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COLLEGE OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

ANALYSIS OF EMISSIONS AND ENERGY CONTENT OF COCONUT HUSK

THIS DISSERTATION IS BEING SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, KNUST IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BSC. (HONS) DEGREE IN AGRICULTURAL ENGINEERING

BY

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DECLARATION

"I solemnly declare that I have wholly undertaken the study reported herein under the supervision of Prof. Ebenezer Mensah and Dr. George Yaw Obeng, and except portions where references have been duly cited, this dissertation is the outcome of my research".

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ABSTRACT

Waste management has always been a huge challenge to Ghana. Waste creates filth and pollutes the environment, breeds infections and facilitates disasters such as flooding. Coconut husk waste is no exception of this situation, as it blocks waterways, creates mosquito breeding sites to cause malaria and becomes nuisance to the environment. Waste coconut husk can be recycled or reused in order to reduce its adverse effects on man and the environment. In this study, 50 coconuts (25 local coconut varieties and 25 hybrid coconut varieties) were purchased form a coconut seller who obtains his nuts from Jomoro District in the Western Region where coconuts are grown on large scale. The coconuts were weighed, dehusked, biocharred and the energy content and emissions were determined using the bomb calorimeter and the Indoor Air Pollution (IAP) meter respectively. The weight of waste obtained after dehusking was calculated on percentage basis to know the percentage of parts that constitute waste. The study results showed that the local variety had energy content of 11.54 MJ/kg while the hybrid variety had an energy content of 9.73 MJ/kg. The emissions values obtained from the local variety was 1078 ug/m^3 for $PM_{2.5}$ and 9.18 ppm for CO while the hybrid variety had 1208 ug/m^3 for $PM_{2.5}$ 10.6 ppm for CO. The results also indicated that 65.5% of the local coconut variety constitute waste while 62.5% of the hybrid constitute waste. From results obtained, it was concluded that the local variety had a higher energy content than the hybrid variety. The emissions values obtained from both varieties indicate that both varieties do not meet the WHO standards. The indication is that burning of waste coconut husk could be harmful to the users and the environment if burning is not done under controlled conditions. The results for percentage of parts that constitute waste implies that a greater amount of the coconut is made up of waste.

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ABBREVIATIONS

CFC – chlorofluorocarbon

CH_4 – Methane

CH_4 – Methane

C-lab - Cook stove testing and expertise laboratory

CO – Carbon monoxide

CO_2 – Carbon dioxide

NH_3 - Ammonia

EC – Energy Commission

EPA – Environmental Protection Agency

GIMP - Ghana Innovation Market Place

GIPC - Ghana Investment Promotion Centre

H_2O – water

HFCs – Hydrofluorocarbons

kJ/K – kilo Joule per Kelvin

LFG – Land Fill Gas

MC – Moisture content

MJ/kg - Mega Joule per kilogram

MPa – Mega pascal

N_20 - Nitrous oxide

NO_X – term for mono nitrogen oxides (NO and NO_2)

O_3 – Ozone

PAH_S – Polycyclic Aromatic Hydrocarbons

PFCs - Perfluorocarbons

$PM_{2.5}$ – Particulate Matter (of diameter less than 2.5 microns) ppm – Parts per million

SD card – Secure Digital card

SF6 - Sulphur hexafluoride

SO_2 – Sulphur dioxide

TCC - Technology Consultancy Centre

ug/m^3 – microgram per metre cube

UNCTAD - United Nations Conference on Trade and Development

UNEP - United Nations Environment Programme

VOC_S – Volatile Organic Compounds

WHO – World Health Organization.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Coconut, scientifically known as *Cocos nucifera* is a perennial fruit that thrives well on sandy soils and mostly in the tropical locations of about 92 countries worldwide. As of 2011, United Nations Conference on Trade and Development (UNCTAD) (2012), recorded a total production data of coconut as 23 million tonnes per year worldwide. Ghana Investment Promotion Centre (GIPC) (2016) reports that coconut cultivation in Ghana is mostly done on small scale. The small scale farming of coconut contributes to about 80% of the total annual production of coconut; that is 179 million nuts out of 224 million nuts.

Every part of the coconut plant is useful (Mamlouk and Zaniewski, 2006). The industrial applications of coconut husk are realized in various sectors such as renewable engineering for energy, soap making and raw materials supplies, wood carving industry for making dolls and wall hangings, construction industry for making roofs and improving health. Furthermore, it is employed in the textile industry for making fibres for clothing and bags.

The fruit is very much appreciated for its juice and food with the husk regarded as waste. This is because there has not been any firm decision on what the husk could be used for. Awareness on the usefulness of the coconut is not much known to Ghanaians, so there is insignificant development in such an area. Ofori-Nyarko (2000), reported that in Ghana, 78% of all the primary sources of energy consumption stems from fuelwood utilization. Also, 80% of households in Ghana depend on fuelwood as a source of energy for cooking and water heating (Energy Commission, 2012). Due to the continuous rise of fuel prices, many either stick or resort to firewood as a source of energy. Even with this condition, as the common wood species become more expensive or scarce, people divert to any fuelwood without considering its effect to the environment when burnt.

1.2 Problem Statement

Coconut husk management attracts very little or no attention in our society today. After the edible portions of the coconut fruit are consumed, the husks are thrown away or burnt. Improper disposal and burning of husks result in the creation of environmental problems such as air pollution and chocked (gutter) mosquito breeding sites that tend to cause cholera, malaria and fever. Local food vendors who use coconut husks as firewood are exposed to smoke which is unhealthy to their health. Coconut husk has become more of an environmental nuisance due to the difficulty in handling it as waste. Coconut sellers have to plead with food vendors to come for the waste and use it as firewood as a way of management. In view of that, payment is made for dumping it at the incinerator.

1.3 Justification

Coconut husk, which is considered waste in our society, will be of much benefit than harm if much attention is centered on the recycle or reuse of the waste. Due to deforestation and shortage of fuelwood in Ghana, there is the need to find an alternative source of energy to sustain the economy. Therefore, the need to investigate the amount of waste that could be obtained from coconut husk, energy content of the husk and levels of pollution during the biocharring process of the coconut husk. This would serve an energy production purpose and also keep our environment clean and healthy.

1.4 Main Objective

To determine the emissions and energy content of coconut husk.

1.5 Specific Objectives

The specific objectives of this project are:

1. To determine energy content of charred coconut husk.
2. To analyse emissions of charred coconut husk.
3. To determine the percentage of coconut parts that come out as waste.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Waste management

Waste management can be defined as the proper handling and storage of any material after it has lost its intended purpose. Waste can either be in the liquid state or solid state. Coconut husk can be considered as solid waste and for this reason, Ghana Innovation Marketplace (GIM) (2009) has defined solid waste as waste that is neither waste water discharges nor atmospheric emissions arising from domestic, commercial, industrial and institutional activities in an urban area.

Waste production has never been a challenge but its management has always been. According to the United Nations Environment Programme (UNEP) (2009), 2.02 billion tonnes of municipal solid waste was generated globally in 2006, following 37.3% increase within 2007 and 2011. Ghana generates about 3 million tonnes of solid waste annually (Otoo, 2013).

2.1.1 Coconut husk waste management

Solid waste management is the discipline associated with the control of the generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations, and that is also responsive to public attitudes (Puopiel, 2010). Coconut waste for that matter, created annually in cities and towns of southern Ghana is estimated to be about 200,000 to 300,000 metric tons ("Greening the Savannah Project ", 2012).

Coconut husk used to be well managed in Ghana, but has over the years seen a drastic decline. It used to be employed in the making of carpets but now little is seen about that. Due to its usefulness being lost in the system, no management practice is being attached to it.

After consuming the copra and juice, the husks are thrown away and they end up rotting in the field or are heaped to be burnt (Meyer, 2001). The coconut husks are littered all around street corners, walkways, backyards, or burnt in open space causing serious carbon pollution ("Greening the Savannah Project'', 2012).

Challenges facing coconut husk management in Ghana as a developing country is in perfect line with observation of Ogawa (2005) such as low collection coverages, irregular collection services, crude open dumping, burning without air and water pollution control. In addition to that, wrong coconut husk management issues in our society is a clear evidence of the views from Puopiel, (2010) that, proper waste collection and proper disposal of refuse are daunting issues facing Ghana.

2.1.2 Utilisation of waste

Crop waste management and utilisation in Ghana is beginning to see the light, in that farmers and consumers have come to the realisation that almost every by-product of every crop is useful in one way or the other.

Coconut husk could be effectively managed and utilised by feeding our local manufacturing industries for the fabrication of carpet, egg crates, crop manure and compost, detergents, yarns and ropes, and many more. This could be done simply by recycling the coconut husk. Furthermore, it could be reused by using them as firewood for domestic and commercial purposes. In the area of domestics, it could be used for boiling water, cooking and heating farm structures when the weather gets cold. In the area of commercial, it could be used to bake bread, prepare foods ("kenkey", "banku", "waakye", "kokonte", "tuo-zaafi" and many more) for sale.

Ayamga *et al*. (2015) identified the potential of residues from sorghum, maize, millet and groundnut residue in the Lawra-Nandom District of Ghana for energy purposes. Gertenbach and Dugmore (2004) also employed the accumulation of residues from crops to feed livestock, with innovative preference to ruminants.

Plate 2.1: Coconut husk for making carpet

Source: https://sites.google.com/a/illinois

Plate 2.2: Coconut husk used as mulch

Source: http://www.braidedroses.com

Plate 2.3: Egg crate made from coconut husk

Source: http://sweetdomesticity.com

Plate 2.4: Coconut husk used for yarns

Source: http://dignitycoconuts.com

2.1.3 Advantages and disadvantages of waste management

2.1.3.1 Advantages

- Reduce pollution.

  Waste management eliminates dirt from the environment thereby providing a refreshing air to breath, clean water to drink, and a tidy environment that tends to destroy the breeding homes of mosquitoes and other harmful microorganisms. It also reduces the incidence of greenhouse gas emissions into the environment (Srinivas, 2015).

- Reduce energy consumption associated with the manufacture of new materials.

  Much energy is saved from the manufacture of new products in that, the waste could be channelled through reuse or little amount of energy factored for changing them into other products (http://www.branz.co.nz/).

- Production of new materials or products.

  When waste is properly managed, new materials or products are formed from it. The cost of these new items are reduced by combining several waste products and few additives or by simply changing the form of the original item and remoulded to form something new.

- Reduces global environmental threats.

  Managing waste is a sure way of offsetting the emissions of greenhouse gases such as CO_2 and CFCs which in turn shall reduce the effect of global warming. Reuse and recycling are fine management practices for achieving this aim.

- Use of organic waste to create compost.

  Proper waste management could be seen in the making of organic waste and compost to feed plants to facilitate growth and development. Compost also gives the soil a fine temperature as well as serving as a barrier to soil erosion.

- Health benefits.

  Removing waste from public areas helps reduce risks to overall health. It reduces exposure to biohazards and reduces infestation of microorganisms. Also, it destroys breeding habitats of harmful organisms.

- Source of raw materials for industries.

  Waste when properly managed could be used to feed our local industries for the manufacture of goods from arts to clothing, and kitchen ware to agricultural inputs. It could also be used to fuel boilers and other huge equipment for production purposes.

- Source of employment.

  Waste management embraces vast job opportunities for a country. There are so many hands needed on deck as far as waste management is concerned. In addition, it is a lucrative area since waste is created every moment.

2.1.3.2 Disadvantages

- Managing waste can present hazards to nearby residents or workers through air pollution, and creating breeding sites for bacteria, viruses and other harmful microorganisms to cause diseases or infections. (Kukreja, 2015).
- Managing waste can sometimes be costly. This is because much capital is being invested in the collection, transport and processing to form the new safe products they are expected to be (Kukreja, 2015).
- Srinivas (2015) points out that managing waste poses another side of nuisance to the people living close to such sites. This is due to the fact that, just the sight of gathering waste is very displeasing and hard to stay by. Also, the whole process emits bad smell into the atmosphere.

- According to Ogunjimi (2015), due to the hazards posed at waste management facilities, many rules and regulations are being set to control movements and activities there. This brings so much restrictions and uneasiness to workers, not making workers work comfortably.
- Srinivas (2015) is of another view that waste management is tedious and requires much time and energy investment. It mostly involves sorting out or re-sorting even after the products have been accumulated through initial sorting. It also requires high energy requirement to attain whatever state one expects the waste to be, and takes a longer time too.

2.2 Biomass and bioenergy

2.2.1 Biomass

Food and Agriculture Organization (FAO) (2012) defined biomass as non-fossil material of biological origin, such as energy crops, agricultural and forestry wastes and by-products, manure or microbial biomass.

Biomass resources include wood and wood wastes, agricultural crops and their by-products, municipal solid waste, animal wastes, wastes from food processing, aquatic plants and algae (Milbrandt, 2009). Generally, biomass is composed mainly of cellulose, hemicellulose, lignin, and small amounts of extractives with variations occurring in the amount of biomass in crop residues due to factors such as variety, age of residue or stage of harvest, physical composition, length of storage, and harvesting practices (Duku *et al*., 2011). According to Duku *et al*. (2011), biomass conversion technologies tested in Ghana are chemical transformation, biochemical conversion (anaerobic digestion) and thermal conversion processes.

Biomass is an energy source, and as such is the major energy source in Ghana contributing about 64% of Ghana's primary energy supply from products including agricultural crop residues such as coconut (Duku *et al*., 2011). Biomass resource utilisation brings advantages such as soil erosion control, waste management, offsetting GHG emissions (Duku *et al*., 2011). Research has proven that using coconut husks can reduce diesel fuel consumption by 62% (Tooy *et al*., 2014).

Ablordeppey (2015) reports that Mr. Joesph Akowuah gave estimates of about 2700 cubic metres of biomass available in Ghana that could yield the production of over 110 megawatts (MW) of power across the country. According to Ablordeppey (2015), the researcher claims that using about 60% biomass available across the country could help generate about 67 MW of power, using small plants that can process a tonne of biomass each.

When biomass is heated or burnt in a closed chamber with limited or no amount of air, it is known as biochar. Biochar production is much like charcoal making which is one of the oldest industrial technologies. A biochar product is also referred to as a charred product. Biochar production is a sure way for mitigating climate change, producing energy, managing waste and applying as a soil amendment (Lehmann and Joseph, 2009).

2.2.2 Bioenergy

According to FAO, (2012) bioenergy refers to renewable energy produced from biomass; which is organic material such as trees, plants (including crops), and waste materials (examples: wood waste from mills, municipal wastes, manure, landfill gas (LFG), and methane from waste water treatment facilities). FAO (2012) is also of the view that bioenergy is energy derived from fuels produced directly or indirectly from biomass such as fuelwood, charcoal, bioethanol, biodiesel, biogas (methane).

State Bioenergy Primer (2009), prepared a report stating that bioenergy is gradually attaining recognition as an alternative for energy due to volatile fossil fuel prices, issues pertaining national energy stability, effects of conventional energy use on the environment, and global climate. Again, FA0 (2012) explains that bioenergy accounted for roughly 10% of the world total primary energy supply in 2009, in which most of this is consumed in developing countries by close to 3 billion people who depend on biomass (wood, charcoal, crop residue and animal waste). Gülzow (2015) reported that these 3 billion people use the biomass for activities such as cooking, which also accounts for 80% of total primary energy supply in some developing countries.

Portner *et al*. (2009) is of the view that, bioenergy utilisation for electricity will serve a massive populace of Africans specifically leaving in rural areas. Again, a study found out that coconut husks have advantages for producing small scale electricity through gasification technology (Tooy *et al*., 2014). However, Dasappa (2011) specifies sub-Saharan Africa as a potential site for electricity especially through agro-residue and the (EC-Ghana, 2006) approves of this fact for Ghana and even for other energy purposes. In addition, Balogun and Liu, (2012) also identified biomass production for energy in Nigeria more specifically for the rural environs.

The International Energy Agency (IEA) (2007) admits that bioenergy projects are environmentally friendly in that they operate with zero or no greenhouse gas emissions, nevertheless, policy makers should understand the biomass resource base, its measurement, constraints from land use and water uptake, nutrient recycling and replacement and its effects on a sustainable basis.

2.3 Emissions and greenhouse effect

2.3.1 Emissions

This section seeks to unravel the mystery of gases emitted by crop residues on the event of burning. Satyendra *et al*. (2013) concluded that, open burning of crop residue significantly increases the level of particulate matter and gaseous pollutants such as $S0_2$, NOx, VOCs, and PAHs in the atmosphere. Stockwell *et al*. (2014) also identified the same gases as Satyendra *et al*. (2013) did, and added that ammonia (NH_3) is also part of these pollutants.

Miller *et al*. (2008) concluded that crop residues could emit N_20 (nitrous oxide) gases and as well act as a denitrifier even to crops on being incorporated into the soil. Crop residue incorporation into the soil is a major source of reducing global warming through the reduction of carbon dioxide, in that when residue is incorporated into the soil, it acts as a sink for carbon on decomposition, mitigating the emission of carbon dioxide to cause harm to the atmosphere (Lal, 2005).

2.3.1.1 Particulate matter (PM) concentrations

Particulate matter is a combination of fine solids and aerosols that are suspended in the air we breathe or individual particles that cluster to form the smoke. This is a major pollutant that is very dangerous to man and environment. There are two main types, thus PM of 1.0 (smaller than the width of a single human hair) and 2.5. The values are representations of the diameter of the constituent particles measured in microns. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water (WHO, 2016). Air quality measurements for PM can be recorded on minutes, hourly, daily, monthly or annual mean basis with units as ug/m^3. Health issues arising from exposure to these gases are cardiovascular and respiratory diseases when chronic and, headaches and fatigue for short period exposure (https://airnow.gov/index.cfm?action=aqi_brochure.index). According to WHO (2014), ambient air pollution killed 3.7 million people specifically belonging to low and middle income nations, which accounts for about 82% of the world population in 2012, while indoor air pollution killed 4.3 million with such attributed to household air pollution caused by cooking and heating their homes with biomass fuel.

2.3.1.2 Carbon monoxide (CO) concentration

Carbon monoxide is an odorless, colorless gas that is formed when the carbon in fuels do not completely burn. Apart from contributing to global warming, it also causes respiratory disorder and lung diseases, disrupts mental alertness and vision (https://airnow.gov/index.cfm?). CO concentration is measured in parts per million (ppm) and can be also be recorded on minutes, hourly, daily, monthly or annual basis.

2.3.2 Greenhouse gas

According to FAO, (2015), greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, the atmosphere itself, and by clouds. The primary greenhouse gases in the earth's atmosphere are water vapour (H_20) carbon dioxide ($C0_2$), nitrous oxide (N_20), methane (CH_4) and ozone (0_3).

On the global front, with reference to the Kyoto protocol, the six main greenhouse gases are: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_20), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF6) (https://en.wikipedia.org/wiki/).

Lal (2005), deduced a relation to greenhouse gas intensity as the ratio of greenhouse gases emitted (carbon equivalent) per real gross domestic product. As global warming is perfectly related to greenhouse gas effect and can never be without climate change, Conway of National Aeronautics and Space Administration (NASA) (2008) helps by defining global warming as the increase in Earth's average surface temperature due to rising levels of greenhouse gases", while climate change is "a long-term change in the Earth's climate, or of a region on Earth.

2.4 Energy content

2.4.1 Energy content of coconut

Energy content of coconut husk simply expresses the quantum of potential energy contained in the coconut husk. Energy content of a substance can be described as calorific value or heat capacity.

2.4.1.1 Calorific value (heating value) of coconut

Calorific value is the amount of energy produced as a result of the complete combustion of a material or fuel. Energy values for coconut husk relating to its moisture content, approximate ash content and lower heating value (FAO, 2000) are represented in Table 2.1.

Table 2.1: Energy values of coconut husk

Moisture content (% dry basis)	5-10
Approximate ash content (%)	6
Lower heating value (MJ/kg)	16.7

Source: FAO, (2000).

Heating values of coconut husk are the amount of thermal energy stored within the coconut husk that can be measured through heating. According to Yokoyama (2008), heating values of coconut residues with respect to coconut shell, charcoal and husk charcoal are represented in table 2.2.

Table 2.2: Heating values of coconut residues

Type of coconut residue	Heating value, MJ/kg
Coconut shell	0.018
Coconut shell charcoal	27
COCONUT husk charcoal	26

Source: Yokoyama (2008).

Energy content for selected parts of the coconut fruit are represented in Table 3

Table 2.3: Energy content for selected parts of the coconut fruit

Biofuel	Energy content (MJ/kg)
Charcoal	30
Coconut husks	10
Coconut shells	18

Source: (http://www.engineeringtoolbox.com/biofuel-energy).

Raghavan (2010), stated that coconut husk has an energy content of 16.7 MJ/kg. Knowledge on energy content allows one to know the energy potential of a crop residue.

2.4.1.2 Heat capacity

Heat capacity is the ratio of the heat added to or removed from a material to the resulting temperature change. Also, it can be described as the amount of energy needed to raise the temperature of a substance by 1˚C.

2.5 COMPOSITION OF COCONUT

Coconut is botanically a drupe from the family *Arecaceae* and can naturally be propagated by seeds. The main agents of dispersal of coconut are animals (man) and water (sea, rivers and others). Domestic varieties include Vanuatu Tall, Sri-Lankan Green Dwarf, Malayan Yellow Dwarf, Equatorial Green Dwarf and West Africa Tall. Apart from West Africa Tall being a pure breed, the others are hybrids.

2.5.1 Physical properties

The coconut fruit is made up of 35%wt husk, 28%wt copra, 12%wt shell, 5%wt milk and 20%wt water (Bradley and Huang, 2006). This implies that the edible part of the coconut fruit is made up of the copra and water, forming 53%wt of the coconut fruit with specific composition as 33%wt as copra (original copra weight and milk weight) and 20%wt as juice. The non-edible part of the coconut fruit is also made up of the husk and shell summing up to 47%wt of the whole coconut fruit, specifically as 35%wt husk and 17%wt shell.

One third of the coconut fruit's make-up is the husk which envelops the hard shell structure of about 3.5 mm thickness (Ganiron, 2013). The external appearance of the husk varies from decidedly dull brown when fully ripe to bright green when immature. There are other varieties of coconut whose husks are either golden yellow or yellow brown. The husk is full of long, coarse fibers, all running in one direction.

2.5.2 Coconut husk

The transverse section of the coconut fruit showing the various parts is represented in Plate 2.5. A coconut husk is made up of the outermost layer (exocarp) and the inner layer (endocarp) that wraps the fruit. The husk is composed of 70%wt pith, a lignin which behaves like phenolic resin and 30%wt fibre, also made from lignin but with a fibrous morphology (Snijder, 2005). The phenolic resin exhibits good properties of an adhesive. The husk also contains cellulose, pyroligneous acid, gas, charcoal, tar, tannin and potassium. The chemicals contained in the coconut husk and its uses are represented in (Table 2.4).

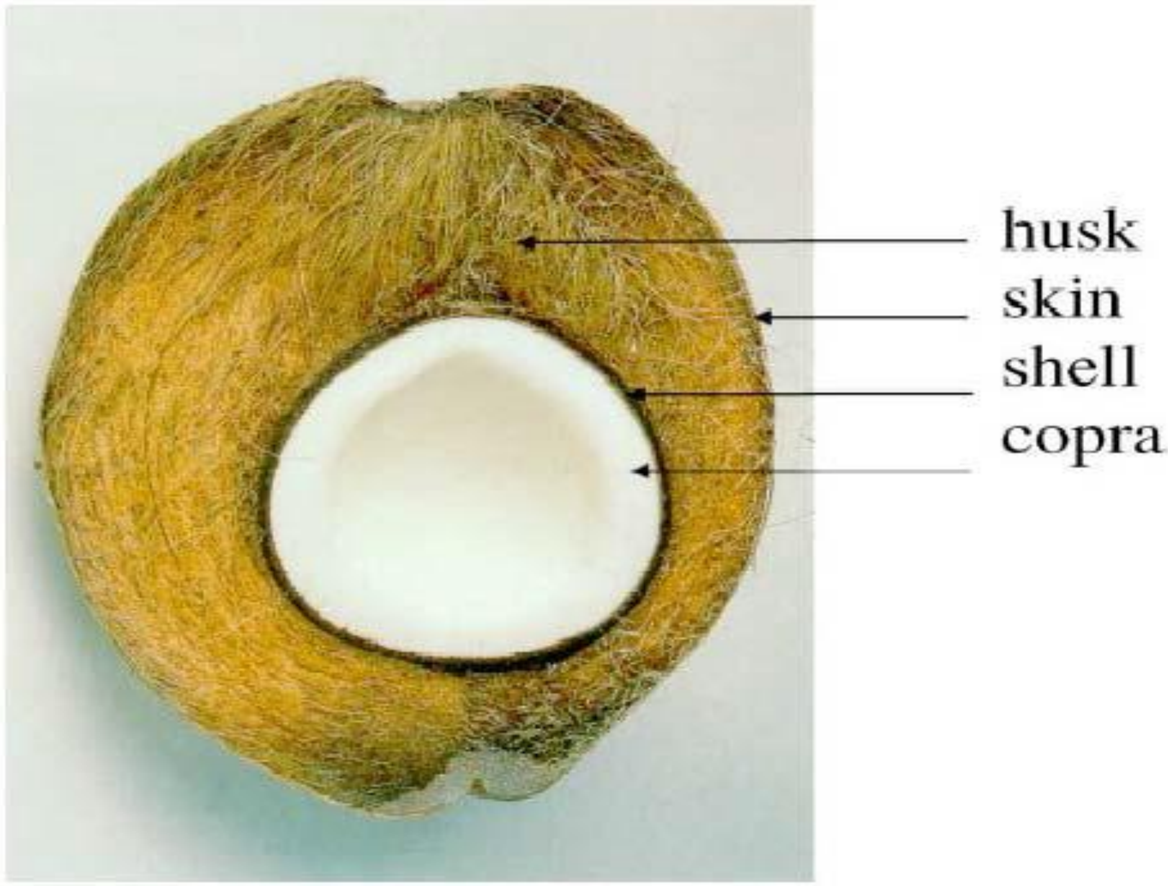

Plate 2.5: Transverse section of coconut fruit
Source: Bradley and Huang, (2006).

Table 2.4: Uses of the chemical properties of coconut husk

Chemical	Uses
Tar	Sealing agent on wood surfaces
Phenolic resin	Adhesive
Tannin	Adhesive
Charcoal	Fuel

2.5.3 Coconut fibre

The coconut fibre is of a thread-like pattern found in the coconut husk. The 30%wt fibre consists mainly of lignin and cellulose. Lignin is responsible for the stiffness of the coir and the cellulose is a water soluble element that absorbs water about ten times its weight in water.

2.5.4 Coconut shell

The coconut shell is the hardest layer of the fruit that houses the copra and juice. According to (Hasanah *et al*., 2012), the coconut shell is also made up of hemicellulose, cellulose and lignin. It is twice as hard as hardwood and has a high-energy density.

2.5.5 Copra

The copra is composed of 50%wt of water, 33%wt of coconut oil and 17%wt of white meal (Bradley and Huang, 2006). The water contains nutritious elements of low fats and high levels of electrolytes for rehydration. The iodine and cetane number of coconut oil puts it on top of options as the best choice for bio-diesel (Diaz, n.d.). The iodine number denotes how finely it will burn in a diesel engine with few particle emissions, while the cetane number denotes how well it will burn at higher temperatures and pressures. The copra also serves as feed for humans and some animals such as pigs and poultry.

2.5.6 Uses of coconut and its husk

To the pregnant woman, 7% of the content of the juice that contains calcium helps in bone formation in the foetus and about 95 g of water which help prevent dehydration. It also contains 7% of magnesium that prevent hypomagnesia that is usually experienced during pregnancy and 7% of sodium that help retain water inorder to prevent dehydration (http://ndba.nal.usda.gov/).

In as much as the copra supplies food to man, it also contains oil that is used for cooking, beauty make up (dressing the hair, skin moisturizer), and making biodiesel. This same oil is used as pest resistant in crop storage structures by smearing it on wood to repell pests away from a crop. Coconut oil is also used to generate electricity especially on small scales (Raghavan, 2010).

Before the 20^{th} century, the coconut husk was widely utilised for the making of thatched roofs, ropes and yarns, door mats, sacks, menial aesthetic constructions and mulching plants. In this 21^{st} century, the uses of coconut are more evident in the fabrication of car seat covers, stuffed chairs, and fibres for clothing to replace polyester fibres. In addition, coconut husk is now employed in the conversion to fuel which is used to power cars, control soil erosion and flood, fertilisers and as aquarium filter. This clearly shows that the utilisation of coconut husk has gained more improvement in these present days than the past.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site, collection of coconuts.

The experiment was conducted at the Cook Stove Testing and Expertise Laboratory (C-LAB, KNUST) and Food Science laboratory which are under the auspices of Technology Consultancy Centre (TCC, KNUST). Coconuts were purchased from a dealer who obtains his coconuts from Jomoro District; one of the 22 districts in the Western Region, located in the south western part of the country. In this study, the pure breed is tagged as local coconut variety while the mixed breed is tagged as hybrid coconut variety.

3.2 Weighing whole fruit

The first step was to weigh all the 25 nuts one by one, and variety by variety. This was done by using an electronic balance and the data was recorded as whole weight for all the 25 nuts. This was done to determine the unit weight for a coconut according to its variety.

3.3 Dehusking

The husk of the coconut was removed from the shell using a cutlass. This was done in direct relation to any coconut initially weighed so that the respective values could tally. Values for this step was recorded as husk weight.

3.4 Weighing the shell and fruit

In order to weigh the shell, the copra and juice were separated from the shell. The shell was weighed separately and recorded as shell weight. The weight of the fruit (juice and copra) was obtained by finding the difference between the whole weight and husk weight. Thereafter, the percentage of parts that constitute waste was computed as;

$$\text{Percentage of waste} = \frac{\text{sum of waste weight}}{\text{total weight}} \times 100\%$$

3.5 Drying

Two main drying methods were employed in this experiment; sun-drying and oven-drying method. Coconut wastes collected from coconut vendors were dried for 6 consecutive times on a 3-day interval. This was done to analyse the behaviour of coconut waste when burnt by local vendors since they treat it as such. The coconut husk was reduced to a moisture content of 8% which is within the moisture content range of fuelwood. This was also set up to analyse the behaviour of coconut husk when treated as wood. For oven drying method, the husk was subjected to 110˚C for 16 hours to reduce its MC to 8%.

Plate 3.1: Field measurement of moisture content using the wood moisture meter.

Plate 3.2: Picture showing dehusking of coconut.

3.6 Charring

The charring experiment was carried out at the Food Processing unit of TCC. The charring unit is metallic drum of dimensions 57cm by 85cm. It has a tunnel attached to the lid as vent. Holes are perforated beneath the container to allow limited entry of oxygen. Under a summer hut, brick stones were mounted to act as stands for the charring unit and also to allow limited amount of oxygen to get to the chamber area. The container part of the charring unit was then mounted unto stones then loaded with the coconut husk ready to be charred. The first part of the experiment was conducted for coconut waste collected from coconut sellers. 5kg each of every sample was weighed and prepared to be charred. When the burning begun and wild fire was observed, the lid was fitted unto the container to stop further entrance of oxygen as well as providing a channel for the smoke to escape. Temperature of the container was recorded at regular intervals of time using an infrared thermometer. The nature of the smoke was observed while the experiment was on-going. The second part of the experiment was conducted using coconut husk of moisture content 8%. The charring test for the reduced moisture content sample was repeated for three times.

3.7 Determination of emissions

The indoor air pollution meter was used for this analysis. Before the experiment begun, the device was opened for about fifteen minutes to allow the device to get accustomed to the local temperature since the carbon monoxide signal is very sensitive to temperature. A slow mode sampling rate was selected due to the duration of the experiment. Thereafter, the meter was turned on for an hour to activate the system. After this, the device was hang at the background or at the charring site for at least ten minutes in order to differentiate between the addition of indoor air pollution and the present ambient. Time at which this was done was recorded. When charring began, few minutes were allowed to elapse to allow the burning to start up well and devoid unnecessary smoke, before timing as “test begins”. After charring, the meter was turned off and time was recorded as “test ends”. There was an SD card that stored the data on the meter. This data was then processed on a computer using software programs such as Terreterm and Livegraph for connecting the meter directly to the computer and plotting graph on the data respectively.

3.8 Energy content determination

The bomb calorimeter was used for analysing the energy content of the coconut husk. The crucible was placed on the weighing pan of the analytical balance to measure and tare its weight. Using the prongs, one gram of the sample was fetched onto the crucible in the analytical balance, then the crucible was placed onto the crucible support of oxygen bomb. Both ends of the firing wire were connected to two electrode rods of oxygen bomb by bending them in a circular manner for firm contact. Thereafter, the oxygen bomb core was moved into the oxygen bomb cylinder that had been filled with 10ml of distilled water earlier on. After that, the oxygen bomb cover was closed tight. Next, the oxygen bomb was filled with oxygen to about 2.8 to 3.0 MPa of pressure. The oxygen bomb was immersed into a bucket of water to determine the presence of leakage. Being satisfied of the outcome, the oxygen bomb was placed inside the bomb calorimeter and closed, then the system automatically begun the test. After about 10mins when the test was completed, the sample had been completely combusted with values of the heat capacity and calorific displayed on the screen of the desktop. The calorimeter was opened to take the sample out. In doing this, oxygen was released using a release valve and then, the crucible taken out, washed in distilled water and cleaned with the bomb towel. This test was also conducted three times, then an average for the heat capacity or calorific value computed.

Plate 3.3: Picture showing researcher winding wires over electrodes on the oxygen bomb of the bomb calorimeter.

Plate 3.4: Sectional view of the C- lab, KNUST.

Plate 3.5: Picture showing the nature of smoke produced after drying coconut waste for 15 days

Plate 3.6: Picture showing the nature of smoke produced after drying coconut waste for 3 days

Plate 3.7: Picture showing initial charring process

Plate 3.8: Picture showing researcher making observations and taking records of time

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 Energy Content of Charred Coconut Husk

Calorific value and heat capacity of charred coconut husk of local and hybrid varieties are represented in Table 4.1. The hybrid variety of coconut had an average heat capacity of 17.68 kJ/K while the local coconut variety had an average of 11.80 kJ/K. For calorific value, the local coconut variety had an average value of 11.54 MJ/kg while the hybrid coconut variety had an average of 9.73 MJ/kg.

Table 4.1: Heat capacity and calorific value of local and hybrid variety of coconut

Coconut Variety	Average Heat Capacity (kJ/K)	Average Calorific Value (MJ/kg)
Local	11.80	11.54
Hybrid	17.68	9.73

The local coconut variety had a higher calorific value compared to the hybrid variety. This implies that at the end of a combustion process, the local coconut variety would produce a higher amount of energy (11.54 MJ/kg) than the hybrid coconut variety (9.73 MJ/kg). The hybrid variety had a higher heat capacity as compared to the local variety. This implies that the hybrid coconut variety would require a higher amount of energy (17.68 kJ/kg) to cause a 1˚C rise in temperature than the local coconut variety (11.80 kJ/K) when subjected to combustion.

The calorific values obtained; 11.54 MJ/kg (local variety) and 9.73 MJ/kg (hybrid variety) differ from Raghavan (2010) recorded calorific value (16.7 MJ/kg) for coconut husk. The difference in these values can be attributed to variations in geographical locations, biotechnology make-up of fruits, weather restrictions, soil nature, as well as experimental site conditions.

In determining the amount of energy from a given mass of coconut, for a waste of 1.46 kg obtained from a local coconut variety, an energy content of (mass × calorific value) = 1.46 × 11.54 = 16.85 MJ would be generated. Whereas, for a waste of 1.12 kg obtained from a hybrid coconut variety, an energy content of (mass × calorific value) = 1.12 × 9.73 = 10.90 MJ would be generated. This again clearly shows that the local variety would yield a better amount of energy than the hybrid variety.

Furthermore, according to Ofori-Agyeman, (2016), the maximum and minimum averages of coconut consumed daily in Kumasi (Ghana) are 134 and 86 respectively. If a local coconut variety weighs 2.23 kg, a total weight for 86 coconuts would yield 191.78 kg. If 50.22% of the coconut consist of the husk, then the amount of husk from the 86 coconuts will be 96.3 kg. From this, the amount of energy that can be produced daily will be 1,111.3 MJ, 33,339 MJ monthly, and 400,069 MJ annually only from Kumasi.

A minimum of 86 coconuts was chosen for the analysis because predictions are best done on minimum conditions. Also, the energy content of the local breed was chosen because people prefer consuming the local variety to the hybrid variety due to its weight and copra content.

4.2 Emissions from charred coconut husk

Analysis of emissions obtained from the study after sun-drying the coconut waste are represented in Tables 4.2 and 4.3. The hybrid coconut variety recorded higher average values of 1208 ug/m^3 for PM concentration and 10.6 ppm for CO concentration, as compared to local coconut variety, with 1078 ug/m^3 for PM concentration and 9.18 ppm for CO concentration.

Table 4.2: Particulate matter and Carbon monoxide concentrations of hybrid coconut variety.

TIME (days)	PM (ug/m^3)	CO (ppm)
3 days	1425	12.1
6 days	996	10.8
9 days	994	8.1
12 days	1300	11.1
15 days	1223	10.4
18 days	1313	11.1
	AVERAGE = 1208	**AVERAGE = 10.6**

Table 4.3: Particulate matter and Carbon monoxide concentrations of local coconut variety.

TIME (days)	PM (ug/m^3)	CO (ppm)
3	1169	9.9
6	937	7.9
9	1390	11.9
12	933	7.8
15	975	8.5
18	1066	9.1
	AVERAGE = 1078	**AVERAGE = 9.18**

PM and CO concentrations obtained from both varieties are represented in Figures 4.1 and 4.2 respectively. PM and CO concentrations of the hybrid variety was between 994 and 1425 ug/m^3 and 12.1 and 8.1 ppm respectively. The local coconut variety's PM and CO concentrations was between 933 and 1169 ug/m^3 and 11.9 and 7.8 ppm respectively.

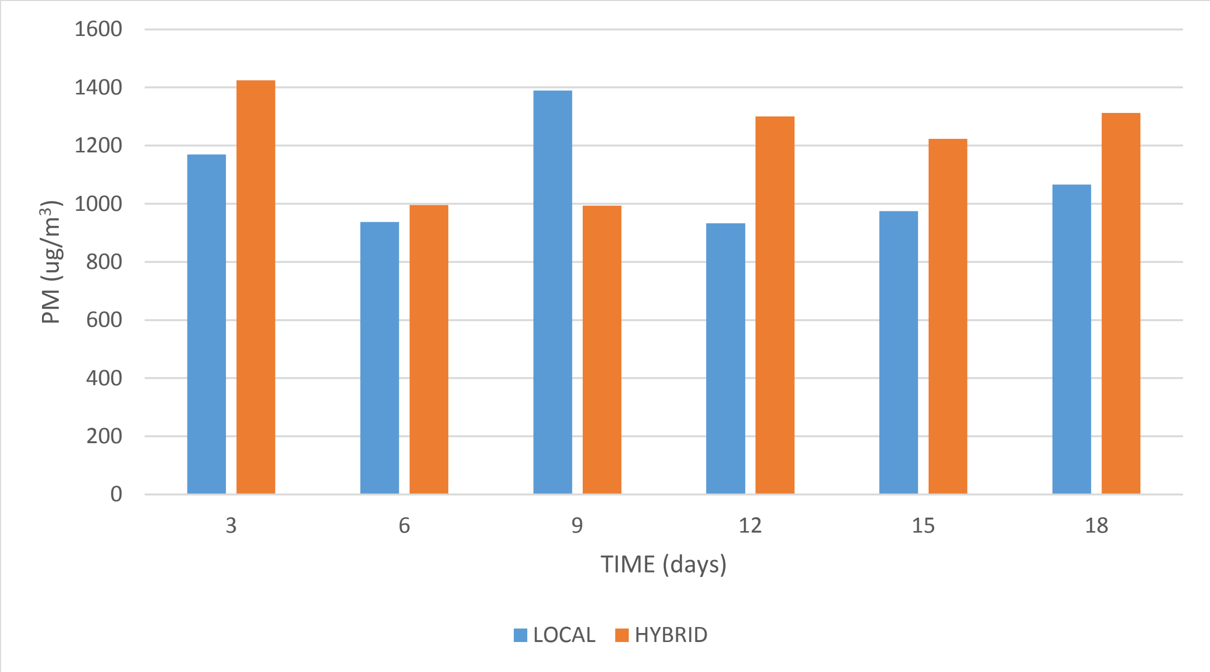

Figure 4.1: Particulate matter concentration of local and hybrid varieties

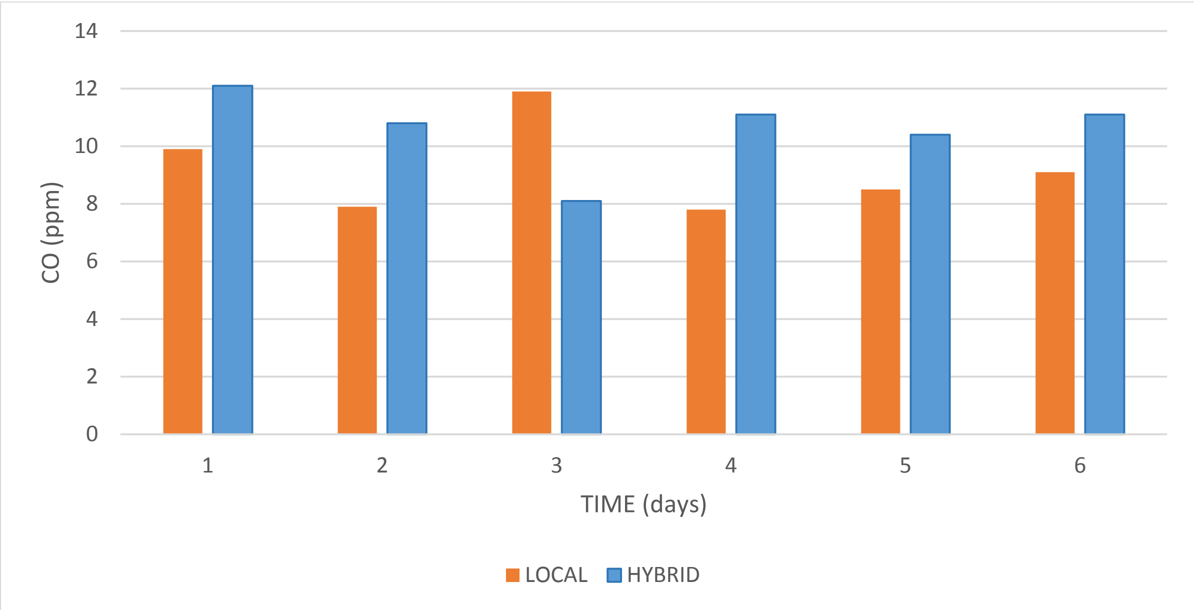

Figure 4.2: Carbon monoxide concentration for local and hybrid varieties

The hybrid coconut variety recorded its highest peak for PM concentration as 1425 ug/m^3 on day 3, while the local coconut variety recorded its highest PM concentration as 1390 ug/m^3 on day 9. The highest CO concentration of the hybrid variety was recorded on day 3 as 12.1 ppm, while the highest CO concentration of the local coconut variety was recorded on day 9 as 11.9 ppm.

$PM_{2.5}$ and CO were specifically chosen for this study due to the effects these emissions pose to man and the environment. Comparing values accumulated from the study to WHO standards, it was realized that values obtained from the experiment were beyond the set limits, hence harmful to man and the environment. Emissions produced after oven-drying method was also harmful because they had values similar to that of the sun-drying method. This means that people who use coconut husks as firewood are under the risks of the effects from PM and CO emissions.

From the study, it was realized that as the number of days for drying increased, the moisture content of coconut waste decreased. It was also realized that as the moisture content decreased, the rate of combustion also increased. This was evident in the type of smoke produced during the charring process and the temperatures recorded during the charring process. Coconut waste with high moisture content produced thick smoke while those with lower moisture content produced less thick smoke. The rate of combustion can be associated with its moisture content.

The PM and CO concentrations did not reduce as the days for the experiment increased. This is due to the changes in ambient temperature, relative humidity and wind directions. However, these variations could be due to conditions of soil that these varieties were grown from, as confirmed by Simoneit *et al*. (2000) that 'emissions from a combustion of any biomass depend directly on the chemical composition of the biomass and combustion conditions'. This is due to the fact that, the coconuts used for the experiment were not coconuts grown from a particular piece of land, rather from different places and by different farmers though all from the Western Region.

4.3 Percentage of parts that result as waste

Average weights of husk, shell and fruit from 25 samples of both coconut varieties is represented in table 4.2. The hybrid variety (1.05kg) represents 66.67% waste whereas, the local variety (1.46kg) represents 65.47% waste. The hybrid variety has a higher percentage waste than the local variety.

Table 4.4: Weight of parts of local and hybrid varieties

VARIETY	Average weight of husk per coconut (kg)	Average weight of shell per coconut (kg)	Average weight of coconut fruit per coconut (kg)
Local	1.12	0.34	0..77
Hybrid	0.80	0.25	0.63

Based on the percentage of parts that results as waste, the local coconut variety (65.47%) is higher than the hybrid coconut variety (62.50%) as indicated in Figures 4.3 and 4.4. This also means that the amount of waste generated from the local variety is heavier than that generated from the hybrid variety.

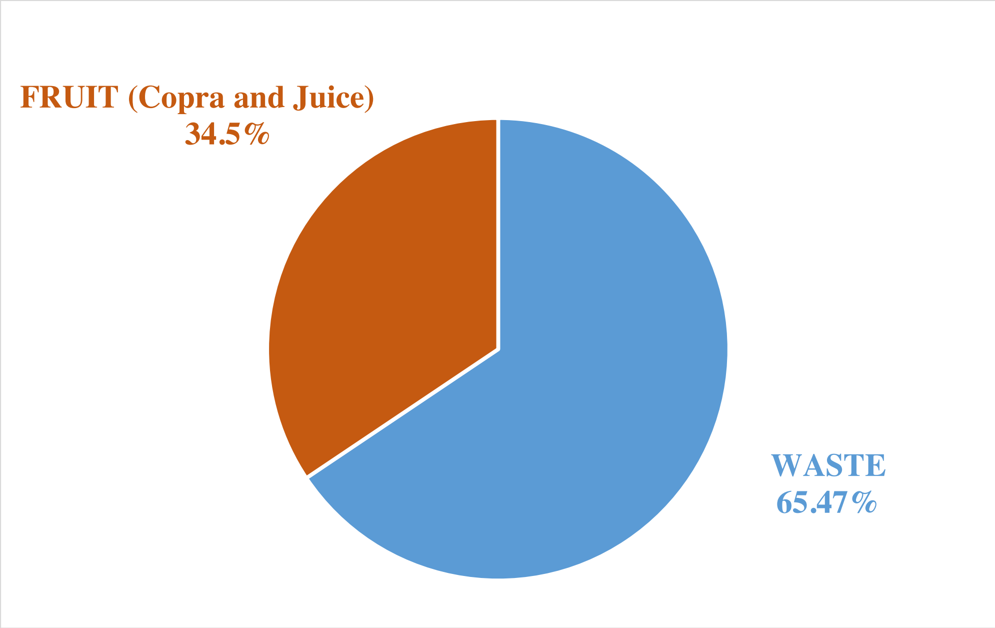

Figure 4.3: Percentage weight composition of waste for local coconut variety.

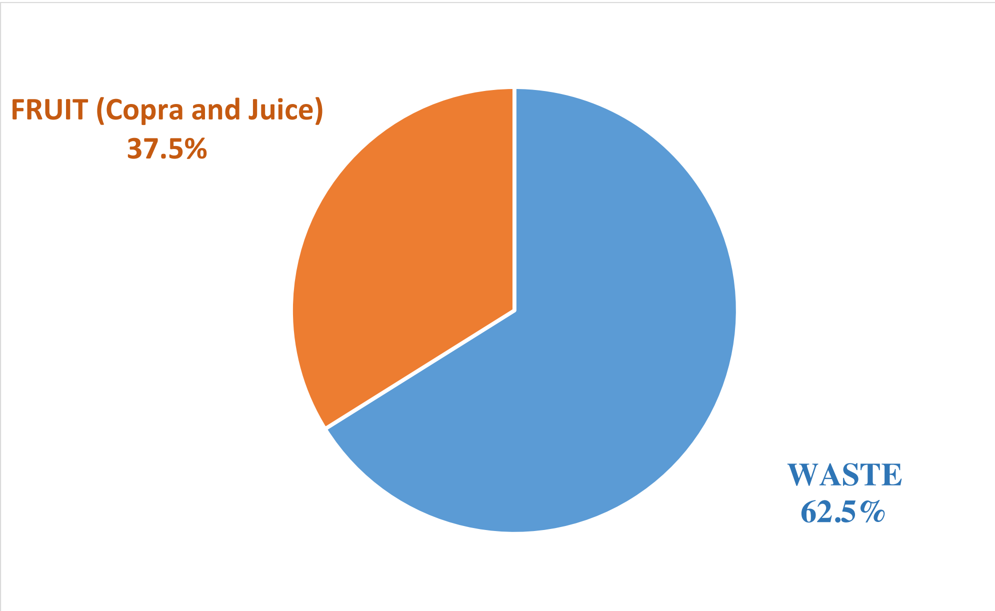

Figure 4.4: Percentage weight composition of waste for hybrid coconut variety.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study sought to determine energy content, emissions and percentage of coconut parts that constituted waste. From the study, the following conclusions were drawn:

- The local coconut variety had a calorific value of 11.54 MJ/kg while the hybrid coconut variety had a calorific value of 9.73 MJ/kg. This means that with an energy content of 11.54 MJ/kg, the local coconut variety would generate greater amount of heat than the hybrid coconut variety which had an energy content of 9.73 MJ/kg.

- Emissions generated from both coconut varieties were beyond the air quality limits. This means that emissions are toxic to man and the environment; thus causing respiratory disorders to man and contributing to global warming.

- The percentage of parts that resulted as waste for the local coconut variety was 65.47% while that for hybrid coconut variety was 62.50%. This implies that a greater proportion of the parts of coconut is waste.

5.2 Recommendations

The following recommendations arose out of the study:

1. Coconut husk could be an alternative to wood due to its energy content which is comparable to wood.

2. A well designed and efficient charring unit should be used for charring that would intend help reduce emissions during the charring process.

3. Due to the greater amount of coconut parts (husk and shell) being waste, it could be a useful biomass for energy, useful raw material for industrial purposes and soil amendments in farming.

4. People who use coconut husk as fuelwood should burn in the open to lessen the effect of emissions on their health.

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APPENDICES

APPENDIX 1

Energy Content of Coconut Husk

Appendix 1 A1

Heat capacity

Table 1A1: Heat capacity of local variety

Readings	Mass (kg)	HEAT CAPACITY (J/K)
1	1.000	12346.89
2	1.000	11918.75
3	1.000	11121.47

AVERAGE HEAT CAPACITY = 11.80 kJ/K

Appendix 1 A2

Table 1A2: Heat capacity of hybrid variety

READINGS	MASS (kg)	HEAT CAPACITY (J/K)
1	1.000	18719.37
2	1.000	21022.58
3	1.000	13289.28

AVERAGE HEAT CAPACITY = 17.68 kJ/K

Appendix 1 B

Calorific value

Appendix 1B1

Table 1B1: Calorific value of local variety

READINGS	MASS (kg)	CALORIFIC VALUE (J/kg)
1	1.000	12815
2	1.000	10174
3	1.000	11628

AVERAGE CALORIFIC VALUE = 11.54 MJ/kg

Appendix 1 B2

Table 1B2: Calorific value of hybrid variety

READINGS	MASS (kg)	CALORIFIC VALUE (J/kg)
1	1.000	9394
2	1.000	9762
3	1.000	10044

AVERAGE CALORIFIC VALUE = 9.73 MJ/kg

Appendix 2

EMISSIONS

Appendix 2A1

Table 2 A1: Moisture content of local coconut variety

DAYS (time)	MOISTURE CONTENT (%)
FRESH	71.2
3 DAYS	36.4
6 DAYS	26.1
9 DAYS	21.7
12 DAYS	16.8
15 DAYS	13.7
18 DAYS	10.3

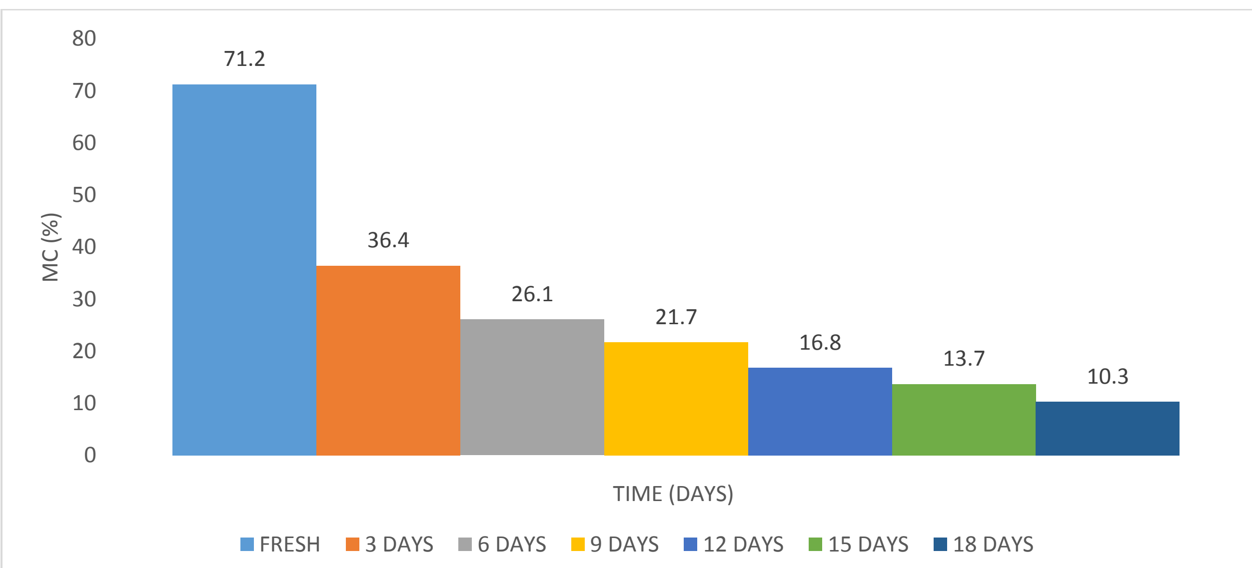

Figure 2A1: Moisture content of local coconut variety for 18 days

Appendix 2 A2

Table 2A2: Moisture content of hybrid coconut variety

DAYS	MC
FRESH	68.3
3 DAYS	32.2
6 DAYS	24.5
9 DAYS	20.8
12 DAYS	17.1
15 DAYS	14.5
18 DAYS	11.9

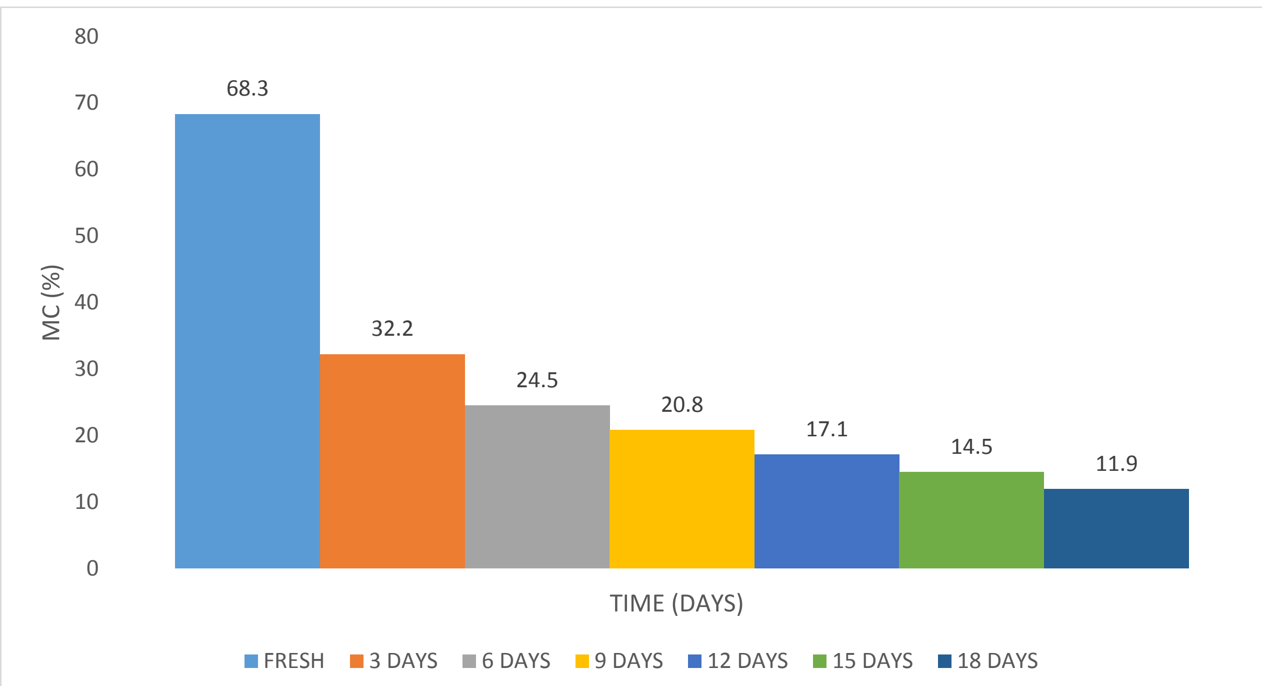

Figure 2A2: Moisture content of hybrid coconut variety for 18 days.

Appendix 2B1

Table 2B1: Temperature produced during the charring of hybrid coconut variety.

DAYS (time)	TEMPERATURE (˚C)
3	74.2
6	126.4
9	131.8
12	146.3
15	235.8
18	390.4

Table 2B2: Temperature produced during the charring of local coconut variety.

DAYS (time)	TEMPERATURE (˚C)
3	102.3
6	136.4
9	189.2
12	240.1
15	365.7
18	406.8

APPENDIX 2 C1

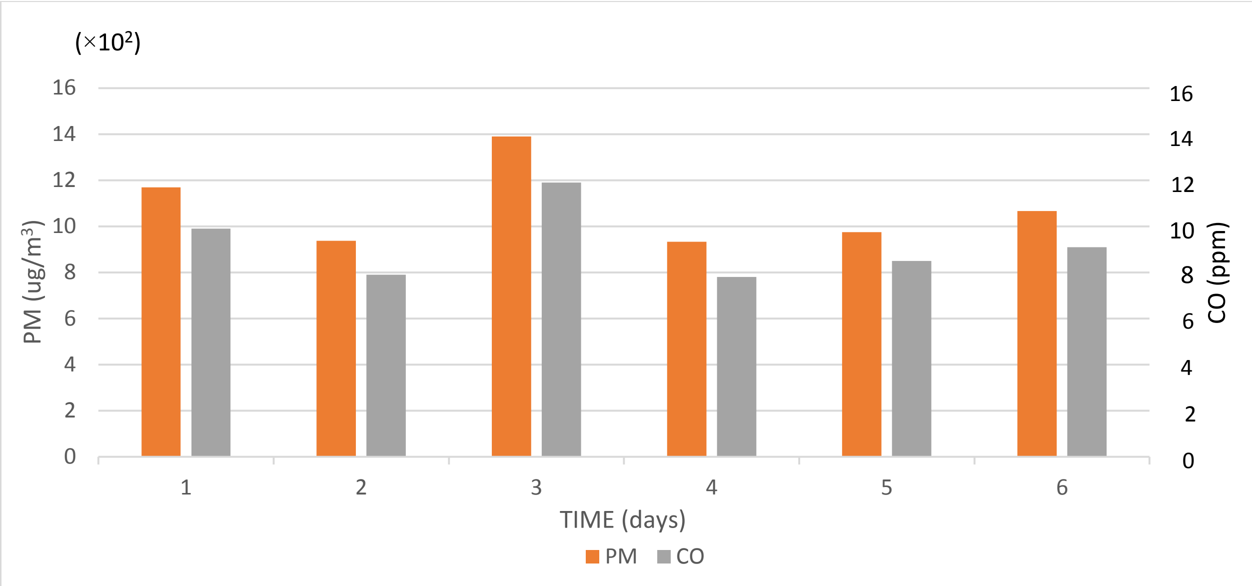

Figure 2C1: Particulate Matter and Carbon monoxide concentrations of local coconut variety

APPENDIX 2C2

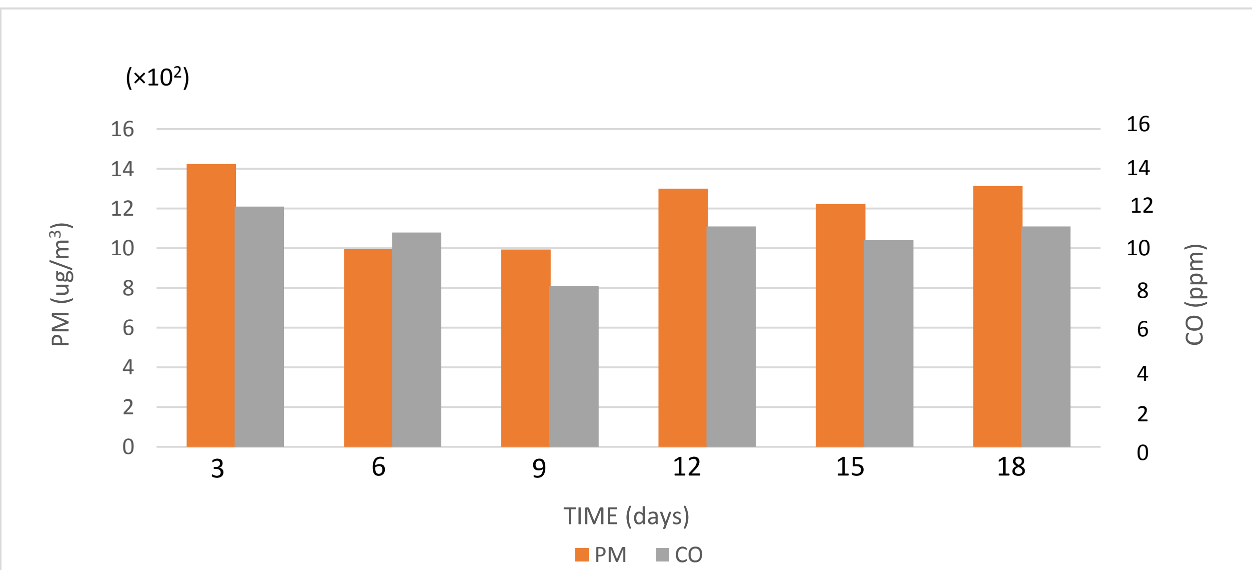

Figure 2C2: Particulate Matter and Carbon monoxide concentrations of hybrid coconut variety.

Table 2D1: WHO standards for particulate matter (2.5) and carbon monoxide concentrations.

POLLUTANT	STANDARD
$PM_{2.5}$	35 ug/m^3
CO	7 ppm

Source: http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf

APPENDIX 3

PERCENTAGE OF PARTS THAT END UP AS WASTE

APPENDIX 3A1

Table 3A1: Weights of parts of local coconut variety

SAMPLES	WHOLE WEIGHT (kg)	HUSK WEIGHT (kg)	SHELL WEIGHT (kg)	WEIGHT OF FRUIT (kg)
s1	3.529	2.079	0.5646	0.8854
s2	1.843	0.887	0.4264	0.5296
s3	1.68	1.0825	0.252	0.3455
s4	2.086	0.844	0.3338	0.9082
s5	1.6445	0.791	0.3025	0.551
s6	2.5385	1.319	0.4062	0.8133
s7	1.6735	0.7035	0.3681	0.6019
s8	2.3005	1.2915	0.2991	0.7099
s9	2.6295	1.41	0.4207	0.7988
s10	2.0265	1.0685	0.2765	0.6815
s11	1.6505	0.7365	0.2533	0.6607
s12	3.2805	1.464	0.2641	1.5524
s13	1.7665	1.048	0.2473	0.4712
s14	2.417	1.353	0.3442	0.7198
s15	3.1525	1.4645	0.5044	1.1836
s16	1.844	0.8565	0.2305	0.757
s17	2.3125	1.0355	0.3468	0.9302
s18	2.176	1.142	0.3238	0.7102
s19	1.6815	0.6875	0.3155	0.6785
s20	1.9005	1.078	0.2523	0.5702
s21	2.259	1.2405	0.2851	0.7334
s22	1.5135	0.867	0.1968	0.4497
s23	2.8225	1.3105	0.4234	1.0886
s24	1.524	0.728	0.4092	0.3868
s25	3.446	1.448	0.5523	1.4457

APPENDIX 3A2

Table 3A2: Weights of parts of hybrid coconut variety

SAMPLES	WHOLE WEIGHT (kg)	HUSK WEIGHT (kg)	SHELL WEIGHT (kg)	WEIGHT OF FRUIT (kg)
s1	1.658	0.925	0.2314	0.5016
s2	1.5475	1.0085	0.2182	0.3208
s3	1.5585	0.893	0.2184	0.4471
s4	1.4395	0.7665	0.1943	0.4787
s5	1.8775	0.9005	0.2804	0.6966
s6	1.7935	0.892	0.2428	0.6587
s7	1.558	0.591	0.2187	0.7483
s8	1.805	0.873	0.2008	0.7312
s9	1.8785	0.7725	0.2205	0.8855
s10	2.0395	0.941	0.1263	0.9722
s11	1.689	0.964	0.278	0.447
s12	1.693	0.5975	0.2377	0.8578
s13	1.8175	0.75	0.254	0.8135
s14	1.8695	0.789	0.2398	0.8407
s15	1.9155	0.7844	0.2394	0.8917
s16	1.8005	0.6865	0.4435	0.6705
s17	1.4564	0.76	0.3178	0.3786
s18	1.4035	0.629	0.2246	0.5499
s19	1.2905	0.5725	0.1255	0.5925
s20	1.363	0.675	0.249	0.439
s21	1.43	0.6195	0.2885	0.522
s22	1.6305	0.744	0.3195	0.567
s23	1.617	0.884	0.125	0.608
s24	1.647	0.89	0.3991	0.3579
s25	2.1105	1.094	0.3345	0.682

APPENDIX 3B1

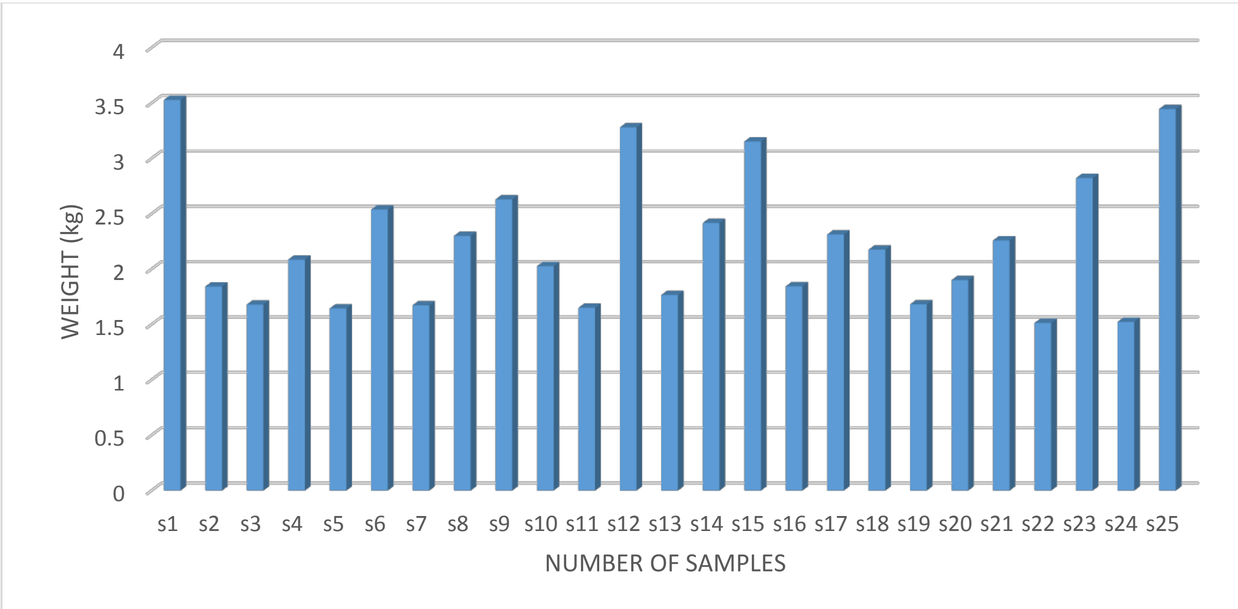

Figure 3B1: Whole weight of local coconut variety.

Appendix 3B2

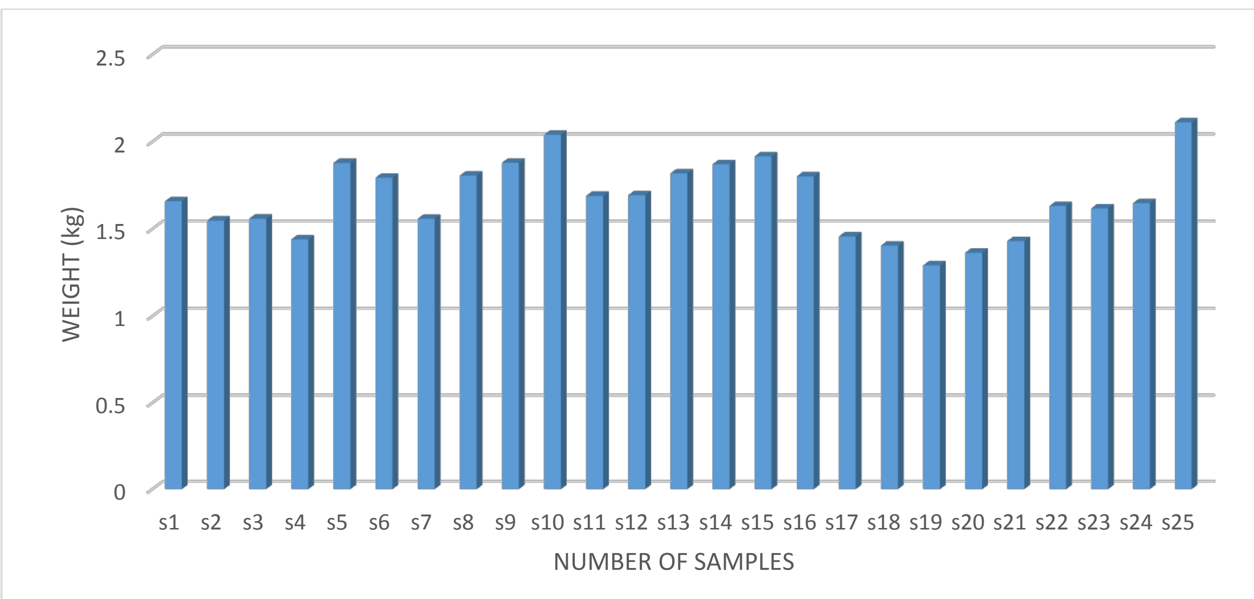

Figure 3B2: Whole weight of hybrid coconut variety.

Appendix 3C1

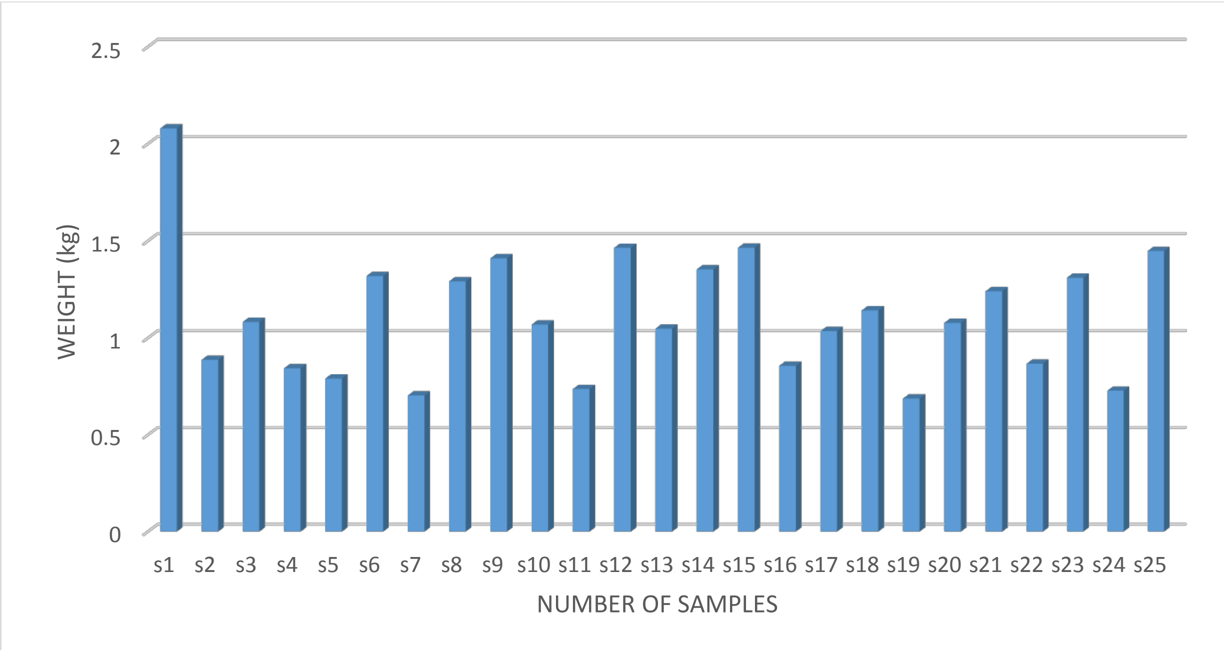

Figure 3C1: Husk weight for local coconut variety.

Appendix 32C

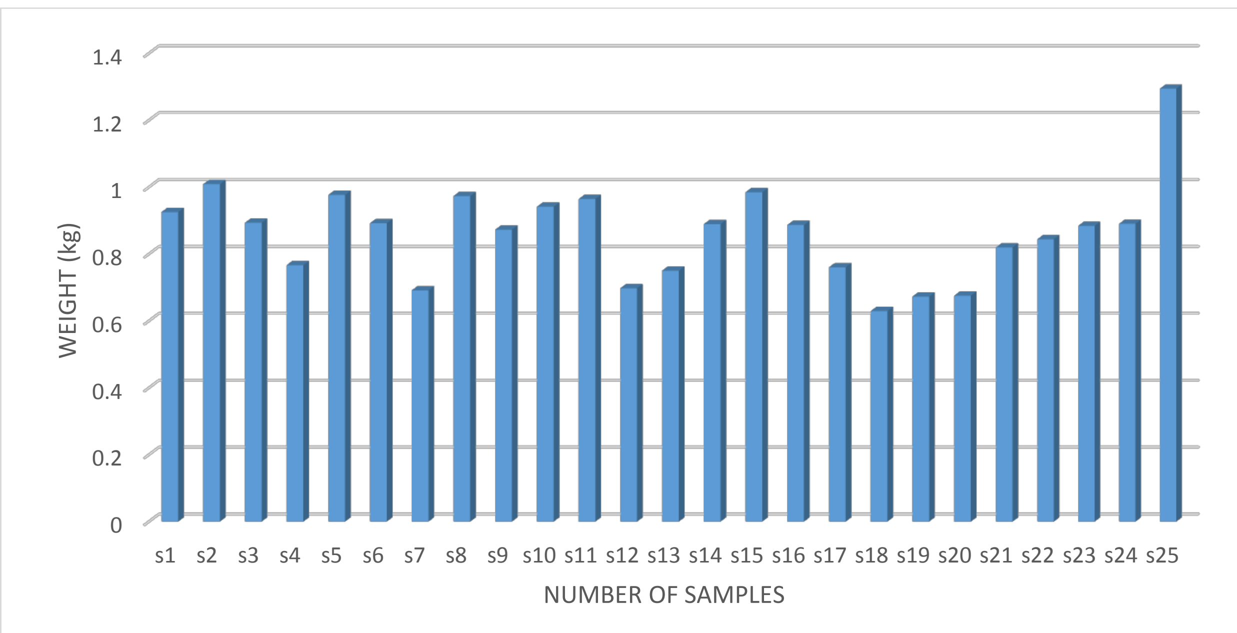

Figure 3C2: Husk weight of hybrid coconut variety.

Appendix 3D1

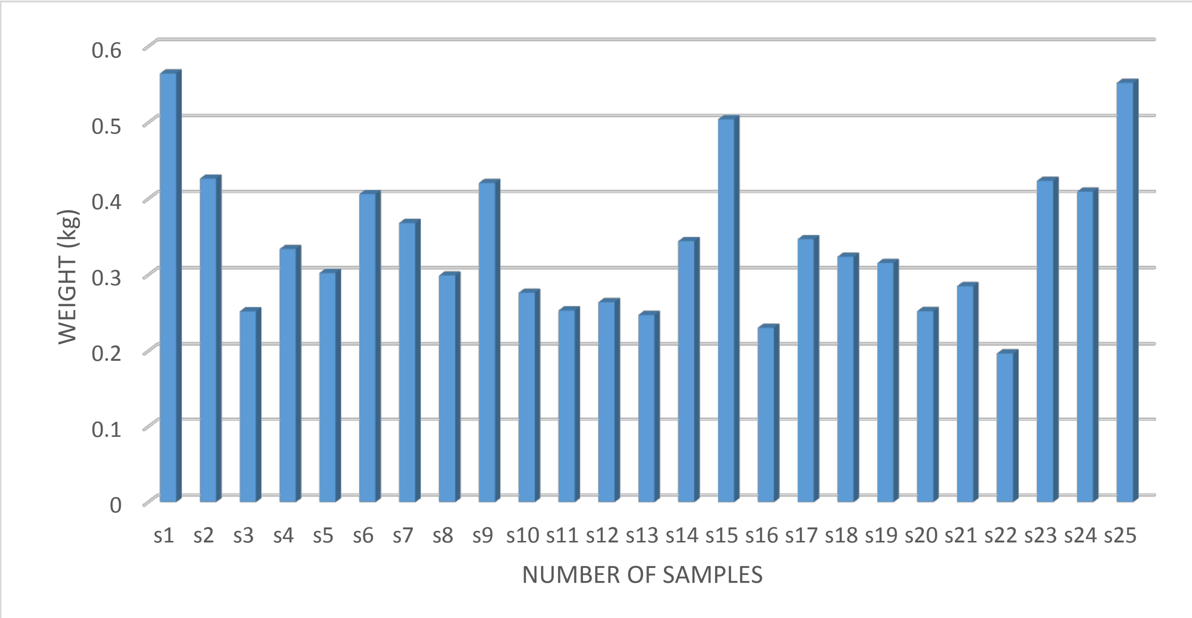

Figure 3D1: Shell weight of local coconut variety.

Appendix 3E1

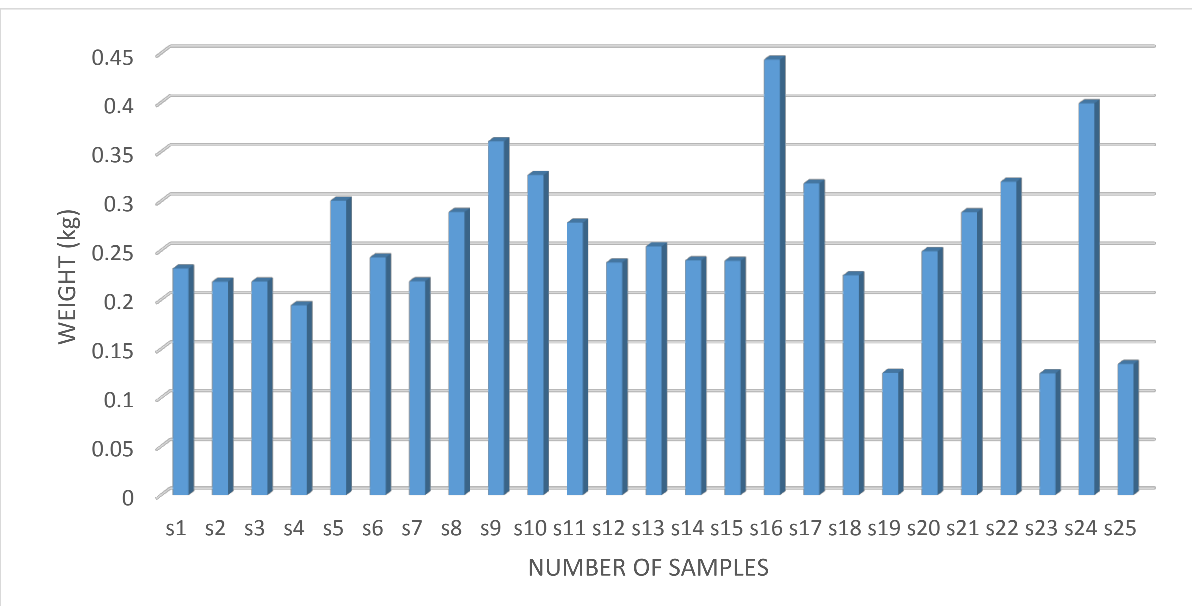

Figure 3E1: Shell weight of hybrid coconut variety.

Appendix 3F1

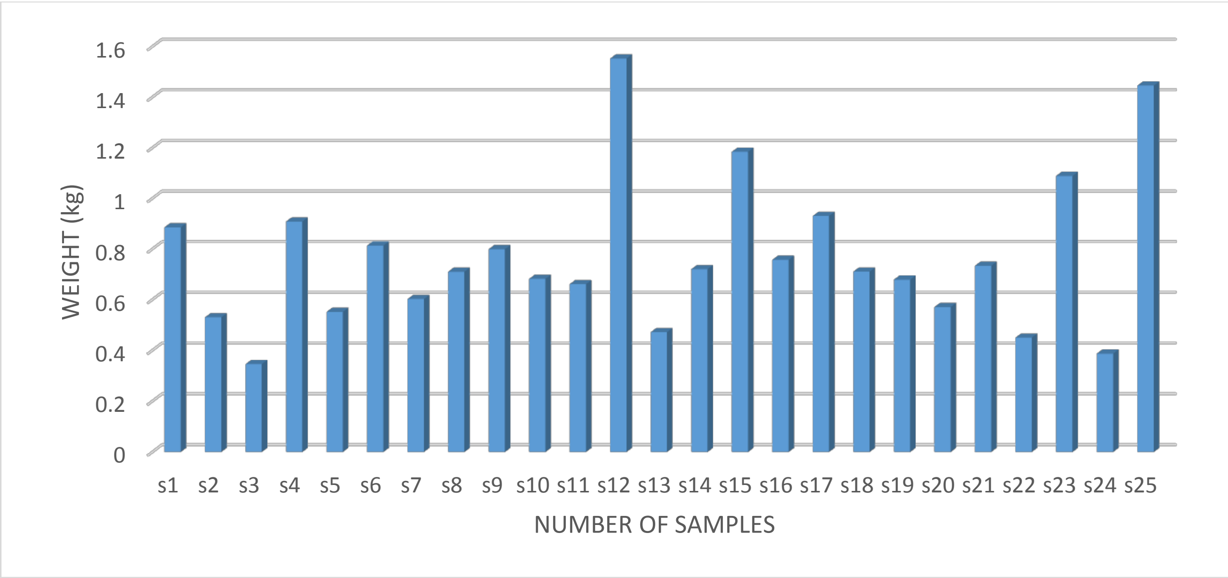

Figure 3F1: Fruit weight of local coconut variety.

Appendix 3F2

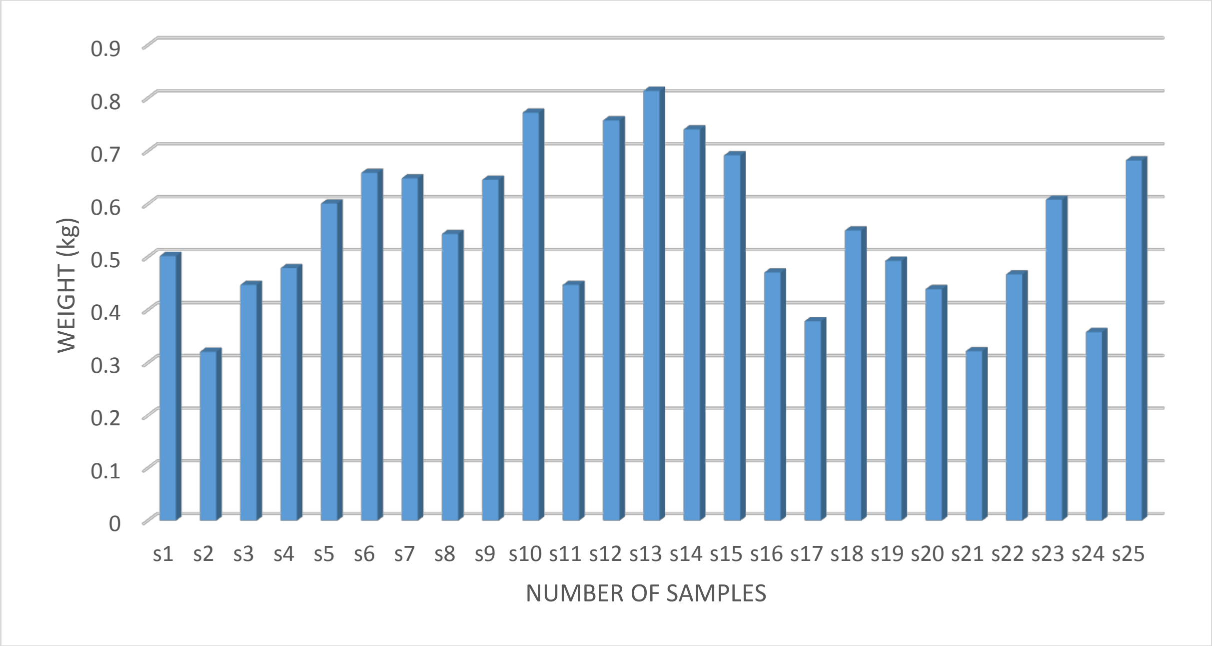

Figure 3F2: Fruit weight of hybrid coconut variety.