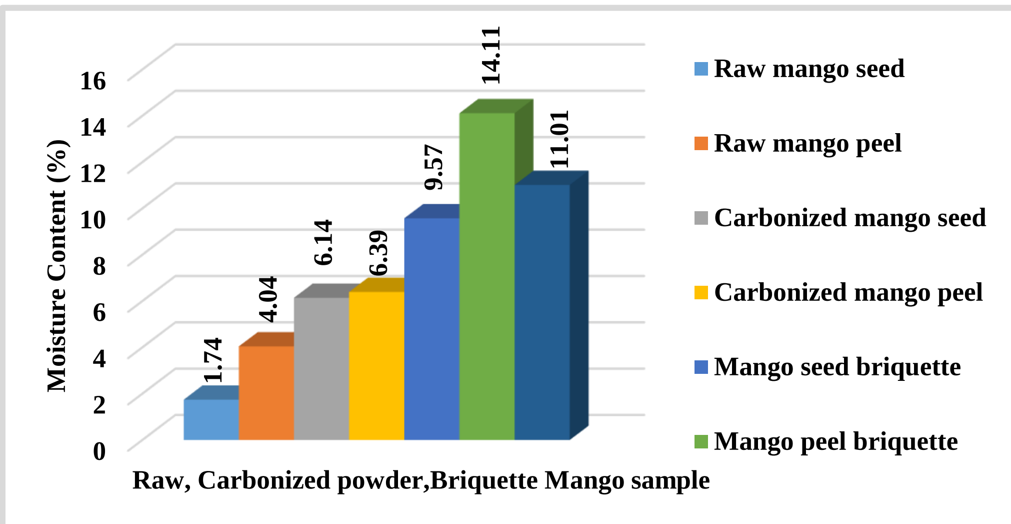


Figure 4.2: Moisture content of raw Mango residues, carbonized and briquettes sample

The produced briquettes were less than the rice husk and corncob briquette which were 12.67% and 13.47%, respectively (Oladeji, 2010). The results full fill the quality specification of charcoal which restricts between 5 to 15% moisture content and to smooth heat transfer, moisture content should be as low as possible (FAO, 1987). Moisture content is one of the key parameters that regulate briquette quality. A lower the moisture content of the briquette, indicates the higher will be the calorific value(Akowuah *et al.*, 2012). Correspondingly, this study showed that the mango seed had 1.74% moisture content which was the lowest from the others and that could be had higher calorific value (6,189.77Cal/gm) compared with others produced briquettes in this study.

4.2.3.2. Volatile Matter

Volatile matter of raw mango seed and peel residue were had the value which was 74.46% and 70.73% respectively, and the volatile matter of carbonized mango seed and peel residue had 30.45% and 42.48% respectively, though the volatile matters of the briquettes produced from carbonized mango seed, carbonized mango peel, a mixture of carbonized seed po wder with carbonized peel powder were 27.69%, 33.41%, and 28.71% respectively. The result shows that, carbonized seed powder had the lowest one then carbonized mango peel, a mixture of carbonized seed and carbonized peel powder had the highest volatile matter. (Figure 4.2).

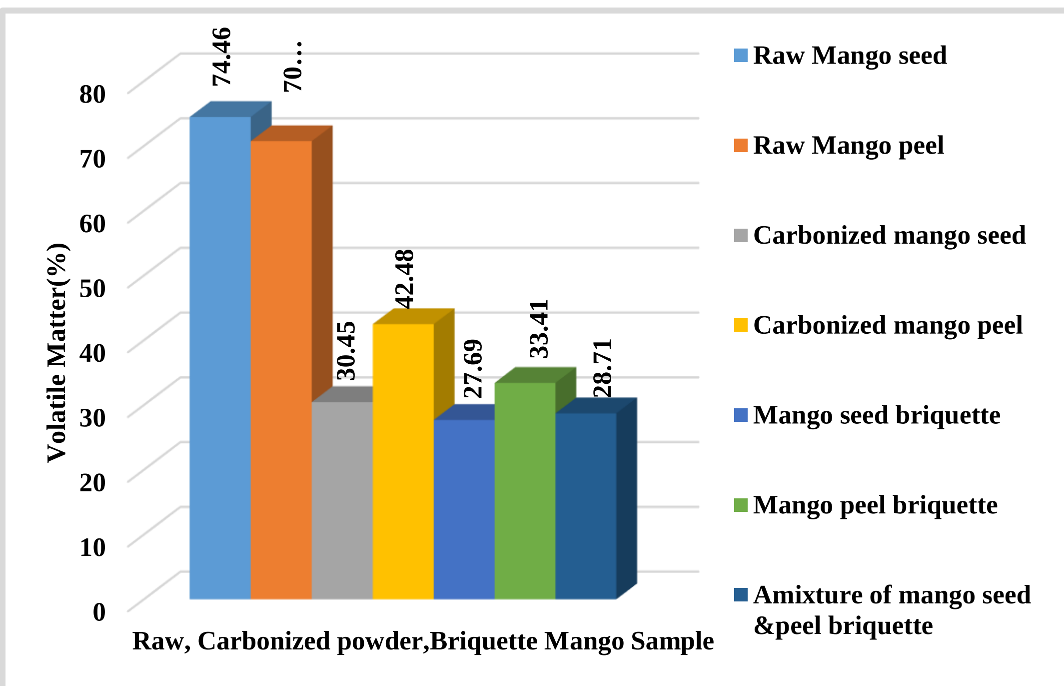


Figure4. 3: Volatile matters of mango residues, after carbonization and briquettes

The volatile matter is the components of hydrocarbon it might be influences the thermal behavior of solid fuels, the structure and bonding behavior influences volatile matter. The weight of the dr y biomass normally contains volatile content in the range 70 to 86% Koppejan and Van Loo, (2012). The result of the raw material used in this study also in line with the above idea (Figure 4.2).

The volatile matter of charcoal can fluctuate from maximum 40% or it may lower up to 5% or less than 5% (FAO, 1985). Good quality charcoal should have volatile matter between 20 to 25% (FAO, 1987). On the other hand, the briquettes produced from carbonized mango seed, a mixture of carbonized seed powder with carbonized peel powder full fill good marketable charcoal has net volatile matter content of about 30% by (FAO, 1985). But the briquette produced from carbonized mango peel residue are not in line with the described criteria by (FAO, 1985).This is might be the mango peel residue was not properly carbonized because of this mango peel briquettes have higher volatile matter.

The briquette produced from carbonized mango peel residue have greater volatile matter comparing to Teppi coffee husk and Teppi coffee pulp briquettes (Merete *et al.*, 2014) to some extent but have lower volatile matter comparing to banana leave briquette (Oliveira *et al.*, 2014) and saw dust briquette, bagasse, sawdust, carbo fire wood and eucalyptus fire wood (Eduardo *et al.*, 2014).

4.2.3.3 Ash Content

The air dried raw Mango seed and peel had the ash content of 4.14% and 6.04% respectively, and the ash content of carbonized Mango seed and Peel were 11.16% and 8.41% respectively, but the ash content of the produced briquettes increased after mixed with clay soil as a binder which had carbonized Mango seed, carbonized Mango peel, and a mixture of carbonized mango seed powder with carbonized mango peel powder were 16.70 %, 18.21 % and 17.30 % ash content respectively (Figure 4.3).

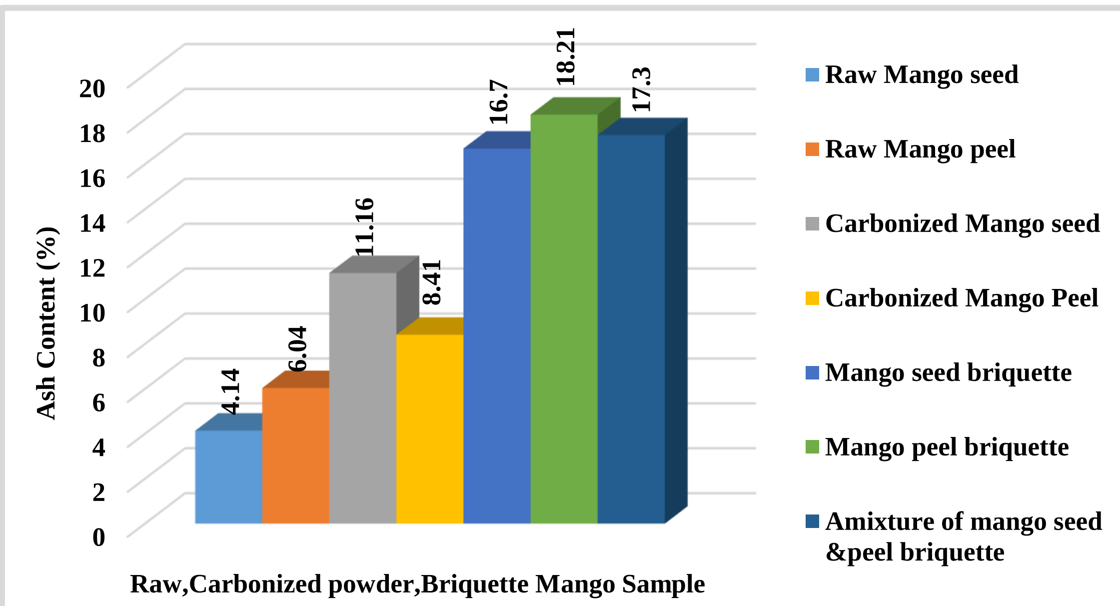


Figure4. 4: Ash contents of mango residues, carbonized and briquettes

Ash is the non-combustible inorganic residue remains after complete combustion. According to FAO (1985), the ash content of charcoal fluctuated from 0.5 to 5% or more than 5% that based on the wood species. The good quality charcoal should have usually the ash content fluctuated from 3 to 4% (FAO, 1987). The ash content of the carbonized Mango seed residue fulfills good quality charcoal described by (FAO, 1987). But, carbonized mango peel (6.04) fail the good quality charcoal criteria by (FAO, 1987) (Figure 4.3) this is due to improper carbonization. For enhanced utilization of briquette, the lower ash content is preferable which increase the combustion efficiency (Akowuah *et al.*, 2012). The binder used to bind the produced briquette was clay soil which is non-combustible which increase ash content (BTG, 2013). Therefore, the binder used in this study, the clay soil increases the ash content of the produced briquettes.

4.2.3.4 Fixed Carbon Content

Fixed carbon in the raw Mango seed and peel were19.66% and 19.19% respectively, and the fixed carbon in carbonized Mango seed and peel were 52.26% and 42.72% respectively,

but this were changed into briquettes mixed with clay soil binder (15%) the fixed carbon of carbonized Mango seed, carbonized mango peel, and a mixture of carbonized seed powder with carbonized peel powder were 46.03%, 34.28% and 42.98% fixed carbon content respectively (Figure 4.4).

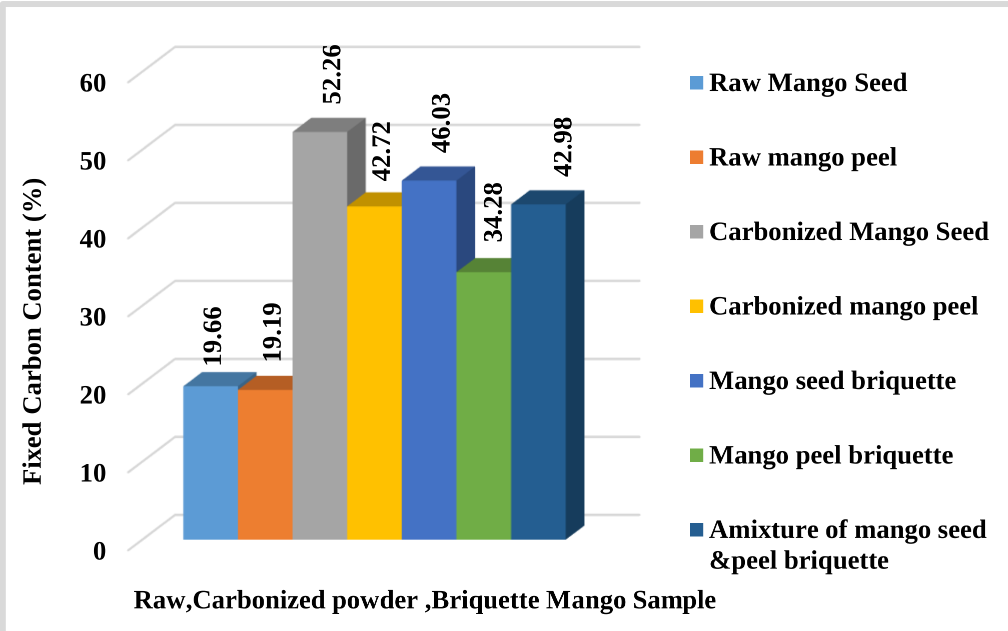


Figure4. 5: Fixed carbons of Mango residues, carbonized and briquettes

According to FAO (1985), the fixed carbon of charcoal fluctuates nearly between 50% up to 95%.the produced mango residue briquettes mango seed briquette had 52.26% fulfils the ranges but the rests mango sample fixed carbon content below the ranges that described by FAO and also mango seed briquette had highest calorific value from the rests of mango samples (Figure 14) this in line with the high fixed carbon content result in high calorific value (FAO, 1985).

The higher the fuel's ash contains, the lower is its calorific value (Loo and Koppejan, 2008) and the high fixed carbon content gives the result of high calorific value (FAO, 1985). From the above concept the fixed carbon content of the produced briquettes in this study had lower, because of higher ash amount was found in to the produced briquettes this is also related to the clay soil used as a binder in this study.

The mango seed fuel briquette is greater than the fixed carbon content of the charcoal briquette produced from Sesame stalk and a mixture of carbonized branch powder with carbonized leaves powder is comparable with Sesame stalk which was a fixed carbon content of 44.40% (Gebresas et al., 2015). All briquette produced from mango residue powder are greater than the fixed carbon content of the charcoal briquette produced from sawdust briquette which was a fixed carbon content of 20.7% (Akowuah *et al.*, 2012) and the whole produced briquette in this study, are greater than the fixed carbon content of briquette produced from wood which had the corresponding value of 1.6% stated by (Malatji *et al.*, 2011).

4.2.3.5 Bulk Density (BD)

The bulk density of the produced briquettes in this study had carbonized Mango seed residue briquettes, carbonized Mango peel residue briquettes, and a mixture of carbonized seed powder with carbonized Peel powder briquettes were 0.60(g/cm3) ,0.56g/cm3 and 0.54 g/cm3bulk densit y respectively, (Figure 4.5).

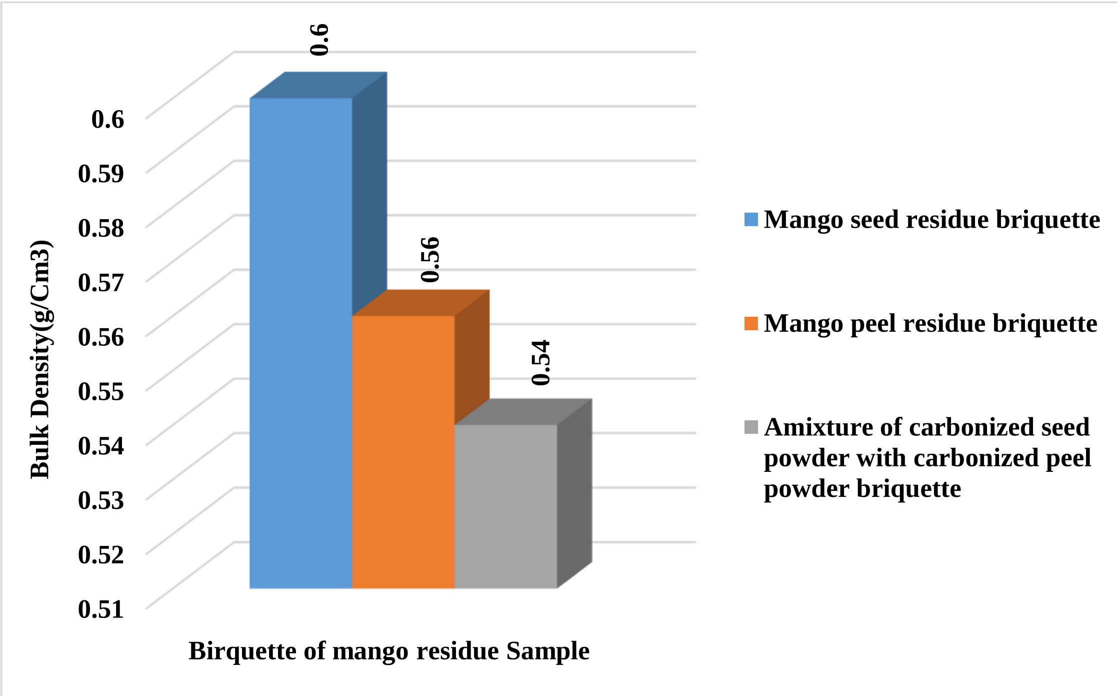


Figure4. 6: Bulk densities of mango residue briquettes

The bulk density is one of the most important parameter of briquettes, where the higher the density, the higher is the energy per volume ratio and its slow burning property. Therefore, high density crops are required in terms of transportation, handling, and storage.

The bulk density achieved from this study were much higher than that of *Eupatorium* spp. with bulk density 0.33 g/cm^3 (Ritesh *et al.*, 2009) and less than the charcoal briquette produced from coconut husks and sawdust which had bulk density of 0.76 g/cm^3 and 0.89 g/cm^3 respectively, (S Suryaningsih *et al.*, 2017) and the charcoal briquette produced from banana leaves briquette which was in the range 0.99 to 1 g/cm^3 (Maia *et al.*, 2014). The lower bulk density in this study was briquettes produced from a mixture of carbonized branch powder with un-carbonized leaves powder (Figure 4.5) that might be due to the combination of carbonized and un-carbonized raw material used to produce the briquette.

4.2.3.6 Calorific Value

The mean calorific value of raw Mango seed residue had lower gross calorific value of 4,560.91 Cal/gm than, the mean gross calorific value of raw Mango peel residue which had 4, 046.08 Cal/gm and both values were increased after carbonization the carbonized Mango seed had gross calorific value of 6,189.77 Cal/gm and the carbonized Mango peel had gross calorific value of 5,902.40Cal/gm. However, Consequence differences of the gross calorific value were found between the produced briquettes. The carbonized Mango seed briquette contained the highest gross calorific value of 5,588.33Cal/gm and the next one was a mixture of carbonized seed powder with carbonized peel powder briquettes which was 5,473.15 Cal/gm and carbonized mango peel briquettes was 4,961.87Cal/gm figure (4.6).

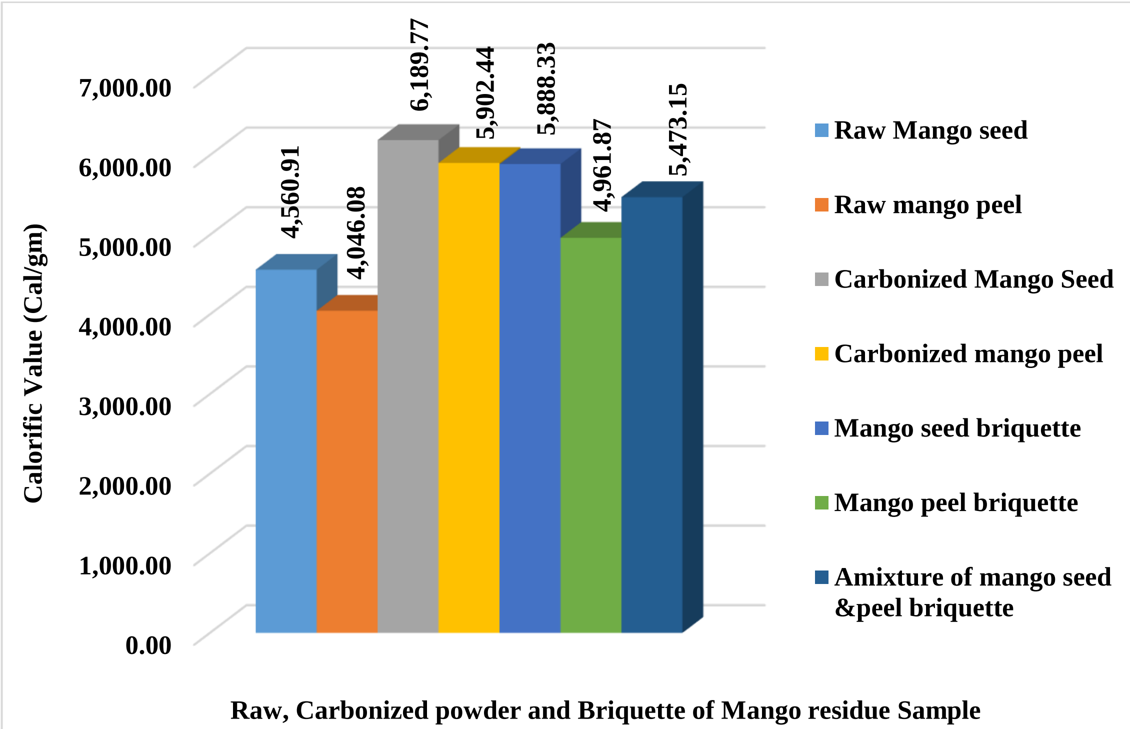


Figure4. 7: Calorific value of raw Mango residues, carbonized and briquettes

Calorific value or heating value regulates the energy content of a fuel. It is also the property of biomass fuel that can be influenced by its moisture content and chemical composition. In addition to this, it is the most important fuel property (Aina et al., 2009). The calorific value of the raw mango seed was less than the carbonized mango seed and carbonized mango seed brique ttes and the carbonized mango seed was greater than the carbonized mango seed briquettes this might be because of the clay soil used as binder in this study.Correspondingly,the gross calorific value of the raw mango peel was less than the gross calorific value of carbonized mango peel and the calorific value of carbonized mango peel briquettes this was because of the clay soil used as a binder in this study but calorific value of carbonized mango peel greater than that of the gross calorific value of carbonized mango peel briquettes .this was because of the clay soil used as a binder in this study. High percentage of volatile matter doesn't mean will decrease the burning capacity. The calorific value after carbonization was higher than fuel briquette which was used clay soil as a binder (Abebe et al., 2017).

Carbonized Mango seed briquette, a mixture of carbonized seed powder with carbonized peel powder briquettes had greater gross calorific value than charcoal briquette made from coffee pulp which was 16,905.62 kJ/kg (Figure 4.6) but less than the gross calorific value of the charcoal briquette made from coffee husk which was 21,106.08 kJ/kg (Merete et al., 2014). All briquettes made from this study except a mixture of carbonized branch powder with un-carbonized leaves powder briquettes had greater calorific value than wood which was 13,803.12 kJ/ kg (FAO, 1999).

4.3. Fuel Performance Test

4.3.1 Combustion and Water Boiling Capacity Test

The test result showed that the carbonized Mango seed, mango peel briquettes and a mixture of seed and peel briquettes are strong heat which got on average 19 min ,21min and 22 min to boil 0 .5 litter of water respectively and to boil one litter of water 24 min,38 min, and 36 min respective ly and also fuel briquettes made from carbonized mango seed , carbonized mango peel and a mixture of seed and peel briquettes had average time taken to turn to ash were 2hr and 14 min, 2hr and 29 min, and 2hr and 26 min respectively (Table 4.8) the performance test was done by using Merchaye stove.

Table 4. 8: The relative time taken to boil water using Merchaye-stove

Briquette type	Average time to boil 0.5Lin(min)	Average time to turn to ash in (Hour & Minutes)	Average time to boil 1Lin (min)	Average time turn to Ash (Hour & Minutes)	Average Calorific Value (Cal/gm)
Carbonized mango seed briquette	21.00 Min	1: 19 Min	26.00 Min	2: 19 Min	6,012.36
	19.00 Min	1: 12 Min	24.00 Min	2: 14 Min	5,512.29
	17.00 Min	1: 10 Min	22.00 Min	2: 10 Min	5,9240.34
Mean ± SD	19 Min±1.15	1: 14Min ± 3.87	24 Min ± 1.63	2: 14 Min ±4.51	5588.33±319.72
Carbonized mango peel briquette	23.00 Min	1: 24 Min	42.00 Min	2: 34 Min	5,336.64
	21.00 Min	1: 22 Min	37.00 Min	2: 28 Min	4,863.46
	20.00 Min	1: 19 Min	35.00 Min	2: 25 Min	4,685.53
Mean ± SD	21 Min±1.29	1: 21 Min ± 2.16	38 Min ± 2.94	2: 29 Min ± 3.74	4,961.87±274.77
Carbonized seed &peel briquette	24.00 Min	1: 25 Min	37.00 Min	2: 30 Min	6,003.02
	23.00 Min	1: 22Min	36.00 Min	2: 24Min	5,214.23
	21.00 Min	1: 20 Min	34.00 Min	2: 25 Min	5,202.21
Mean ± SD	22 Min±1.41	1: 22Min ± 2.08	36 Min ± 1.19	2: 26 Min ± 2.64	5,473.15±374.70

The result for fuel performance test of the produced fuel briquette made from carbonized mango seed showed that there is no smoke (smoke free) except at a startup, no spark formation, no soot production, no smell or odor but mango peel residue have smoke and smell or odor until 10 min after startup. The carbonized fuel briquette made from mango seed had almost similar qualities when compared with sesame stalk which was 20 min (Gebresas *et al.*, 2015). Furthermore, the study indicated that the time taken to boil a given amount of water highly related to the calorific value.

4.3.2 Total Emission Test

The total gas emissions of mango residue fuel briquette with the recommended preferable range of CO, NO, NOx, CO_2, and O_2. The table below clearly indicated that the gas emission produced by the fuel briquettes confirms to the recommended range of Indian standard for portable solid biomass cook stove.

The highest hardiness of the briquette results in lower dust and CO emission and higher amounts of fixed carbon increase the probability of more complete oxidation and extensive combustion in addition to these briquettes having high amounts of fixed carbon have low dust and CO emission (Mopoung and Udeye, 2017). The hardiness of the briquettes is related to the dust and CO emission. So that the results found in this study, in line with the above described idea.

Table 4. 9: The total emission test of produced briquettes

Emissions (average)	CO2 (%)	CO (PPM)	O2 (%)	NO (%)	NOX (%)
Mango seed briquette	0.26	842	20.01	3.16	2.0
Mango peel briquette	0.37	923	20.03	6.23	3.0
Eucalyptus briquette	0.75	5369	20.8	8.51	6.23
Preferable standard range	0-20	0-1000	0-25	-	-

Where 1% CO = 10,000 ppm

The carbonized Mango seed and peel fuel briquettes had total CO emissions of 842 (0.08%) ppm and 923 ppm (0.09%) respectively. The carbonized Mango seed and peel fuel briquettes had lower CO emission than charcoal briquettes produced from eucalyptus briquette had total CO emission of 5369 ppm (0.54%).

The carbonized mango seed and peel fuel briquette had lower CO emission banana peel and banana bunch which had total CO emission of 3463 ppm (0.35%) and 1568 ppm (0.16%) respectively, (Mopoung and Udeye, 2017). The gas mixtures of atmosphere with a low concentration of CO in the range up to 4,947 ppm (0.5%) do not present any toxic threat to consumers according to international standard for the Determination of Toxicity of Gases as cited by (Mopoung and Udeye, 2017). Therefore the produced fuel briquettes from mango seed and peel do not cause any risk to consumers.

4.4. Evaluation of the Energy Potential of the Fuel Briquettes

The result showed that the average calorific mean value of the briquette produced from carbonized Mango seed was found to be 23,391.9 kJ/ kg (Table 4.7). If 3,182,816.6 kg carbonized Mango seed (Table 4.4) was mixed with (15%) of the clay soil used as binder in this study, the city might possibly produce 1,909,689.6 kg of briquettes from the seed residues only (Table 4.4), which would the amount to a total energy approximately 44.67×10^9 kJ.

As shown in table 4.7, the average calorific mean values of the briquette produced from carbonized Mango peel was 16,936.3kJ/ kg. If 1,739,540.5 kg of carbonized Mango peel (Table 4.4) was mixed with (15%) of the clay soil used as binder in this study, the city might possibly produce 974,142.6 kg of briquettes from the peel residues only (Table 4.4), which would the amount to a total energy of approximately 16.49×10^9 kJ.

In addition to that, the average calorific mean values of the briquette produced from a mixture of carbonized Mango seed with carbonized Mango peel was 22,909.8 kJ/ kg (Table 4.7). If the total amount 4,922,356.6 kg of carbonized Mango seed and peel (Table 4.4), was mixed with

(15%) of the clay soil used as binder in this study, the city might possibly produce 2,883,832.2 kg of briquettes from a mixture of carbonized seed and peel (Table 4.4), which would amount to a total energy of about 66.06×10^9 kJ.

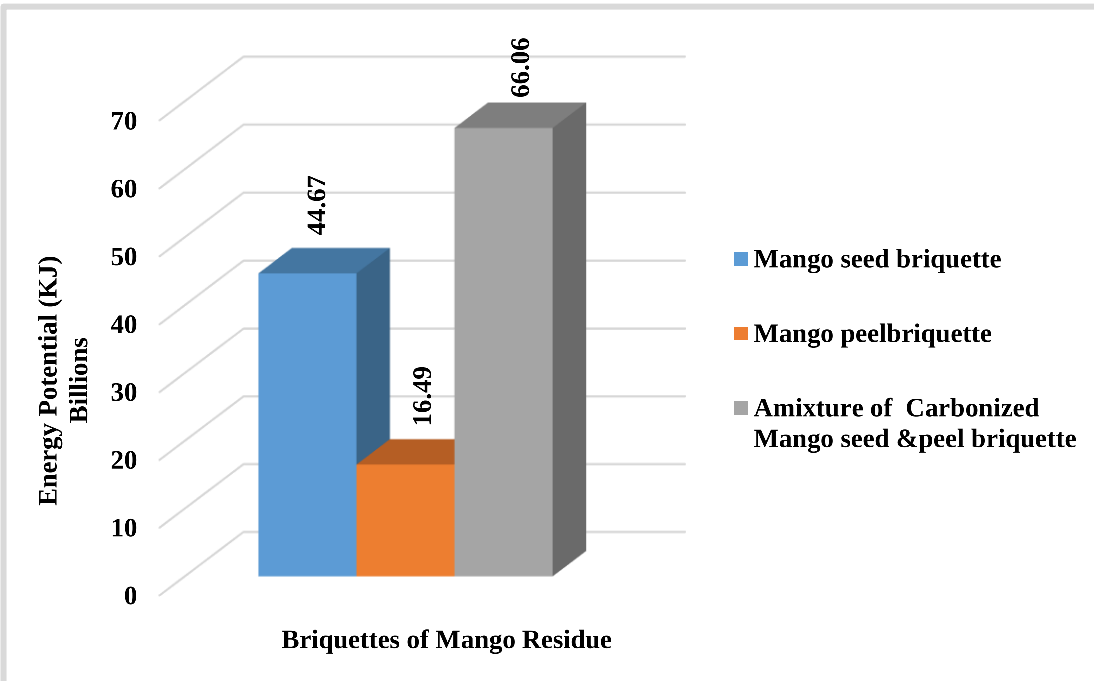


Figure4. 8.Energy potentials of mango residue briquette

4.5 The energy potential of mango briquettes and its wood charcoal and fuel wood substitution

Estimated Fuel wood substitution the conversion factors which is one (1) ton of charcoal produced from 6 m3 fuel wood and 1 kg charcoal produce 30.8MJ of energy which is equal to 30,800 KJ energy (FAO,1999) and amount of CO2 that were reduced due to fuel wood substitute were estimated according to conversion factors (Girard,2002).The produced briquettes from ma ngo residue can substitute wood charcoal that produced by cut down of tree which estimated based on the above idea. The Mango seed briquette had 23,391.9 KJ/kg calorific value and a total potential of 1,909,689.6 kg and that can produce a total energy of $44.67*10^9$ KJ that substitute 1,450 ton of wood charcoal and in turn can substitute 8,702 m^3 fuel wood as a result this substitution 4,785 ton of CO_2 that release to the environment reduce due to the produced mango seed briquettes as shown in (Table4.10) and the mango peel briquette had 16,936.3KJ/kg calorific value and a total potential of 974.142.6 kg and that can produce a total energy of $16.49*10^9$ KJ that substitute 535.4ton of wood charcoal and in turn can substitute 3,212.4 m^3 fuel wood as a result this substitution 1,767 ton of CO_2 that release to the environment reduce due to the produced mango peel briquettes (Table4.10) and mixture of mango seed and mango peel briquette had 22,909.8KJ/kg calorific value and a total potential of 2,883,832.2Kg and that can produce a total energy of $66.06*10^9$KJ that substitute 2,144.8 ton of wood charcoal and in turn can substitute 12,868.8m^3 fuel wood (Table4.10) that estimated based on one(1) tone of charcoal produced from 6m^3 of fuel wood (FAO,1999) (FAO,1999) as a result this substitution 7,077.8ton of CO2 that release to the environment reduce due to the produced mixture of mango seed and mango peel briquette which estimated according to (Girard, 2002) 250 kg of charcoal e quivalent to 0.825 tons of CO_2.

Table 4.10: The energy potential of mango briquettes and its wood charcoal and fuel wood

Substitution

Type of briquettes	Calorific value (KJ/Kg)	Energy potential (KJ/year)	Wood charcoal substitution (ton/year)	Fuel wood substitution (m^3/year)	CO_2 emission reduction (ton/year)
Mango seed briquette	23,391.9	$44.67*10^9$	1,450.3	8,702	4,785
Mango peel briquette	16,936.3	$16.49*10^9$	535.4	3,212.4	1,767
A mixture of mango seed &mango peel briquette	22,909.8	$66.06*10^9$	2,144.8	12,868.8	7,077.8

Note. Where, 1KJ/Kg = 0.2389Cal/gm

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In Ethiopia there is substantial dependence on traditional biomass is leading to different environ mental and socio-economic problems, so that to decrease such problem the current study is important which is on the "production and characterization of fuel briquette from Mango (mangifera indica) residue for diversification of household energy sources" the study was conducted by taking a raw material (sample) of 230 kg quantity of wet mango residue and fuel briquettes were produced using a material like:- digital balance, Philippine drum kiln model ,beehive briquette machine and the laboratory analysis was done by ASTM procedure.

The result of the study showed that fuel briquette produced from Mango waste was found a more quality Alternative energy source for household use.The fuel briquette produced from Man go seed have higher fixed carbon content and calorific value with values of 46.03 ± 0.80%and 5, 588.33 ± 319.72 Cal/gm respectively and have lower moisture content, volatile matter, and ash content values of 9.57 ± 0.47 %, 27.69± 0.60% and 16.70 ± 0.36% respectively, compared with the results of briquettes produced in this study. On the other hand, the results of the study indicated that the fuel briquette produced from a mixture of carbonized mango seed and peel have higher fixed carbon content and higher calorific value with a value of 42.98 ± 0.49% and 5,473.15 ± 374.7 Cal/gm, respectively and lower moisture content, volatile matter, and ash content with a value of 11.01 ± 0.81%, 28.71 ± 0.74% 17.30 ± 0.29 % respectively, compared with fuel briquette produced from mango peel, excluding the fuel briquette produced from mang o seed. Furthermore, from the average wet Mango residue potential which was 4,922,356.6 kg, the study indicated that 2,883,832.2kg of fuel briquette can be produced from a mixture of carbonized Mango seed and peel, this amount could possibly produce around $66.06*10^9$ KJ of energy and this substitutes nearly 2,144.8 ton of fuel wood charcoal in turn substitute $12,868.8m^3$ of fuel wood and 7,077.8 ton of CO_2 that release to the environment reduce due to the produced a mixture of carbonized mango seed and peel briquette.

Therefore, the study concluded that briquette produced from mango waste have high potential as an alternative a source of environmental friendly energy source, which is that reduces pollution as well as provides a sound mango waste management option. Moreover, production of briquette s from mango seed and peel helps to reduced CO_2 emission by reducing the deforestation rate, re duce indoor air pollution as a result of providing renewable, clean, and sustainable energy as a substitute for fuel wood and charcoal.

5.2. Recommendations

Ultimate analysis would be resounding out to assess the chemical composition of fuel briquette produced from Mango waste. Furthermore, survey on cost analysis and adoption of this technolo gy has to be carried out to show the acceptability and future market potential for mango waste briquettes among households and processing industries.

The quality of briquettes produced from mango seed are highly influenced by the binder types used. Therefore, to minimize binder effect other binder options like starch, molasses, etc. are recommended.

The government should encourage and scale up the investment in fuel briquette production to subsidize fuel consumption, and give intensive policies for the investors who invest on fuel briquette production.

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7. Annex

Annex7.1. Letter of summarized (average) experimental results.

	GEOLOGICAL SURVEY OF ETHIOPIA	**Doc.Number: GSE/F 5.10-2**	**Version No: 1**
	GEOCHEMICAL LABORATORY DIRECTORATE		**Page 1 of 1**
Document Title:	**Hydrocarbon Laboratory Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: - 27/02/2020

Customer Name: - Solomon mekonnen.

Request No: - GLD/RN/094/20

Report No: - GLD/TR/133/20

Sample type: - coal

Sample Preparation : - 60 Mesh

Date Submitted: - 27/01/2020

Number of Sample: Eight (8)

Elements to be determined: (Moisture, Volatile matter, Fixed carbon and Ash), Calorie.

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

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.
MS-MR	9.57	27.69	46.03	16.70	5588.33
Mp-MR	14.11	33.41	34.28	18.21	4961.87
MS+MP-MR	11.01	28.71	42.98	17.30	5473.15
CMP-PWd	6.39	42.48	42.72	8.41	5902.40
CMS-PWd	6.14	30.45	52.26	11.16	6189.77
Adms-S	1.74	74.46	19.66	4.14	4560.91
Admp-s	4.04	70.73	19.19	6.04	4046.08
EL-ER	8.12	23.14	56.07	12.67	6065.93

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

Analysts

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Approved By

Alemnesh Abate

Quality Control

Negash Worku

Geological Survey of Ethiopia Central Geological Laboratory

Annex 7.2 Letter that support mango potential estimation.

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አሶሳ

The Benishangul Gumuz Regional State Agriculture and Natural Resource Bureau

Assosa

ቁጥር: Ref. No- ለ/፲፬/226

ቀን: Date:- 03/04/2012

ለተማሪ ሶሎሞን መኮንን

<u>ባሉበት</u>

ጉዳዩ፡- <u>የማንጎ ምርትን መረጃ ስለመስጠት ይሆናል</u>

ከላይ በርዕሱ ለመጥቀስ እንደተሞከረዉ በሀዋሳ ዩኒቨርሲቲ በወንዶ ገነት ደንና ተፈጥሮ ሀበት ኮሌጅ በሁለተኛ ድግሪ ትምህርታቸዉ እየተከታተሉ መሆኑን ገልፆ ለምርምር ፁሁፍ ስራቸዉ የሚያገለግላቸዉን የአምስት ዓመት የማንጎ ምርት መረጃ እንድሰጣቸዉ በደብዳቤ ቁጥር 2088/1.23/12 በቀን 26/02/2012 ዓ.ም የጠየቁ መሆኑን ይታወቃል፡፡

ስለሆነም በጠየቁት መሰረት የክልላችን የአምስት ዓመት የማንጎ ምርት መረጃ ከዚህ በታች በሰጠረገዡ በመግለፅ የሰጠናችዉ መሆኑን እናሳዉቃለን፡፡

ከሰላምታ ጋር

ሺባባው ታ/[illegible] ማሂ
Shibabaw T[illegible] Mahi

የሰብል ልማትና ጥበቃ ቴክኖሎጂ ማስ/ዳይሬክቶሬት ዳይሬክተር
Crop Pro/& Protection
Technology Promotion
Directorate Director

ቤ/ጉ/ክ/መ ግብርናና ተፈጥሮ ሀብት ቢሮ
The B/G/R/S Agriculture [illegible] Natural Resource B[illegible]

Email: - _______ መልስሲጽፉልንየእኛንቁጥርይጥቀሱ ☏Tel-251-057-775-01-50Fax 251-057-775-07-26In Replying Please Quote our Rf.No.