


# Investigation on post-harvest processing of fruits using a Solar-Bio-energy Hybrid Dryer

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Dissertation submitted in fulfilment of the requirements for the degree [Master of Science in Crop Science](#) at the North West University

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## **DEDICATION**

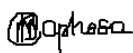
To my precious parents, Lovemore and Regina Maphosa; your love, prayers and support have been priceless to me. To my one and only brother Shay Maphosa; you are amazing.

## DECLARATION

I declare that this dissertation hereby submitted to the North-West University for the Master degree in Agriculture (Crop Science) is my own independent work and has not been previously submitted by me to another University. All sources that have been used or quoted have been correctly acknowledged by means of references.

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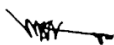
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## LIST OF ABBREVIATIONS

GDP	Gross Domestic Product
C/N	Carbon/Nitrogen ratio
MC	Moisture content
B1	Bio-energy reactor 1
B2	Bio-energy reactor 2
B3	Bio-energy reactor 3
B4	Bio-energy reactor 4
B5	Bio-energy reactor 5
AT	Ambient temperature
NA	Nutrient agar
pH	Potential Hydrogen
Min.	Minimum
Max.	Maximum
r	Pearson's correlation
N	Nitrogen
H	Hydrogen
C	Carbon
O	Oxygen
ANOVA	Analysis of variance
PDA	Potato Dextrose Agar
NA	Nutrient Agar
NWU	North-West University

## LIST OF PAPERS

The following papers were included in the study:

- i. Maphosa, B., Ramachela, K. and Mhundwa, R. (2019). 'Design and development of a solar fruit dryer', Paper presented at the 6<sup>th</sup> *Southern African Solar Energy Conference*. Eastern Cape province, South Africa.
- ii. Maphosa, B., Ramachela, K. and Mhundwa, R. (2019). 'Design and development of a hybrid bio-solar energy fruit dryer', "*Food Security and Safety: African Perspectives*". NWU. Submitted for review.

## ABSTRACT

Fruits and vegetables are key sources of vitamins and minerals that are essential for a healthy diet. They are, however highly perishable, shortening their shelf life. To address this, various processing technologies such as the traditional open sun drying have been explored. This practice, however, leaves the products vulnerable to dust contamination, rodent attack and non-uniform drying. Furthermore, it is an inconsistent process that is dependent on solar availability thereby extending the drying process. This inconsistent process promotes microbial contamination, remoistening of products and reduced quality of the products. It is on this basis that a solar-bio-energy hybrid powered fruit dryer was designed and developed. The aim of this technology is to enhance the drying process through continuous drying and increased drying rates using clean energy that is easily accessible to smallholder farmers. The hybrid fruit dryer consists of a solar collector, drying chamber and bio-reactor unit. Banana fruit and Kei apple were evaluated in this study to make dried banana discs and Kei apple and banana fruit leather. The banana fruit was pretreated in lemon juice and dried in the hybrid dryer. To make the fruit leather, Kei apple was blended with banana fruit and honey then the paste was dried in the hybrid drier. The control experiment was traditional open sun drying. The ambient temperature range was between 15-38°C and the temperatures of the solar-bio-energy hybrid dryer air reached above 80°C. Air temperatures and drying rates were negatively correlated with  $r = -0.66$ , whereas relative humidity and drying rates were strongly positively correlated with  $r = 0.90$ . The solar-bio-energy hybrid dryer had a higher drying rate and efficiency compared to open sun drying and to drying the fruit without the bio reactor unit. It was also capable of drying the fruit beyond sunshine hours. The availability of this technology to rural communities would contribute to food security at household level by making processed fruits and vegetables available in-between cropping seasons. This is often referred to as hunger periods. Furthermore, this technology produces good quality value-added products that are marketable to a wider consumer catchment. It also has the potential to facilitate employment creation in rural areas and bio-entrepreneurship amongst women and the youth through the production of high-quality value-added products.

**Keywords:** solar drying; agro-processing; bio-energy; dried fruit.

## CHAPTER ONE

### INTRODUCTION AND LITERATURE REVIEW

#### 1.1 Background of the study

South Africa has diverse weather and climatic conditions that enable the production of a wide variety of fruits and vegetables (Ntshagase, 2016). Consequently, it is ranked within the top ten (10) exporters of agricultural produce in the world (DAFF, 2015). Despite this, 153 million people in Sub-Saharan Africa, are reported to have suffered from severe food insecurity in the period 2014/2015 (FAO, 2017a). South Africa is not exempted from this as 30-40% of South African households do not have assured access to adequate diets, which consequently relates to the lack of physical availability of quality food in the rural areas (Maremera, 2014).

Unavailability of food is further exasperated by post-harvest losses, which often occur because of poor storage facilities (FAO, 2016). About one-third of all the food produced in the world is lost or wasted during post-harvest (FAO, 2014). In developing countries, up to 40% of total food is lost before it reaches the market due to a lack of adequate post-harvest storage and processing amongst other factors (FAO, 2016). These post-harvest losses are particularly prevalent in smallholder farmers, who often do not have the modern fresh produce storage facilities such as cold rooms.

Inaccessibility of high tech storage facilities has led to the local communities across Sub-Saharan Africa initiating and developing indigenous processing technologies. Indigenous post-harvest technologies are important for the rural communities in their strategy of reducing post-harvest losses and food insecurity. These strategies generally involve traditional drying and various other storage and preservation methods (Maponya and Mpandeli, 2015). Drying is highly significant as it has been used for decades as a preservation method that is cheap and convenient for farmers and household use (Hii *et al.*, 2012). Sun-drying has notably been the most common method but owing to factors such as difficulties in controlling of; temperatures, contamination and rate of drying, there have been efforts to improve this by designing better solar dryers (Hii *et al.*, 2012). Although solar dryers are relatively efficient, they have the limitation of providing inconsistent heat as they are subject to solar radiation which often varies as the weather changes. High-quality performance solar dryers are out of reach to small scale farmers as there are expensive and the auxiliary heat source such as diesel, petrol, gas, coal or electricity are equally out of reach due to high costs, in-availability or unreliability (Hii *et al.*, 2012).

In order to establish a continuous flow of energy that drives the solar drying process, it is necessary that a farm-based supplementary heat energy source such as compost heat be explored in order to

achieve an efficient and effective drying process. This is in line with the global shifting away from the use of fossil fuels towards the use of renewable energy in agricultural processes (Sims *et al.*, 2015). Compost is easily accessible to the small scale farmer and is thus suitable as a bridging heat energy supply for the solar dryer.

Composts have been known to generate heat energy and have been investigated for their use in heating glasshouses during cold periods and show potential for further uses in agriculture (Smith *et al.*, 2017). Compost heat is a result of complex metabolic processes where microorganisms generate heat through the use of oxygen, carbon and nitrogen to produce their own biomass (Román *et al.*, 2015). Based on these studies, it is considered that the use of compost heat to increase temperatures to optimum drying temperatures would improve the efficiency of the solar dryer. In this study, compost heat will also be referred to as bio-energy.

The drying of fruits can be described as the evaporation of moisture from the fruit and this is a result of simultaneous heat and mass transfer processes (Hii *et al.*, 2012). The heat transfer can be from conduction, convection or radiation or a combination of these processes (Tiwari, 2016). Before the fruit is dried, it goes through a preparative procedure where it is washed, sliced and pitted (if required) and then it may be pre-treated using methods such as blanching, sulphite dips or ascorbic acid dips (Hii *et al.*, 2012). After the preparative procedure, the fruit can then be dried. The drying process is stopped when the required moisture content is reached which should be between 10-20% (wet basis) (Patel, 2016). The dried fruit can then be further processed and or stored thereafter.

### **1.1.1 Problem statement**

Fruits such as banana and Kei apple are very important in human nutrition but due to their high respiratory rate and ethylene production, they cannot be naturally kept for long periods. The banana fruit is ranked in the top ten fruits globally however; its high perishability makes it vulnerable to post-harvest losses along the value chain. Post-harvest losses have been reported to reach up to 80% in some developing countries without storage facilities hence the use of dryers and other forms of equipment (Kitinoja and AlHassan, 2012, Abrol *et al.*, 2014). Solar dryers operate intermittently; they are restricted to use during the day only. At night, the product is vulnerable to microbial attack, texture changes, and non-uniform drying and decreased drying rates (Hii *et al.*, 2012). Consequently, there is a need for appropriate technology for small scale farmers that helps improve the keeping quality of dried fruit through the use of locally available energy such as solar energy and bio-energy. Furthermore, this technology would significantly reduce post-harvest losses as it allows overripe fruit to be used as fruit leather for value addition purposes.

### **1.1.2 Justification**

The study would contribute to improving the keeping quality of products by increasing drying rate, uniform texture, reduced overheating and contamination. The significance of this study would be to assist in the reduction of post-harvest losses and increase the shelf life of dried fruits. This study would also lead to increased bio-entrepreneurship projects in line with the National Development Plan to increase employment particularly in the Small to Medium Enterprise sector (SAICA, 2015). In addition, the bio-entrepreneurship projects would lead to increased food security and quality of life for the small scale farmers. It would also expand knowledge on further uses of bio-energy in agriculture beyond heating greenhouse tunnels and water as use of compost as a source of heat energy is still to be fully explored because a limited number of previous studies have investigated it (Nwanze and Clark, 2015; Zhao *et al.*, 2017). The available literature is often disjointed and there is little information on the biomass used to generate the heat recovery values. Furthermore, this study was significant as consumers now want products that retain more of their original characteristics after being dried. Various countries have enforced stringent quality regulations to protect consumers and avoid bioterrorism (Hii *et al.*, 2012). Other benefits of using bio-energy to supplement solar drying would include increased nutrition through a shortened drying period, marketability for export markets and time savings for small scale farmers.

Overall, the output of this study would benefit small scale farmers, agro-processors, renewable energy promoters and food-insecure households amongst other beneficiaries through the use of renewable energy to produce value-added products with an extended shelf, thereby reducing post-harvest losses and food insecurity.

### **1.1.3 Research questions**

- i. What is the effect of bridging solar dryers with bio-energy on the quality of the dried fruit?
- ii. What is the effect of bridging solar dryers with bio-energy on the drying efficiency of the system?
- iii. What is the drying rate of banana fruit and Kei apple and banana fruit leather dried using a solar - bio-energy hybrid dryer?
- iv. What is the optimum heat energy recovery phase of the compost for the post-harvesting processing of fruits?

### **1.1.4 Aim and objectives**

The aim of this study was:

- i. To develop a clean energy efficient and low cost dryer that is suitable for fruit processing for small scale farmers.

**The specific objectives included:**

- i. To compare the drying efficiency of the hybrid bio-energy dryer to open sun drying on fruits.
- ii. To analyze the drying rate of the fruits in a forced convection solar dryer connected in series with a bio-energy reactor.
- iii. To analyze the effect of processing on the nutritional content of the dried banana fruit and the Kei apple and banana fruit leather.
- iv. To determine the optimum heat energy recovery phase compost during the post-harvest processing of the fruit.

**1.1.5 Organization of dissertation**

The subsequent organization of the dissertation is as follows: Chapter 1 includes; the literature review of the study, the description of South African fruit and dried fruit production, review of the drying systems used by small scale farmers in South Africa, details of the drying process, review of dried fruit importance, properties, quality attributes and uses and bio-energy and its uses in agriculture. Chapter 2 presents the analysis of microbial diversity and its effect on temperature profiles in five selected bio-energy reactors. It includes a detailed description of the experimental layouts and procedures performed. In addition, the experimental facility which constitutes of laboratories and equipment, the instrumentation used for monitoring and analyzing data is presented. Chapter 3 presents the design of the bio-energy charged solar dryer as well as data collection and analysis which are clearly elaborated. Chapter 4 presents the sensory evaluation and nutritional components of dried bananas and Kei apple fruit rolls. Additionally, the procedures performed and the evaluation are explained in detail and analyzed. Chapter 5 is the overall discussion and recommendations.

**1.1.6 Delimitations**

This study was limited to small scale usage and may need further assessment to be suitable for large scale or industrial usage. The study used material that was cheap and locally available. In addition, this study was limited to banana and Kei apple fruits.

### **1.1.7 Limitations**

The researcher was limited to designing the equipment without physically seeing an existing hybrid solar dryer machine.

## **1.2 Literature review**

The Global population is anticipated to have a sharp increment in the next 30 years (FAO, 2017b). As a result, food insecurity can be expected to increase due to food unavailability and negative climate change effects on agriculture. This food insecurity could further be exasperated by post-harvest losses that are currently being experienced. It is reported that in developing countries, up to 40% of total food is lost before it reaches the market due to a lack of adequate post-harvest storage and processing technologies amongst other factors (FAO, 2016). These post-harvest losses are particularly prevalent in smallholder farmers who often do not have the modern fresh produce storage facilities such as cold rooms. As such, they are often resorting to the use of various indigenous post-harvest technologies as an effort to reduce the post-harvest losses and contribute to food security. In addition, these technologies have been acknowledged that they assist in improving the livelihoods and nutrition of smallholder farmers by making foods available between cropping seasons which is often referred to as “hunger periods” (IRENA, 2015).

### **1.2.1 Importance of fruits and vegetables in human diets**

Fruits and vegetables are important sources of micronutrients and various other beneficial nutrients such as vitamins and proteins (Slavin and Lloyd, 2012). The elements that are found in fruits are an important integral part of a healthy human diet. Furthermore, the beneficial medicinal properties of fruits and vegetables have been closely linked to decreased risks to chronic diseases including obesity, high blood pressure, coronary heart disease and some cancers (Oguntibeju *et al.*, 2013). A vast body of research has been carried out on the diet and nutrition aspects of fruits and vegetables (Bhupathiraju *et al.*, 2013; Conklin *et al.*, 2014; Miller *et al.*, 2016; Van Lin *et al.*, 2018). Significance of their phytochemical or antioxidant properties has been established (Anbudhasan *et al.*, 2014). Antioxidants assist in the prevention or the delay of cell damage (Yadav *et al.*, 2016). Furthermore, antioxidants obtained in foods such as fresh fruits have been noted to be more effective than those obtained from chemical processing (Anbudhasan *et al.*, 2014). Fruits can be consumed in a wide variety of forms including fresh fruit, fruit juices and dried fruit.

Although the fruits and vegetables are beneficial to human health, there are several factors that influence their consumption levels by respective communities or individuals and these include: income availability, diet, socioeconomics, geographical location and age (Miller *et al.*, 2016). As a

result, the quality, variety and quantity of fruits and vegetables consumed by respective individuals varies in communities depending on their cultural and socioeconomic background. (Bhupathiraju *et al.*, 2013). A study carried out on young adults found that there was increased psychological wellbeing in young adults that had higher intake of high-quality fruits compared to those consuming lesser quantities or quality (Ahmed *et al.*, 2018). Another study found that financial hardships were associated with a lower diversity of fruit and vegetable consumption for older men and women (Conklin *et al.*, 2014). A separate study on children concluded that children's overall diet quality was closely linked with the diversity of fruits consumed (Ramsay *et al.*, 2017).

Similarly, the importance of fruit and vegetable consumption is reflected in the increased production trends for particular areas (FAO, 2017b). Smallholder farmers and subsistence farmers play an important role in the global food production system due to their contribution to food security and nutrition (Fanzo, 2017). However, their efforts are compromised by various challenges that lead to significant post-harvest losses.

### **1.2.2 Overview of horticultural production in South Africa**

South Africa has diverse climatic conditions enabling it to produce a wide variety of fruits. Fruits produced include deciduous fruit, citrus fruit, subtropical and exotic fruit. The horticultural sector plays a significant role in contributing to the GDP and employment creation (DAFF, 2019). In the year 2017/2018, the gross value of agricultural production increased by 4.7%, leading to R82 million. The horticultural sector was the second-highest contributor to this increase by 27%. In addition, the sector plays a part in foreign exchange through a strong export focus (DAFF, 2019). Furthermore, it enables food security and production of raw materials to secondary sectors such as manufacturing thereby reducing dependence on importation of raw materials.

Fruits are predominantly grown by large scale commercial farmers however; there are some economic contributions from smallholder and subsistence farmers (Van Lin *et al.*, 2018). Current global trends indicate that more fruits such as berries, bananas and plums are becoming more popular and increasing in production and consumption. South Africa is not exempt from these trends and approximately 90% of the fruit grown in South Africa is exported with the rest being sold or processed locally (Van Lin *et al.*, 2018). Most of the fruit for local consumption is sold fresh with only 29% being processed. Among the tropical fruits, bananas have been noted to be the most widely grown and eaten in South Africa (Mashau *et al.*, 2012). This is possible because of its ease to grow, drought tolerance and high nutritional value such as energy micronutrient content.

### 1.2.3 Banana fruit overview

In this study, Banana and Kei apple fruit were used. Banana fruit (*Musa* spp.) is the fourth most important crop consumed globally after rice, wheat and maize (Alemu, 2017). It is a non-seasonal crop and as a result, it is available throughout the year (Dotto *et al.*, 2018). In South Africa, banana is mainly grown in Mpumalanga, Limpopo and Kwa-Zulu Natal under sub-optimal and sub-tropical conditions (DAFF, 2011; DAFF, 2017). Most of the fruit produced is consumed by the domestic markets with a part of it used for processing (DAFF, 2017). It is distributed to National fresh produce markets and can also be distributed to informal traders and processors directly by the farmers. Despite this, local banana producers can barely meet the increasing demand for the fruit as a result, the fruit is imported regularly (DAFF, 2017).

Bananas are rich in nutrients which include; carbohydrates, dietary fibre, Calcium, Potassium, Iron, Vitamins A, B<sup>6</sup> and C (Kumar *et al.*, 2012, Sidhu and Zafar, 2018). Additionally, they have a wide range of bioactive compounds which include; carotenoids, phenolics and flavonoids (Singh *et al.*, 2018; Kookal and Thimmaiah, 2018). Bioactive compounds have been noted to assist with anti-inflammatory actions, bone health and reduction of neuro-inflammations (Teodoro, 2019). Banana is a climacteric fruit that is; fruit that continues to ripen after harvesting and requires appropriate storage and handling so as not to predispose them to accelerated spoilage. A study conducted in Limpopo showed that banana was the most prevalent fruit sold by street vendors however, there were high post-harvest losses associated with it due to lack of storage facilities and appropriate value addition technologies (Mashau *et al.*, 2012). This study, therefore, selected banana fruit for its ease of availability, popularity and to introduce a low-cost value-addition technology that addresses the post-harvest loss challenge associated with it.

### 1.2.4 Kei apple fruit overview

Kei apple (*Doyvalis caffra*) is a fruit tree that is indigenous to Southern Africa (NRC, 2008). In South Africa, it can be found in Kwa-Zulu Natal, Limpopo and Mpumalanga provinces (Aremu *et al.*, 2019). The Kei apple tree can be cultivated in orchards however; it is more commonly grown as a hedge and as solitary backyard shrubs (NRC, 2008; Omotayo *et al.*, 2018). It is drought-resistant however; it produces best under sub-tropical climates and on humus-rich soils where it can bear fruit throughout the year (NRC, 2008). The Kei apple is edible however it is very sour. Despite this, it is consumed in many local communities in South Africa. The fruit can be eaten in a variety of ways which include; sprinkled with sugar, mixed in porridges, desserts and fruit salads (Aremu *et al.*, 2019). Kei apple fruit has been noted to have many nutritional benefits which include: antibacterial properties, antioxidants and it is rich in phytochemicals (Loots *et al.*, 2006; Sivakumar,

2018). Furthermore, it can be used for off-farm income sources and as a cash crop (Omotayo *et al.*, 2018). Despite its potential as a cash crop, it is still considered underutilized. This study selected Kei apple fruit to further promote processing of nutritious indigenous fruit thereby increasing food security and bio-entrepreneurship. In addition, the low-cost processing of the fruit will reduce its post-harvest losses.

### **1.2.5 Post-harvest challenges faced by smallholder farmers in fruit production**

#### **a) Post-harvest losses**

Post-harvest losses can occur in various stages after harvesting. These stages include handling, transportation and storage. However, storage, in particular, is a significant stage as inefficiencies in this stage can result in food contamination and massive financial losses. Fresh fruits contain large amounts of moisture that allows the development of microorganisms and some biochemical processes that can lead to increased perishability and spoilage (Rawat, 2015). Other possible causes of spoilage in fruits include insect damages, bruising/ cuts on the protective epidermal layer of the fruit and enzymatic activities present in the plant tissues (Hammond *et al.*, 2015). However, microorganisms have been identified as the greatest cause of fruit spoilage (Rawat, 2015). Therefore, factors that influence microorganism growth and development during storage such as temperature, humidity, respiration and air need to be controlled to minimize spoilage (Hammond *et al.*, 2015). However, the conventional technologies are energy-intensive and out of reach to most smallholder farmers. Post-harvest loss mitigations that focus on farm-level activities are often ineffective (Affognon *et al.*, 2015). Consequently, there is a need for technological diversification whereby new processing and value addition innovations are explored.

#### **b) Climate change impact on food security**

Climate change is characterized by droughts, erratic weather conditions, water scarcity amongst other changes (Harvey *et al.*, 2018; Donatti *et al.*, 2019). The impact of climate change hamper efforts by the smallholder farmers to increase agricultural output (Harvey *et al.*, 2018). Climate change not only impacts food production levels but can also increase post-harvest losses. As a result, food security is threatened by both decreased production losses and post-harvest losses. The increasing temperatures can reduce the quality of the fruits by negatively affecting the physiology of fruits. In addition, the rate of respiration increases with increasing temperatures resulting in spoilage (Wiebe *et al.*, 2019). Excessive rainfall, floods and other extreme weather events damage transportation routes and infrastructure creating challenges in the transportation of fresh agricultural

produce (Srivastava, 2019). Further implications of climate change on food security include the reduction of available arable land (Wiebe *et al.*, 2019). Reduced arable land results in decreased food production levels and resource competition. In addition, climate change variations increase pest and disease incidents (Wiebe *et al.*, 2019; Srivastava, 2019).

### **1.2.5 Smallholder access to technology**

Investments and policies that support smallholder farmers particularly in developing countries are minimal or lacking (Ndirangu *et al.*, 2016). The lack of government input coupled with a lack of skills and knowledge further hinders production by smallholder farmers. Most of the machinery used in agriculture is capital intensive hindering small scale farmers from accessing it (IRENA, 2015). The lack of technological input is further exasperated by poor natural resources management found in most smallholder farmers. Consequently, small scale farmers are limited in mitigation options against post-harvest losses.

### **1.2.6 Food preservation technologies currently used by smallholder farmers**

There are various traditional food storage and processing methods used by smallholder farmers to minimize spoilage of fruits. However, they require improvement to a level that can minimize food losses and increase quality. In addition, these improved technologies should be affordable inexpensive and cost-effective for smallholder farmers. Currently, some of the storage and processing technologies include: fermentation, evaporative cooling, clay pot refrigeration, bucket storage and drying.

#### **a) Fermentation**

Fermentation can be described as a process that produces optimum conditions for lactic acid bacteria to be dominant. An acidic flavour is then imparted to the food producing an unsuitable environment for microorganisms that cause spoilage (Asogwa *et al.*, 2019). However, acidic flavours are not widely accepted as palatable and are subject to consumer preferences (NRC, 2008). Fermentation increases the digestibility of proteins and bioavailability of minerals (Adeyeye, 2017).

#### **b) Evaporative cooling**

A common form of evaporative cooling is clay pot refrigeration cooling. During this refrigeration, two pots of different sizes are used. The smaller pot is placed inside the bigger one and in between the pots, sand and water mixture are placed (Ndukwu, 2011; Prabodh, 2016). Also, charcoal can be used in place of sand during evaporative cooling (Ndirangu *et al.*, 2016). In the event that charcoal is used, the food to be preserved is placed inside the smaller pot and water is sprinkled on the

charcoal lining. The evaporation of the water between the pots provides the cooling effect. However, evaporative cooling cannot be used for an extended period of time due to the high moisture content of the foods. Microorganisms that can cause spoilage require high moisture contents.

### **c) Shade storage**

Fruits to be preserved are kept in buckets or dishes and placed under a shade (Bikam, 2015). The shade slows down the respiration of the fruits. However, as it does not stop the respiration process, this method cannot be used for long term preservation of fruits.

### **d) Drying**

The drying of fruits can be described as the evaporation of moisture from the fruit and is as a result of simultaneous heat and mass transfer processes (Hii *et al.*, 2012). The heat transfer can be from conduction, convection or radiation or a combination of these processes (Tiwari, 2016). Before the fruit is dried, it goes through a preparative procedure where it is washed, sliced and pitted (if required) and then it may be pre-treated using methods such as blanching, sulphite dips or ascorbic acid dips (Gyurova *et al.*, 2014). After the preparative procedure, the fruit can then be dried. The drying process is stopped when the required moisture content is reached which should be between 10-20% (wet basis) (Patel, 2016). The dried fruit can then be further processed and stored thereafter.

Traditionally, open sun drying is used where the prepared fruit is placed on mats or trays in the open and exposed to the sun's radiation. This method of drying has some constraints such as pests and microbial attacks, it is labour intensive, prone to dust contamination and large space is required as well as high discoloration amongst other things. Consequently, solar dryers with enclosed drying chambers are used to mitigate these challenges.

Dried fruits contain concentrated sugars and are rich sources of vitamins and minerals. In addition, they are sources of dietary fibres which are essential for a healthy diet (Gyurova *et al.*, 2014). The phytochemicals which can be found in dried fruits include; carotenoids, phytosterols, polyphenols, phenolic acids, flavonoids, anthrocyanads and phytoestrogens (Chang *et al.*, 2016). These phytochemicals can assist in reducing risks against some diseases including; diabetes, bone diseases, glaucoma and some cancers (Gyurova *et al.*, 2014; Chang *et al.*, 2016).

There is a high demand for dried fruit products with over 2 million metric tons of dried fruits being traded around the world annually. In South Africa, dried fruit production has increased from 4 615

tons in 1995/96 to 8 984 tons in the year 2016/17 and more than 50% of the dried fruit product is exported. Presently there has been a global peak of interest in healthy living and consumption of healthy foods and South Africa has the potential to meet these demands and progress upwards in the dried fruit value addition chain.

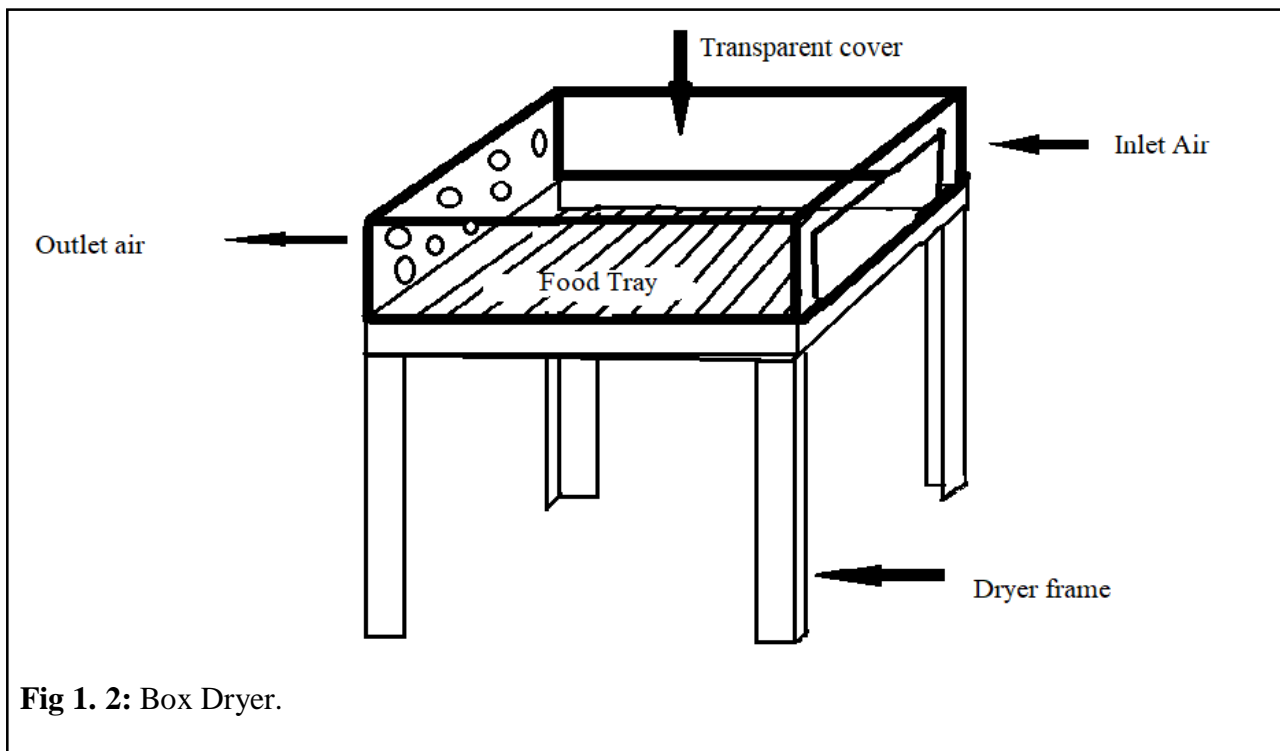
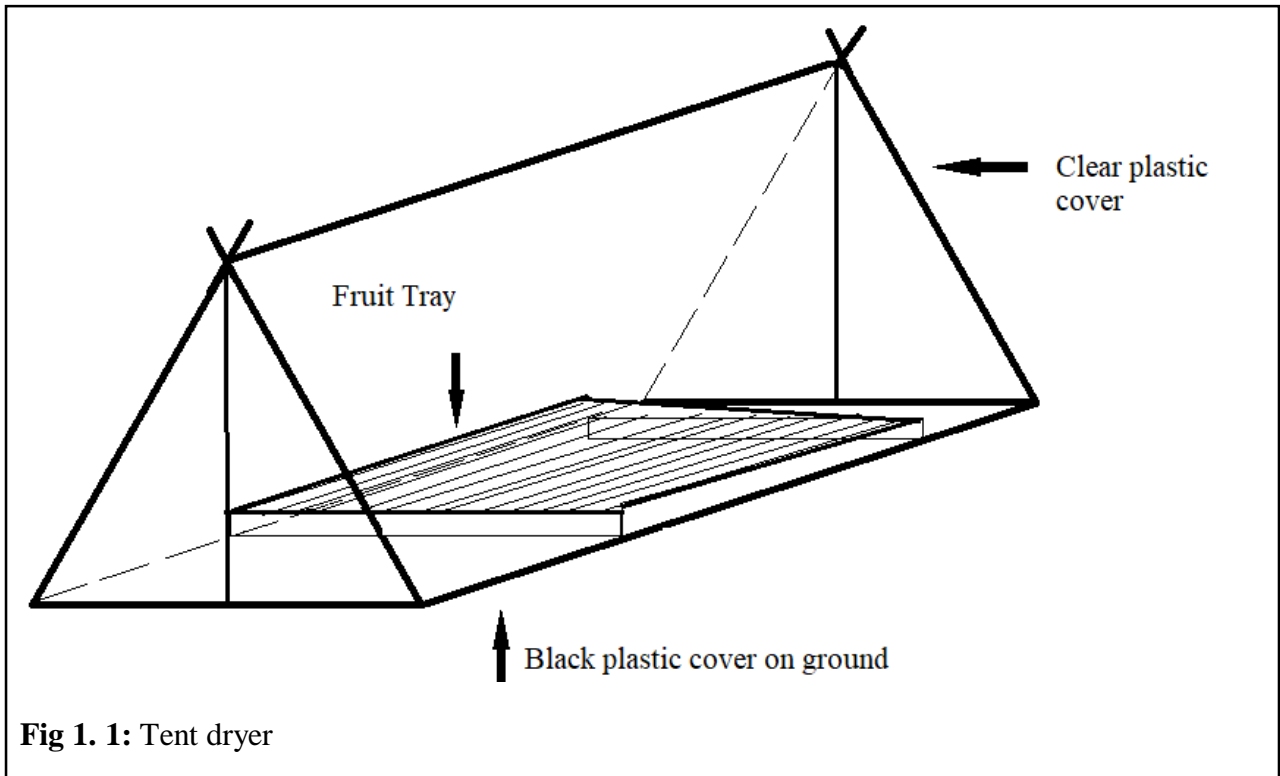
### **1.2.7 Overview of solar fruit dryers**

Solar fruit drying can be described as a food preservation technique that reduces moisture content in fruits leading to increased shelf life. It relies entirely on solar radiation and available sunshine hours.

The most common classification of solar food dryers is by air circulation, dryer arrangement and heat transfer (Toshniwal and Karale, 2013). Further common classifications include: direct mode fruit dryers, indirect mode fruit dryers and mixed-mode dryers that use both short wave and long wave radiation (Sontakke and Salve, 2015).

#### **a) Direct solar dryers**

In a direct solar fruit dryer, the fruit to be dried is covered by a transparent cover that enables short wave radiation that is then converted to long wave radiation and increases air temperatures in the dryer. The materials used for the transparent cover are usually plastic or glass which do not allow long wave solar radiation to escape. However, it is acknowledged that plastic is less durable than glass as it is affected by wind and the continued exposure to the sun. Examples of direct solar fruit dryers include tent dryers and box dryers as illustrated in Fig 1.1 and Fig 1.2. The tent dryer has a frame covered by clear plastic and the ground is covered by black plastic or clean surface painted black. Sides of the tent dryer can also be made from black plastic or painted black to increase heat absorption (Tiwari, 2016). The box dryer is usually constructed from wood or cardboard boxes with air gaps or holes for air circulation. A transparent cover is placed on top to allow for the sun's radiation to penetrate.

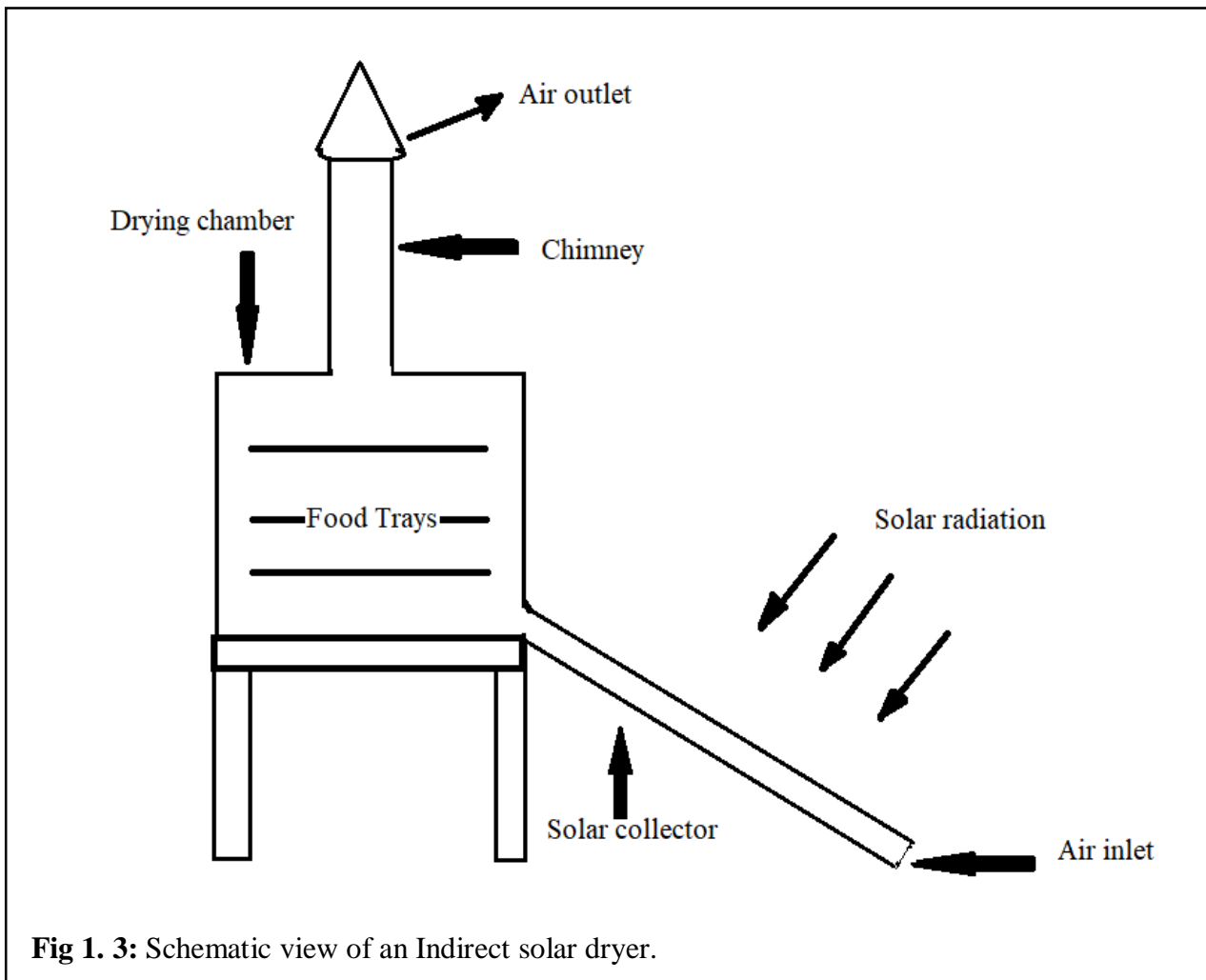


The main advantage of direct solar fruit dryers is that they are a very low-cost technology because they are made from locally available materials. These materials can include: cardboard boxes, plastic and wood (Toshniwal and Karale, 2013; Tiwari, 2016). However, the short wave radiation has a negative effect on the quality of the dried fruits. In addition, non-uniform drying and

excessive discoloration due to overheating of air temperatures in the drying chamber are common occurrences associated with direct solar fruit dryers (Sahu *et al.*, 2016).

### b) Indirect solar dryers

In indirect solar fruit dryers, fruits are placed in a direct sun radiation-proof drying chamber and are not directly exposed to short wave radiation (Sahu *et al.*, 2016; Gupta *et al.*, 2017). Solar collectors are part of the main components of these dryers. The hot air that is heated in the solar collectors removes moisture from the fruits resulting in an efficient drying process. Fig 1.3 shows a diagrammatic illustration of an indirect solar fruit dryer. To manage the drying process, air blowers or fans can be used to control air circulation in the drying chamber (Gupta *et al.*, 2017).



**Fig 1. 3:** Schematic view of an Indirect solar dryer.

Although good quality dried fruits are produced in indirect solar dryers, the added components such as; solar collectors, fans and other air circulation components make the technology capital intensive.

### **c) Mixed-mode solar dryers**

These dryers incorporate features from both indirect and direct solar fruit dryers. The fruit to be dried is directly exposed to the sun's radiation and heated air from solar collectors. As a result, the drying rate is considerably faster. In addition, the capital and maintenance costs are higher than that of indirect solar fruit dryers or direct solar fruit dryers (Sahu *et al.*, 2016). These of dryers can be used in the infrastructures such as greenhouse tunnel dryers and some solar cabinet dryers suitable for large scale drying (Tiwari, 2016).

### **d) Solar dryers with auxiliary heating**

Solar drying is limited to daytime drying. Some fruits have a high moisture content and daytime drying is insufficient. The time that the drying process is halted during the night has an impact on the quality of the product and provides an opportunity for re-moisturizing of the product and microorganism contamination (Tiwari, 2016; Nemš *et al.*, 2018). It is on this basis that solar dryers with auxiliary heating sources are designed. Advances in these solar dryers have even led to the drying of fruits even under unfavourable weather conditions. The most common auxiliary heat sources include: electricity, wood, charcoal and fossil fuels. However, some of these are unsustainable and have a detrimental impact on the environment. To increase drying efficiency, utilization of heat storage systems has also been explored. In this instance, latent heat or sensible heat which is heat required to change the temperature of the substance with no phase change. Examples of the material used in heat storage include: granite, gravel, sand, water and paraffin (Agrawal and Sarviya, 2016; Chauhan and Rathod, 2018; Nemš *et al.*, 2018).

## **1.2.8 Renewable energy utilization in agro-processing**

Historically, fruit production and agro-processing machinery and equipment have been largely driven by fossil fuels (IRENA, 2015). However, the use of fossil fuel is noted to be a key contributing factor to global warming and climate change. As a result, the negative impacts of climate change have led to the growth of global interests in research, policies and technologies aligned with renewable energy (Chel and Kaushik, 2011; Torshizi and Mighani, 2017). Renewable energy is considered to be clean energy and has less detrimental impacts on the environment than fossil fuels. The main forms of renewable energy include: solar, wind, hydro, geothermal and bio-energy (Chel and Kaushik, 2011; IRENA, 2015). Renewable energy can be utilized in agro-processing technologies that include; solar dryers, evaporative coolers, solar cookers, bio-energy heaters and cookers, bio-waste electricity generated processors and solar coolers (IRENA, 2015; Ndirangu *et al.*, 2016; Torshizi and Mighani, 2017).

The use of renewable energy in agro-processing is sustainably cost-effective to smallholder farmers, youth and women as it is noted that it has the potential to contribute to employment creation and bio-entrepreneurship opportunities (Ndirangu *et al.*, 2016; Van Lin *et al.*, 2018). Renewable energy utilisation enables farmers to diversify the production of value-added products and reduce post-harvest losses during seasons of surplus produce. Renewable energy use reduces greenhouse gas emissions and the cost of production which is critical for smallholder farmers (Mo, 2016). As a result, farmers would have the capacity to produce quality products and meet the increasing demands for high quality dried fruits and vegetables (Spivey, 2015). In addition, the increased shelf life of fruits minimises the risk of contamination (IRENA, 2015). This, therefore, makes the promotion of renewable energy important for the growth of the agro-processing industry particularly with smallholder farmers (Ndirangu *et al.*, 2016).

The recent developments in renewable energy have heightened the research interest in heat recovery during biodegradation (Smith and Aber, 2018). However, the agricultural utilization of the heat recovered during biodegradation has been mostly limited to hotbeds for crop production, greenhouses and hot water uses ;(Sokolovs *et al.*, 2015; Zhao *et al.*, 2017; Smith *et al.*, 2017). There are hybrid solar dryers that use renewable energy and biomass however, these dryers have focused mainly on the burning of biomass and extracting the flue gases for drying (Tibebu *et al.*, 2016). Flue gases can be described as a mixture of gases produced during the combustion of fuels that may be released to the atmosphere. An approach that recovers the bio-energy produced during biodegradation for drying of fruits has not been studied and developed.

### **1.2.9 Biodegradation process**

Organic waste disposal is a global challenge that has detrimental impacts on the environment (Gonawala and Jardosh, 2018). An effective process that assists in the reduction of organic waste is biodegradation (Aziz *et al.*, 2018). Aerobic biodegradation can be described as a controlled biochemical process in which microorganisms transform coarse organic matter to a homogenous stable end product in the presence of oxygen (Bohacz, 2017; Bong *et al.*, 2017; Comesaña *et al.*, 2017). The aerobic biodegradation process is shorter compared to the anaerobic process. In addition, higher temperatures that sanitize the bio-waste from pathogens are produced and, depending on the biomass, there are no unpleasant odours produced (Raza and Ahmad, 2016). The temperatures that are produced during aerobic biodegradation can reach between 65-70°C. These excessive temperatures can be utilized for the drying process of fruits. The biodegradation process can be limited by factors such as moisture content (MC), pH, Carbon Nitrogen (C/N) ratio, particle size, temperature and aeration (Uçaroğlu and Alkan, 2016).

In addition to biodegradation being used to treat organic waste, it has spurred interest from entrepreneurs and policymakers as it can be used as a source of energy and other products for income-generating projects and provision of job opportunities (Bortolotti *et al.*, 2018; Bundhoo, 2018). Furthermore, the biodegraded biomass itself has widespread benefits and uses such as mulching, increasing the moisture retention capacity of the soil, reduction of the risk of erosion and regulation of soil temperature (Lohri *et al.*, 2017). In addition, it can be used as a bio-fertilizer to supply macronutrients and micronutrients and supplies them as available nutrients of slow-release which is beneficial to plant nutrition (Vázquez *et al.*, 2015; Sharma and Yadav, 2018). Biodegraded biomass can also be used as a potting media.

#### **a) Types of biodegradation processes**

There are various biodegrading technologies and these include the following: windrows, passively aerated windrows, forced aeration static piles, enclosed/in vessel biodegradation and vermicomposting (Manyapu *et al.*, 2017). The most common are the windrow, aerated static pile and the in-vessel biodegradation (Burile *et al.*, 2017). Windrows are elongated heaps of organic waste requiring mechanical turning and aerated static piles are piles of organic matter with aeration pipes or blowers in or at the base of the pile requiring little or no mechanical turning (Boldrin *et al.*, 2009; Bobeck, 2011; Burile *et al.*, 2017). The windrow and aerated static pile require large areas of space and are usually used for large composts or centralized biodegrading (Burile *et al.*, 2017). Centralized biodegradation poses challenges such as increased greenhouse gas emissions, high investment costs, higher energy for operation and difficulty to discover end users to utilize the biodegraded biomass (Bong *et al.*, 2017; Mu *et al.*, 2017). In contrast, vessel biodegrading is when the biodegradation process is confined to a building, container or vessel (Manyapu *et al.*, 2017). It is considered more efficient than the windrow and aerated static pile biodegrading technologies (De Campos *et al.*, 2017). It provides more environmental control such that optimum temperature, moisture, and oxygen can be maintained (Malakahmad *et al.*, 2017). It is usually used to achieve biodegradation in a smaller area and takes a shorter amount of time compared to windrow and aerated static pile technologies and additionally producing better quality biomass (Manyapu *et al.*, 2017; Alkoaik *et al.*, 2018).

#### **b) Review of bio-energy reactors**

Due to challenges associated with centralized biodegrading of organic waste, there has been an increasing trend towards decentralized biodegrading which is offered by bio-energy reactors (Mu *et al.*, 2017; Bhave and Joshi, 2017). A bio-energy reactor can be described as a container or vessel in

which biological reactions occur and thus the main function of a bio-energy reactor is to provide a suitable environment in which microorganisms can efficiently produce a target product. There are many factors that should be considered in the design of bio-energy reactors for compost use such as operability, vessel shape, material construction, energy requirements, heat retention, homogeneity of compost and the impact of biological reactions (from feedstock used or physicochemical properties of the bio-waste) on the bio-energy reactor (Vázquez *et al.*, 2015). Although it occurs in various scales and setups, it does not usually exceed 5 tons of waste per year (Bortolotti *et al.*, 2018).

In-vessel biodegradation has benefits such as; reduced economic and environmental costs due to the lower distances that the waste can be transported, it is less capital intensive, enhances environmental awareness in a community and manages waste effectively (Boeykens *et al.*, 2015; Abeliotis *et al.*, 2016; Mu *et al.*, 2017). Factors that need to be monitored in the bio-energy reactor include; moisture content, aeration, and temperature (Ermolaev *et al.*, 2014; Vázquez *et al.*, 2015). When the temperature exceeds the required optimal stage to destroy pathogens in the biomass, this heat can be used for agricultural and industrial process including the drying of foods.

Studies on small scale biodegradation in relation to temperature and bio-energy reactor design are limited (Arrigoni *et al.*, 2018). Despite this, the bio-energy reactor plays an important role as it influences the biodegradation process, biological reactions occurring inside the bio-energy reactor, operational aspects and the end biomass product itself (Storino *et al.*, 2017; Bortolotti *et al.*, 2018; Arrigoni *et al.*, 2018). The biological reactions that occur in the bio-energy reactor can be manipulated for heat recovery purposes and this heat can be used during the drying process.

### **Bio-energy reactor geometrical shape**

The geometric shape of bio-energy reactors is an important factor and influences the resulting compost, ease of operation and management of the composting system. The common bio-energy reactors for decentralized composting include bin bio-energy reactors (rectangular, cone and truncated cone, trapezoidal sides with square base), vertical cylinder bio-energy reactors and rotary drums (Arrigoni *et al.*, 2018). The geometric shape can also be influenced by the available space. For heat recovery purposes for the fruit drying, the geometric shape must facilitate air tubing and turning of the compost hence, rotary drums are most suitable.

### **Material selection and design stability**

To select the appropriate material for making the bio-reactor, multi-criterion decision-making methods are employed (Athawale and Chakraborty, 2012). The chemical properties of material help

to determine the deteriorative characteristics through chemical reactivity or other substances thus assessing if it can be used or processed for use. The physical properties such as mechanical properties (tensile strength, wear resistance, corrosion resistance, and density), thermal properties, optical properties and magnetic properties also assist to determine which material is eventually selected (Prendeville *et al.*, 2013). Additionally, the cost of material, availability, environmental impact and other critical parameters are assessed to determine the final appropriate material for making the bio-reactor. Some materials may be ideal but inaccessible or costly or impractical. Materials such as glass may be appropriate as they will not react with the feedstock but impractical outside as they are subject to breakage and costly. Other materials may also not be considered due to climatic reasons. Common materials used in bio-energy reactors include plastic, metals and wood (Yuwono *et al.*, 2016; de Campos *et al.*, 2017; DiGiacomo *et al.*, 2018). Plastic bio-energy reactors are mostly made of high-density polyethylene material or other recycled plastics (Abeliotis *et al.*, 2016). They have the advantage of being lightweight and corrosion-resistant than most metals. Metallic bio-energy reactors have to be corrosion resistant or painted with anti-corrosive coating as chemical reactions could introduce contamination. Wood also needs to be treated so as not to degrade from the moisture in compost or climatic factors (Neugebauer and Sołowiej, 2017). As the solar drying process occurs outdoors, the bio reactor that is used for heat recovery purposes must have properties that do not deteriorate in outdoor conditions.

The stability of the bioreactor design is a factor of the design as it has an impact on the ease of operation of the bioreactor. When the bioreactor is not sturdy or robust, it could pose a danger to the operator. A study by (Faverial and Sierra, 2014) included the use of compost bins that were unstable and fell apart during the study resulting in contents being exposed and this could lead to rodent attack and spread of harmful pathogens. To minimize the instability of a bioreactor, steps should be taken to ensure sturdiness such as incorporating a frame or reinforcement (Jain *et al.*, 2018).

### **Agitation and aeration**

Agitation is important in the composting process as it not only produces homogeneity in mixtures but also allows aeration of the bio-energy reactor (Kalamdhad and Kazmi, 2009; Rich *et al.*, 2018.). Agitation may be driven by a component in the bio-energy reactor such as a stirrer, hand tool, propeller or may be part of the bio-energy reactor. As part of the bio-energy reactor, baffles that are obstructing vanes on the sides of the bio-energy reactor can be used to cause agitation (Storino *et al.*, 2016; Burile *et al.*, 2017).

Aeration can occur in a mechanized manner or passively as part of the bioreactor design (Bhave and Joshi, 2017; Desai and Shah, 2018) Designs using passive aeration may use perforations, slatted

sections, grid openings or large openings incorporated in the bio-energy reactor (Tatàno *et al.*, 2015; Poongodi and Damodharan, 2016; de Campos *et al.*, 2017a).

In summary, fruits and vegetables are essential to human health however; they have a short shelf life. This short shelf life of these horticultural produce increases the post-harvest challenges faced by smallholder farmers. Lack of access to appropriate value addition technologies further compounds post-harvest losses. As a result, farmers and agro-processors have to rely on preservation technologies such as drying and other traditional drying methods which however have been reported to have limitations. These limitations can be reduced through the use of a hybrid bio-solar dryer with an enclosed drying chamber that when connected in series with bio-energy can enable an efficient continuous drying process.

## CHAPTER TWO

### ANALYSIS OF MICROBIAL DIVERSITY AND THEIR EFFECT ON TEMPERATURE PROFILES IN FIVE SELECTED BIO-ENERGY REACTORS

#### 2.0 Introduction

Bio-energy generation occurs as a result of biochemical processes that are driven by various microbial species (Sokolovs *et al.*, 2015). These microbial species include bacteria, fungi and Actinomycetes (Graves *et al.*, 2000; Román *et al.*, 2015). The biodegradation process in organic waste is influenced by factors such as aeration, moisture content and the composition of the microbial growth media material (pH, particle size, C/N ratio) (Raza and Ahmad, 2016; Livleen *et al.*, 2016). Effective management of the biodegradation process results in sufficient heat generation by microorganisms present in the biomass. This heat is required to destroy weeds, pathogens as well as fly larvae (Román *et al.*, 2015). As a result, the temperature profile is one of the most significant indexes to the various stages of biodegradation (Nelson *et al.*, 2006; Mohamed sunar *et al.*, 2014). Furthermore, the growing trends in renewable energy have resulted in an increased interest in biomass heat recovery technology (IRENA, 2015).

The biodegradation process has three key temperature phases. These phases are characterized by the respective microorganisms that are dominant in the biomass during a particular temperature phase. The first phase is the psychrophilic temperature phase and is below 20°C (Mohamed sunar *et al.*, 2014). The second phase is the mesophilic phase and ranges between 20-45°C and the third phase is the thermophilic phase ranging between 45-80°C (Coleman and Smith, 2014). Bacteria are mainly dominant in the mesophilic and thermophilic stages whereas fungi and Actinomycetes are mostly dominant in the mesophilic stages (Graves *et al.*, 2000).

The initial stage is dependent on the ambient temperatures and the temperatures of the microbial growth media material thus it can begin at either psychrophilic or mesophilic temperature phases (Graves *et al.*, 2000). During this stage, bacteria rapidly break down the easily degradable compounds including sugars, amino acids and proteins. Bacteria producing lactic and acetic acids enable microorganisms to degrade these organic acids (Bernal *et al.*, 2017). As the microorganisms break down these compounds they produce carbon dioxide, water and heat (Graves *et al.*, 2000). The heat energy is released during microbial respiration. However, this process only occurs during aerobic conditions (Román *et al.*, 2015).

As the degradation of the biomass progresses, temperatures within the biomass increase. This occurs as a result of heat generated through microbial metabolism and oxidation of cellulosic

materials leading to thermophilic conditions (Zhao *et al.*, 2017). This heat that is produced takes the form of either latent heat and or heat required to change the temperature of the substance with no phase change (Smith *et al.*, 2017). The main compounds that thermophilic microorganisms break down are lipids and hemicelluloses. However, organoheterotrophic bacteria are dominant during the transformation to thermophilic conditions (Livleen *et al.*, 2016; Bernal *et al.*, 2017). During this phase, rapid degradation occurs as a result of more heat being produced than that which is lost to the surroundings. It is at this point that oxygen and nutrient levels are rapidly depleted due to the increase in microbial population and metabolism. In addition, sanitization of the biomass pile will occur during the peak thermophilic stage (Román *et al.*, 2015). Sanitization occurs when harmful temperature-sensitive pathogens are destroyed due to the high temperatures. The most pathogens in bio-waste include *Salmonella* spp. *Escherichia coli* and they are destroyed at temperatures of 55°C and above (Déportes *et al.*, 1995; Román *et al.*, 2015). In addition, it is important to note that mesophilic microorganisms will survive as either spores or become dormant until the temperatures are conducive again (Livleen *et al.*, 2016; Bernal *et al.*, 2017).

After the thermophilic stage, cooling begins until it reaches optimum conditions for mesophilic microorganisms to be dominant. The mesophiles further degrade cellulose, hemicellulose and lignocellulosic material (Román *et al.*, 2015; Bernal *et al.*, 2017). When the mesophiles have exhausted the nutrients, the curing stage begins. During the curing stage, the biomass temperatures begin to decrease until they reach ambient temperatures and the chemical compounds produced from the biochemical reactions become stable (Gerba and Pepper, 2019). At the end of the curing stage, the biomass is said to be mature (Román *et al.*, 2015).

## 2.1 Heat recovery

Surplus heat can be extracted when the temperatures exceed the optimum conditions (55-60°C) for thermophilic microorganisms (Zhao *et al.*, 2017). The thermal energy that is produced during biodegradation not only has the advantage of being a source of renewable energy but, also utilizes heat that would have been normally lost to the environment (Smith *et al.*, 2017). However, the heat recovery process is an intricate process, requiring specific conditions for it to be efficient. This is due to the thermophilic microorganisms which are highly sensitive to changes in parameters (Sokolovs *et al.*, 2015). When excessive heat is extracted, the temperature drop inside the biomass will cause the biodegradation process to decelerate or cease (Zhao *et al.*, 2017). Conversely, when minimal heat is extracted, the high temperatures will destroy beneficial thermophilic microorganisms resulting in inefficient biodegradation (Neugebauer *et al.*, 2014). Heat recovery has many uses that include; industrial and domestic settings such as greenhouses, hotbeds and domestic

hot water (Smith *et al.*, 2017). In addition, it must be noted that there is potential for further utilization and exploration of heat recovery from the biodegradation process.

Although the heat recovery of biomass has the potential to provide alternative clean renewable energy, it is not well documented and researched (Zhao *et al.*, 2017). However, this has been largely attributed to the dynamic and complex nature of the biodegradation process and biomass material (Sokolovs *et al.*, 2015; Neugebauer, 2018). As a result, this study was therefore undertaken to analyze the temperature profile in the biodegradation process of biomass in five selected bio-energy reactors with varying biomass compositions and to further determine the factors with the greatest impact on the heat-generating microorganisms in the respective bio-energy reactors.

## **2.2 Specific objectives of the study:**

- i. To identify microbial species active at the different temperature phases.
- ii. To analyse the effect of moisture content, pH, C/N ratio and ambient temperatures on the temperatures recorded in the bio-reactors.
- iii. To determine the shelf life of the biodegraded biomass for heat generation capacity.

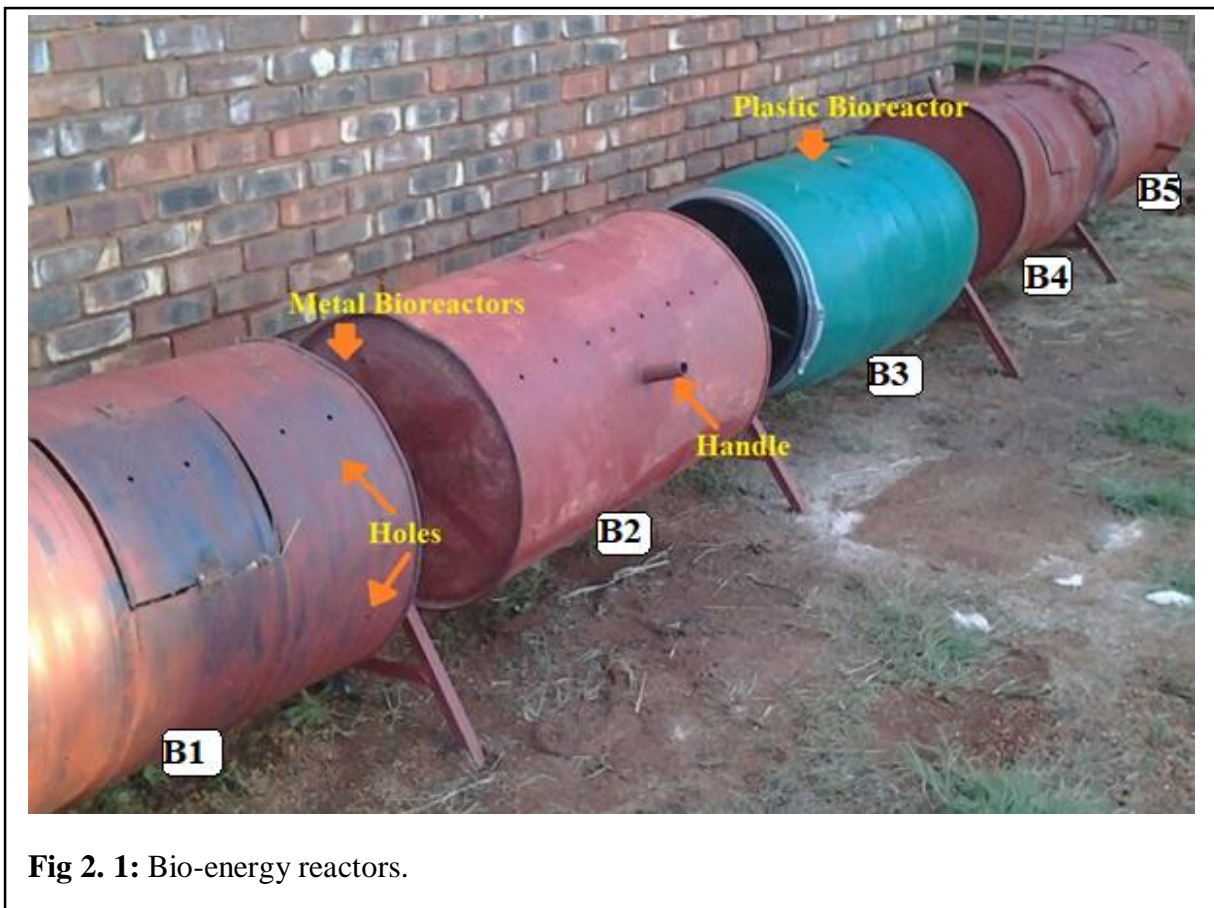
## **2.3 Materials and methods**

### **2.3.1 Experiment description**

The experiment was carried out in Mafikeng and analysis of the samples was carried out at the North West University Molelwane (NWU) Farm laboratories; 25°40.459'S, 26°10.563'E. Ambient temperatures in Mafikeng range between 27°C to 37°C in summer and -3°C to 25°C in winter.

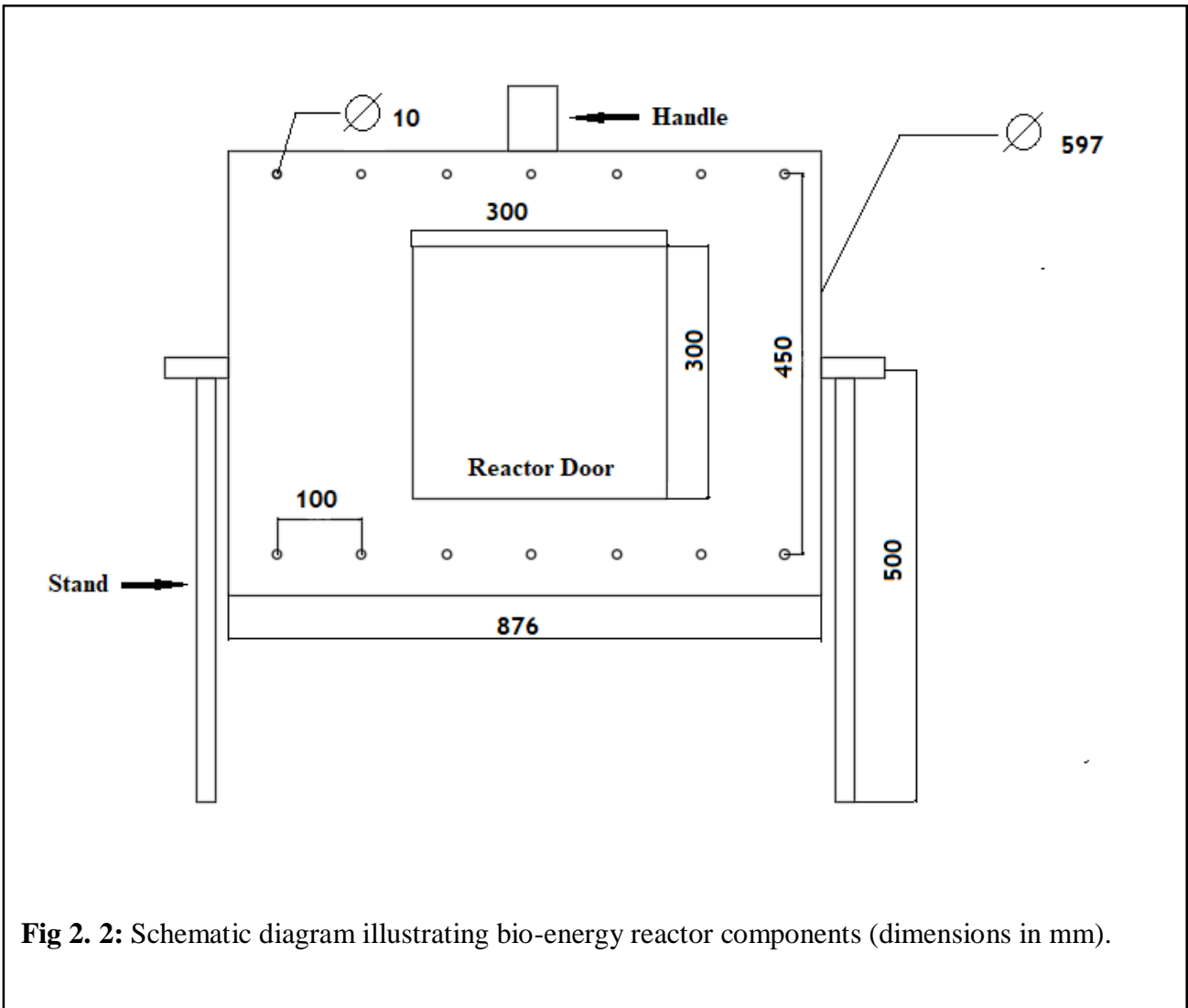
#### **a) Bio-energy reactors**

Five 200L drums were used to make the bio-energy reactors. Four of the bio-energy reactors (B1, B2, B4, B5) were made from recycled steel metal drums and one bio-energy reactor (B3) was made from a polyethylene plastic drum. The plastic drum was used to assess if the use of a plastic drum influenced temperatures attained in the bio-energy reactor as this was crucial for heat recovery purposes. The bio-energy reactors were arranged as shown in Fig. 2.1.



**Fig 2. 1:** Bio-energy reactors.

The inside diameter of the bio-energy reactor is 597 mm and the length is 876 mm. The bio-energy reactors were assembled horizontally on stands 500 mm from the ground to enable ease of rotating the reactors manually to ensure homogeneity of the growth media during aeration. All the bio-energy reactors had 10 mm diameter openings drilled with a spacing of 100 mm and 450 mm on the periphery of the bio-energy reactors (Fig. 2.2) for natural air circulation to enable aerobic biodegradation and leachate drainage (Manu *et al.*, 2017). The metal bio-energy reactors were primed with red oxide paint to prevent rusting. A handle was attached to each unit for use for spinning the bioreactors thereby aerating the biomass inside the bioreactors. The spinning of the bioreactors was carried out at a two-day interval in the first week of the experiment followed by a three-day interval in the second week (Nelson *et al.*, 2006; Ogunwande *et al.*, 2008; Manu *et al.*, 2019). Each bio-energy reactor had a square opening of 300mm by 300mm for feeding the microbial growth media into the bio-energy reactor.



**Fig 2. 2:** Schematic diagram illustrating bio-energy reactor components (dimensions in mm).



These openings were designed to enable effective closure to prevent spillage of the microbial growth media when aerating the biomass. After each layer of dry leaves or sawdust, one litre of water was used to moisturize the microbial growth medium (Kaluarachchi *et al.*, 2018). The total amount of water used per bioreactor was six litres bringing the total mass of bio-energy reactor content to 60 kg.

**b) Microbial growth media**

There were five bio-energy reactors with different growth media in each respective bio-energy reactor. The proportions of the bio-energy reactor contents are shown in Table 2.1. The first bio-energy reactor (B1) consisted of fresh cattle manure mix. The fresh cattle manure was collected from NWU farm from the fresh heaps collected from the herd of cattle available at the farm. The cattle are grass fed dairy cattle including Jersey and Ayrshire breeds. The second and third bio-energy reactors, (B2 and B3) had chicken manure mix. The chicken manure was collected from egg laying chickens bred at the NWU farm. The layer breed is the Leghorn breed. B3 is the plastic bio-

energy reactor. The fourth bio-energy reactor (B4) did not have livestock manure at all but, it contained a mixture of sawdust, dry leaves and green grass clippings (lawn). The fifth bio-energy reactor (B5) also did not have livestock manure but, it had urea, sawdust, dry leaves and green grass clippings (lawn).

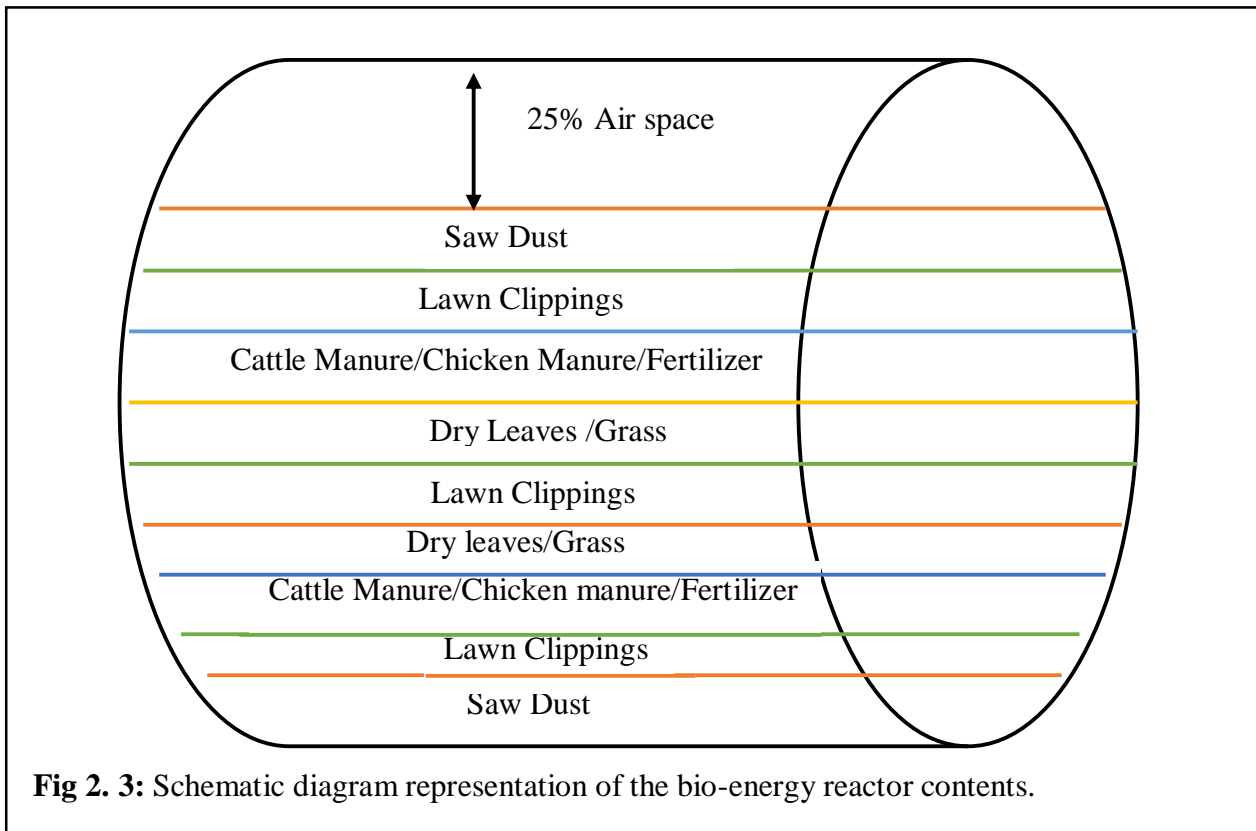
**Table 2. 1:** Summary of bio-energy reactor growth media contents.

Bio-reactor type 	B1	B2 and B3	B4	B5
Bio-reactor content 	(kg)	(kg)	(kg)	(kg)
Cow manure	32	X	X	X
Dry peach leaves	5	5	12	12
Green grass Clippings	10	10	30	28
Saw Dust	7	7	12	12
Chicken Manure	X	32	X	X
Fertilizer (Urea)	X	X	X	2

X indicates products not used in the bio-energy reactors.

Where: B1-cattle manure mix, B2-chicken manure mix, B3-plastic bio-energy reactor chicken mix, B4-grass mix, B5-Urea mix

Alternate layers of the different microbial growth medium were placed in the bio-energy reactors at depths of 100 mm. The medium for B1 included cattle manure mix, grass clippings, dry leaves, and saw dust. The medium for B2 and B3 included chicken manure, dry leaves, grass clippings and saw dust. The medium for B4 included grass clippings, saw dust and dry leaves whereas, the medium for B5 included urea, saw dust, grass clippings and dry leaves. The top layer was left with a 25% volume space for ease of sub-sampling for microbial analysis as well as to allow air movement. However, the first and final layer was the sawdust layer to assist in insulation against heat losses and loss of moisture at the start of the experiment (Bajko *et al.*, 2018). Fig 2.3. shows the schematic diagram of the bio-energy reactor layout of contents.

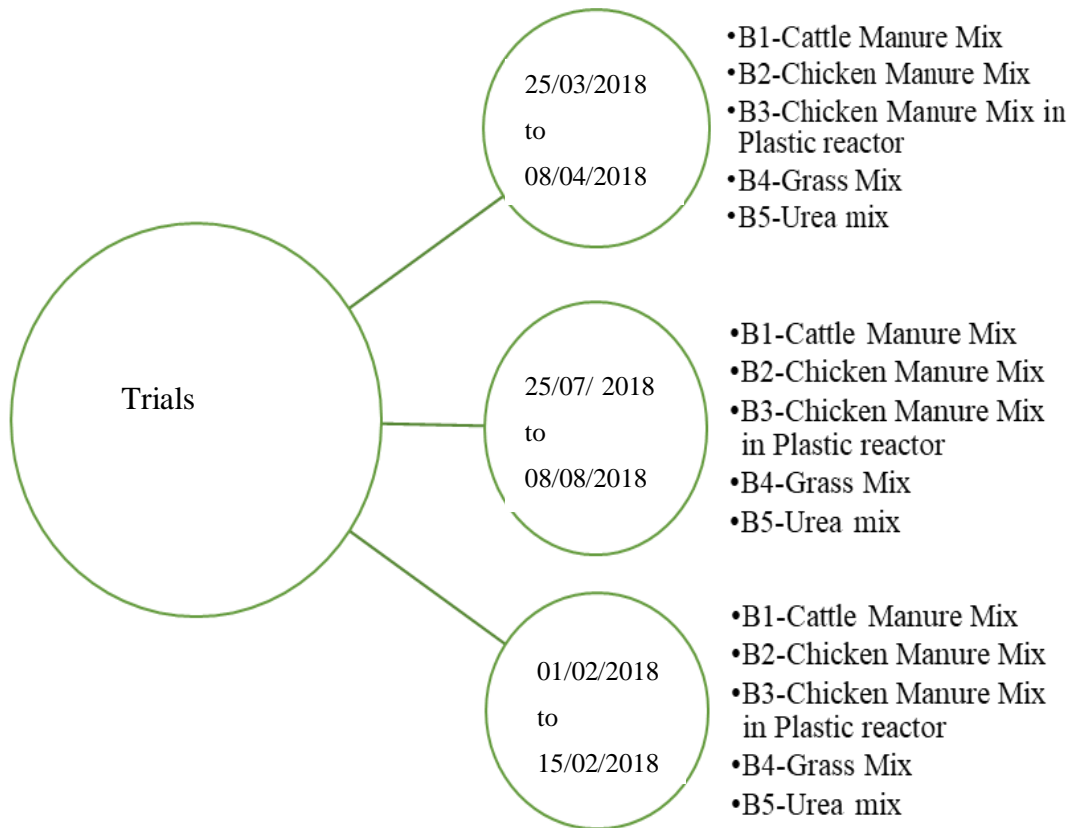


**Fig 2. 3:** Schematic diagram representation of the bio-energy reactor contents.

The respective organic material composites were only homogenized during turning. Turning of the bio-energy reactors to enable aeration was carried out at an interval of two days in the first week whereas, in the second week, it was performed at an interval of three days. In addition, the turning was only carried out at 8 am and the bio-energy reactors rotated twice to complete an aeration cycle. Temperatures were recorded using digital thermometers using spot measurement at 3 different points and the averages recorded. The temperatures were recorded at 4-hour intervals starting from 08:00 Hrs. Fig. 2.4 shows the digital thermometer used for measuring temperature. Samples were taken for physiochemical analysis and microbial frequency analysis throughout the experiment and collected into sealable plastics with the use of hand gloves. The samples were collected at 4 different points per bio-energy reactor and homogenized to make a composite sample. Two trials were undertaken during summer and one trial was undertaken during winter as illustrated in Fig. 2.5. The winter trial was only done once as access to green lawn clippings was limited as winter progressed.



**Fig 2. 4:** Digital thermometer.



**Fig 2. 5:** Block diagram for the trials and bio-energy reactor treatments.

### 2.3.2 Analysis

#### a) Microbial analysis

Twenty-five grams (25 g), of the homogenized substrate composites was mixed with 200 ml of distilled water and stirred with a stirrer for ten minutes. Serial dilution with a dilution factor  $10^{-6}$  was used for isolation (AOAC, 2000). The final dilution was plated (1ml) on both Potato Dextrose Agar (PDA) and Nutrient Agar (NA) growth media. The PDA was used for fungi growth analysis and NA for bacteria. Each sample was replicated three times and the petri dishes were incubated at the following respective temperatures: 24°C, 37°C and 45°C to resemble the conditions from which the samples were collected from i.e. mesophilic and thermophilic conditions.

After the fungal communities were determined, a single spore sub culturing was carried out to obtain pure cultures for further identification. The fungal identification was done using their respective morphological colony characteristics and microscopic features (Anastasi *et al.*, 2005; Pasupathi and Devendrian, 2018). Morphological features included: colony shape, colour, texture and formation. Bacterial isolates were also characterized depending on their colony morphological features.

#### **b) Physicochemical analysis**

The moisture content (MC) of the samples was determined using the oven-dry method where initial samples were weighed then dried for 24 hours at 105°C (ASTM, 1993; Makan *et al.*, 2013). The dried sample was re-weighed and MC expressed as a percentage of the dried sample. The pH was determined by mixing each sample with water in a ratio of 1:10 (soil: water) then left for 1 hour so that maximum salts could be dissolved (EPA, 2004). The pH was determined using a pH meter, PHS-25C Microprocessor Bante Instruments (Ameen *et al.*, 2016). The C/N ratio was determined using a LECO machine, TruMac CNS/NS version 1.3x. The average of the samples collected per trial was recorded.

#### **c) Statistical analysis**

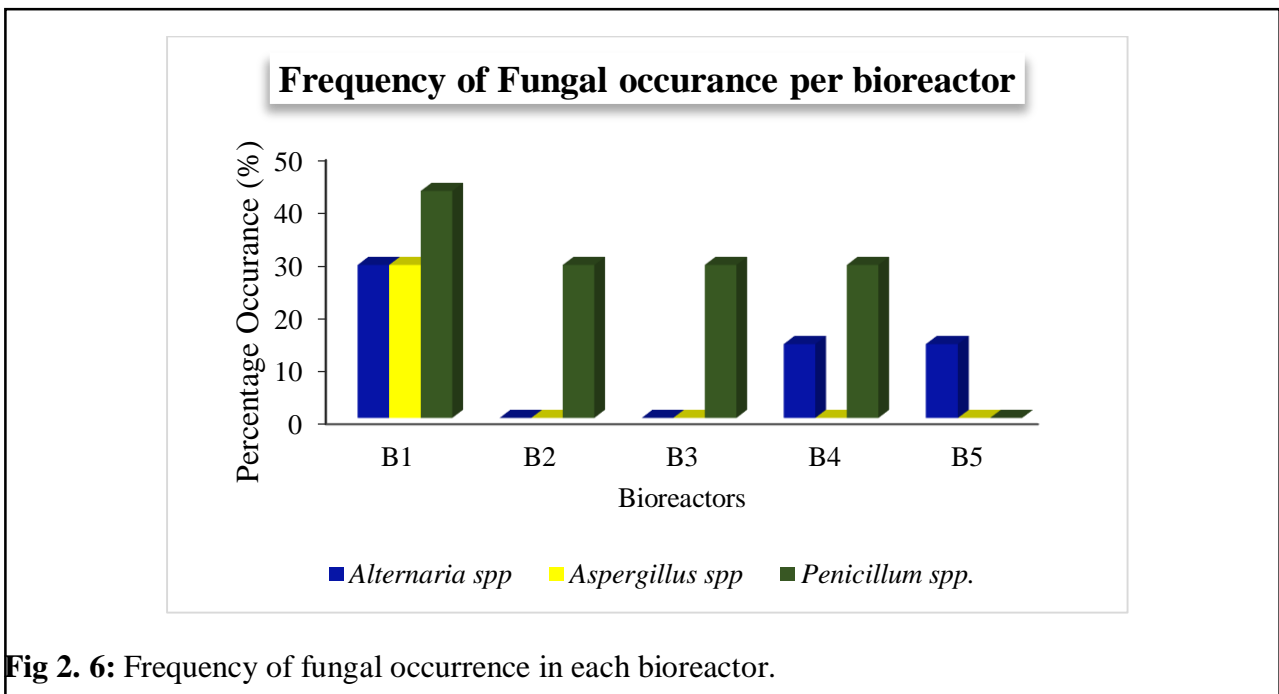
A Pearson correlation coefficient analysis was used to analyze the relationship between temperature (8 am temperature profile), pH, MC and C/N ratio in all the bio-energy reactors. The 8 am temperature profile was selected because the samples for physicochemical analysis were collected at that time. Further, these physicochemical parameters were subjected to Analysis of variance (ANOVA) using GenStat software package version 17.1.

## **2.4 Results**

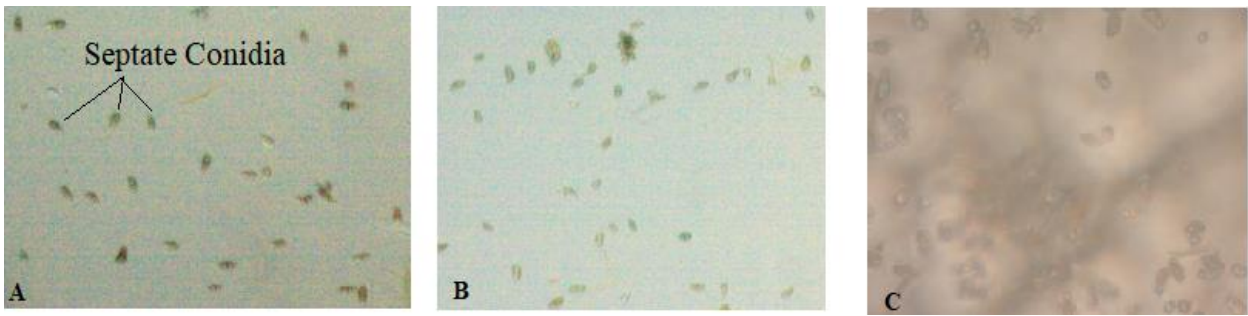
### **2.4.1 Fungal identification and characterization**

The fungal isolates that were identified in B1 (cattle manure mix) included; *Aspergillus* spp., *Alternaria* spp., and *Penicillium* spp. whereas in B2 and B3 (chicken manure mix) only *Penicillium* spp. was identified. *Alternaria* spp. was identified in both B4 (grass mix) and B5 (urea and grass mix) however, *Penicillium* spp was only identified in B4. As a result, B5 was the only bioreactor where *Penicillium* spp. was not identified. *Aspergillus* spp. are known to produce cellulolytic enzymes that degrade cellulose during biodegradation (Mehboob *et al.*, 2014). *Alternaria* spp.

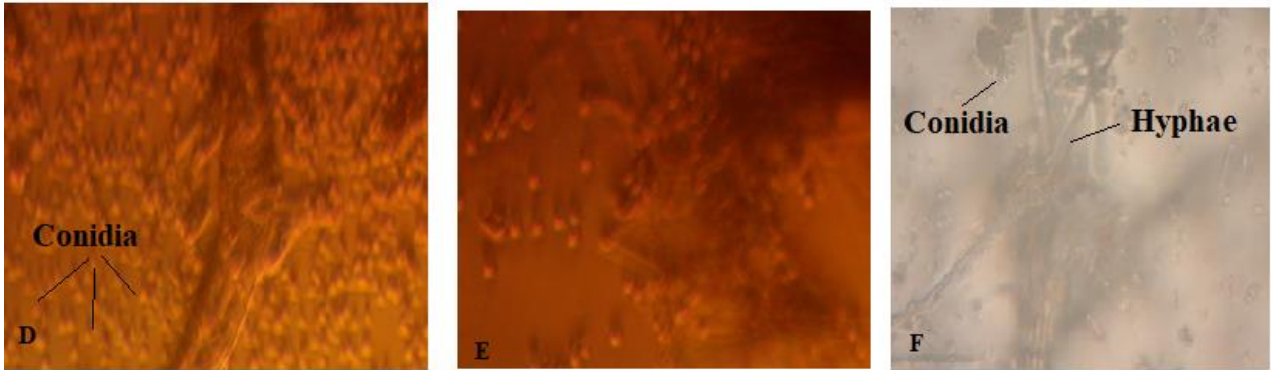
produce lignocellulolytic enzymes that degrade lignin and cellulose present in biomass (Kaur, 2017). *Penicillium* spp. are able to produce extracellular enzymes with good lignocellulosic hydrolysis performance (Krogh *et al.*, 2004). Some of the extra cellulolytic enzymes produced include; cellulase xylanase, protease, pectinase and peroxidase (Naraian and Gautam, 2018). Fig. 2.6(a-c), Fig. 2.7(d-f) and Fig. 2.8 (g-f) present the microscopic images obtained during the fungal identification. High fungal species diversity was noted in B1 which had the cattle manure mix. Interestingly, *Aspergillus* spp. was identified during the thermophilic phase in B1. Similarly, *Alternaria* spp. and *Penicillium* spp were identified during the thermophilic phase in B4 which had the grass mix. The fungal species obtained during the different phases of the biodegradation process are presented in Appendix II.



**Fig 2. 6:** Frequency of fungal occurrence in each bioreactor.



**Fig 2. 7: (a-c):** Microscopic images of *Alternaria* spp.



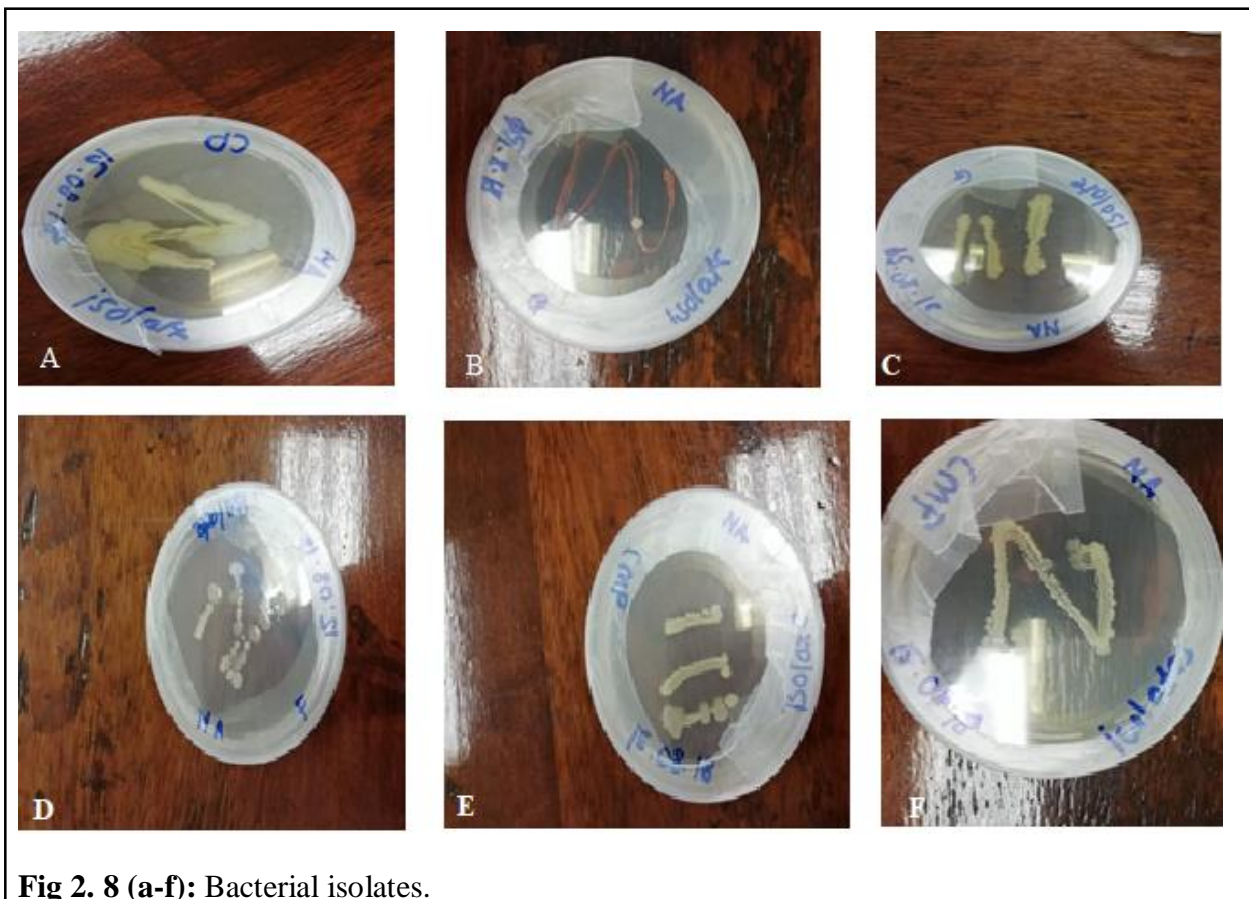
**Fig 2. 7(d-f):** Microscopic images of *Penicillium* spp.



**Fig 2. 7(g-h):** Microscopic images of *Aspergillus* spp.

#### 2.4.2. Bacterial isolation

The bacterial isolates that were obtained during the experiment are shown in Fig. 2.8 (a-f).

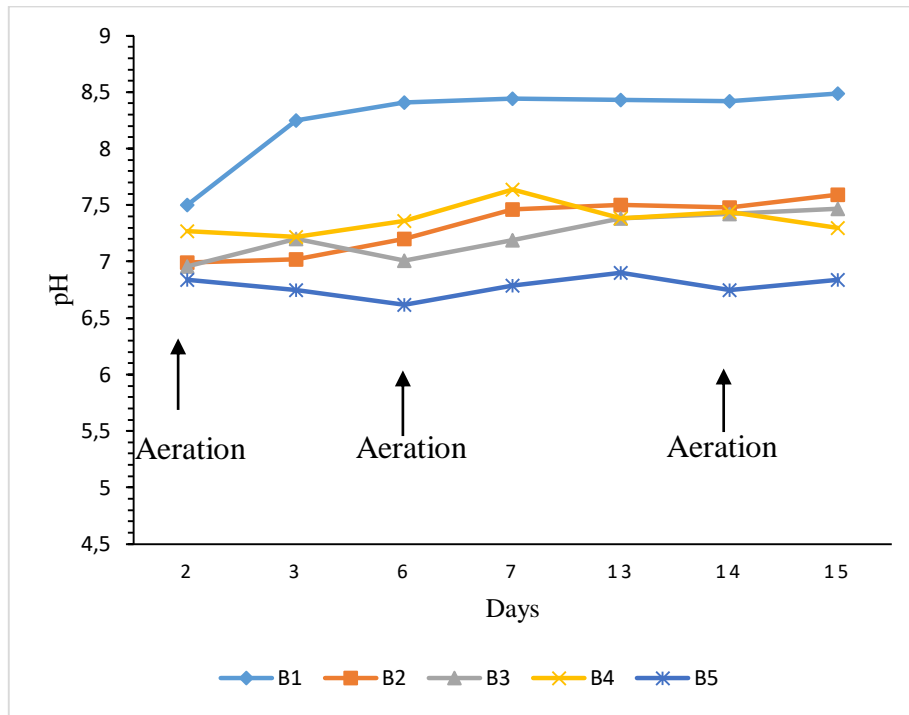


**Fig 2. 8 (a-f):** Bacterial isolates.

Based on their morphological characteristics and other studies, the bacterial isolates possibly included; *Bacillus*, *Esterichia coli*, and *Staphylococcus* spp (Wei *et al.*, 2018, Nakasaki *et al.*, 2019, Zhu *et al.*, 2019).

### 2.4.3. pH analysis in the bio-energy reactors

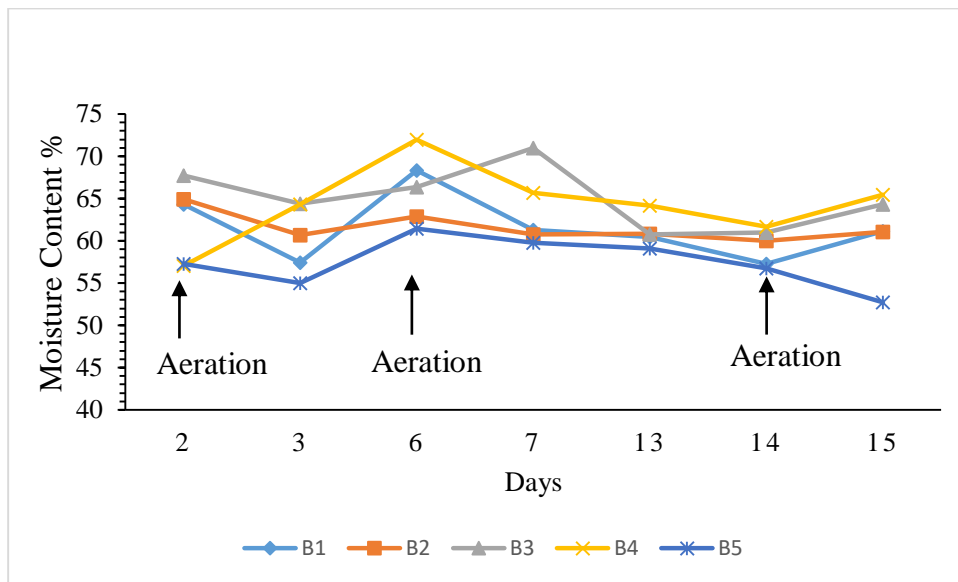
The pH of the different microbial growth media in the reactors was strongly statistically significantly different at  $P \leq 0.05$ . B5 (bioreactor with urea and grass mix) had the same initial and final reading of 6.84 (Fig 2.9). Additionally, it had the lowest maximum pH i.e.6.9 and minimum pH reading of 6.62.



**Fig 2. 9: pH readings in all the reactors.** Where: B1-cattle manure mix, B2-chicken manure mix, B3-plastic bio-energy reactor chicken mix, B4-grass mix, B5-Urea mix. A general increase was noted from the initial pH to the final pH except in B5.

#### 2.4.4 Moisture content assessment

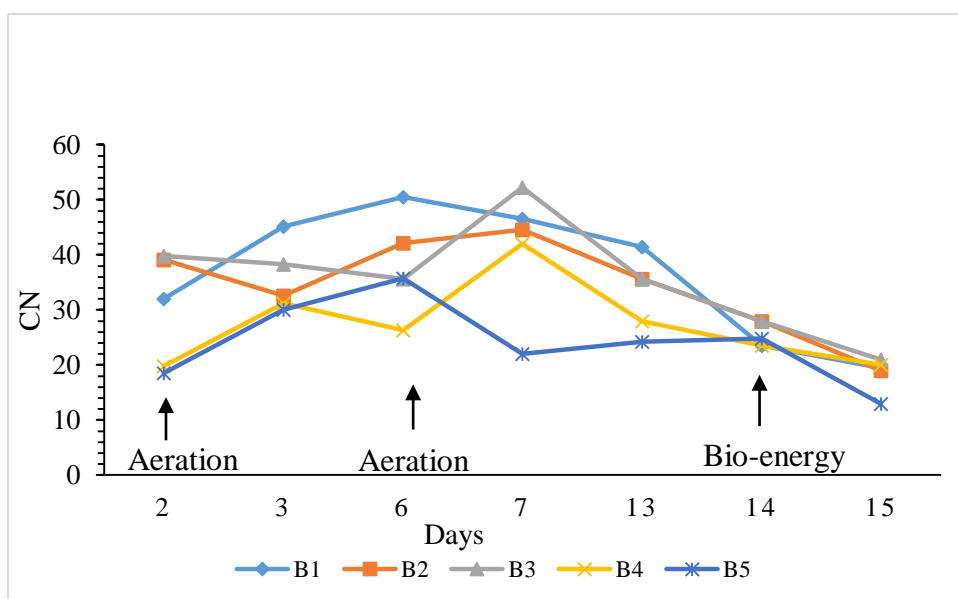
With regard to moisture content (MC), B5 had the lowest minimum MC of 52.72% and maximum MC 61.43%. The plastic bio-energy reactor retained moisture and as a result, the minimum MC of 60.47% that was observed was the highest in all the bio-energy reactors. The MC recorded appeared to be impacted by aeration as shown in Fig.2.10. Furthermore, there was a statistically significant difference between the moisture contents in the different microbial growth media at  $P \leq 0.05$ .



**Fig 2. 10: Moisture content in all the bio-energy reactors.** Where: B1-cattle manure mix, B2-chicken manure mix, B3-plastic bio-energy reactor chicken mix, B4-grass mix, B5-Urea mix. A general decrease in moisture content was noted from the initial moisture content.

#### 2.4.5 Carbon nitrogen ratio assessment

There was a general trend of an increase in the C/N ratio for all the bio-energy reactors which reached a peak value which was followed by a steady decrease from day seven as shown in Fig 2.11. Further, the C/N ratios were found to not be statistically significantly different between the various bioreactors ( $P \leq 0.05$ ).

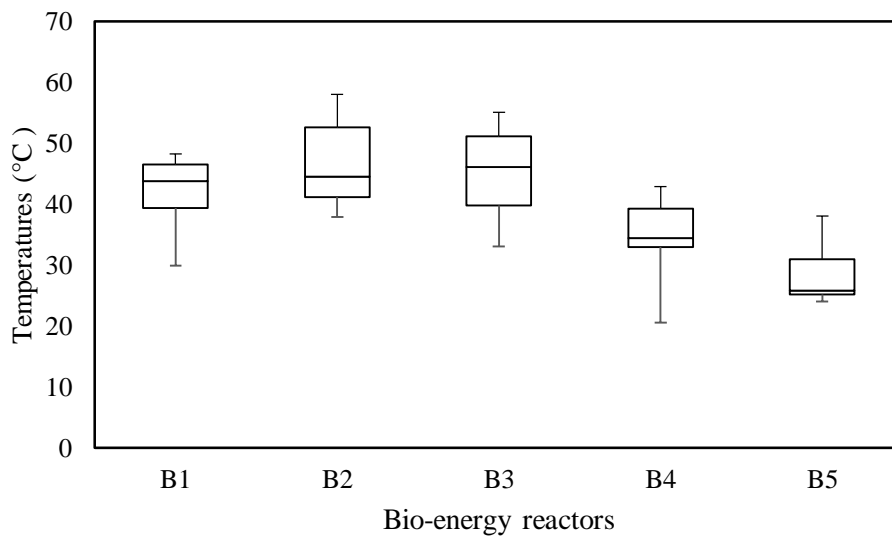


**Fig 2. 11: C/N ratios in all the bio-energy reactors.** Where: B1-cattle manure mix, B2-chicken manure mix, B3-plastic bio-energy reactor chicken mix, B4-grass mix, B5-Urea mix. A steep increase in the C/N ratio was noted across all the bio-energy reactors followed by a steady decline.

## 2.4.6 Temperature

### 8 am temperature profile

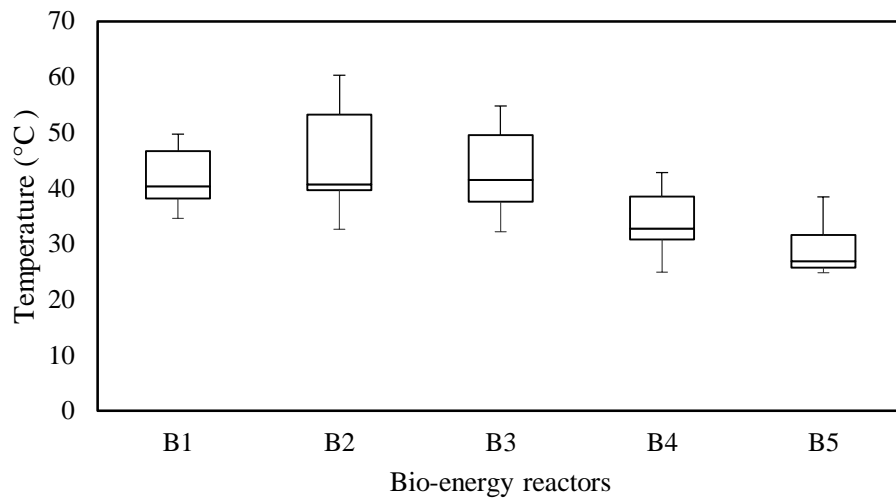
The median values of B1, B2 and B3 bio-energy reactors with cattle or chicken manure were noted to range between 43.8 and 46.1°C (Fig. 2.12). The median values indicate the mid values in the data points. The box plots further indicated that the bio-energy reactors with grass mix and urea mix (B4 and B5) had overall lower temperatures with median values of 34.4°C and 25.8°C respectively compared to the bio-energy reactors with cattle or chicken manure.



**Fig 2. 12: Box and whisker plots of 8 am temperature for all the reactors.** Bars start at the lower quartile and end at the upper quartile with the black line in the middle representing the median. Temperature recordings from the grass mix and urea mix bio-energy reactors were the lowest compared to the other bio-energy reactors.

### 12 pm temperature profile

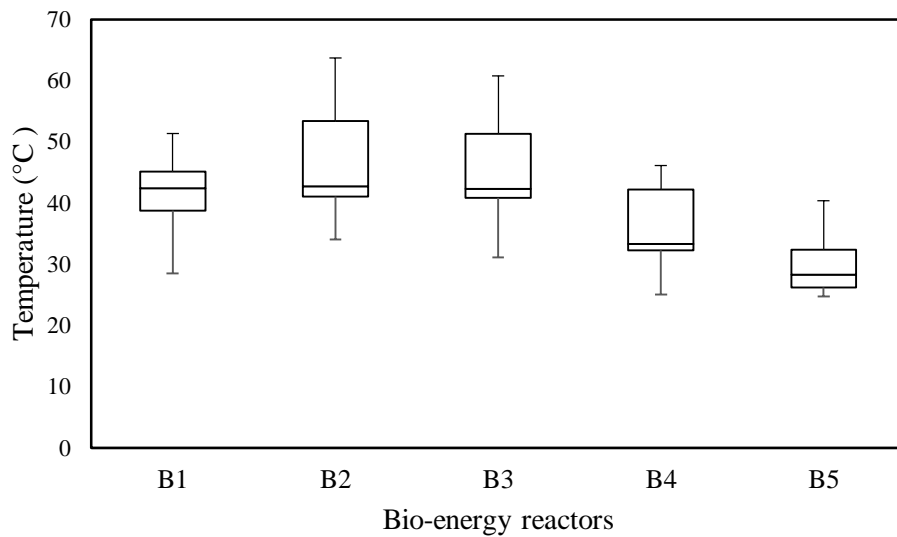
Analysis of the box and whisker plots at 12 pm indicated that the medians for the cattle or chicken manure were noted to range between 40.4 to 41.5°C hence the temperatures obtained in these bioreactor were relatively higher. (Fig. 2.13). Furthermore, B4 and B5 showed likely differences to the bio-energy reactors containing cattle or chicken manure. Interestingly, the 8 am median values for B1, B2, B3 and B4 were higher than 12 pm temperatures median values by an average of 3.9°C. Furthermore, the decrease in B5 temperatures between 8 am and 12 pm was not large.



**Fig 2. 13: Box and whisker plots of 12 pm temperature for all the reactors.** Bars start at the lower quartile and end at the upper quartile with the black line in the middle representing the median. Temperature recordings from the chicken manure bio-energy reactors were higher compared to the other bioreactors. The 12 pm temperatures were generally lower than the 8am temperatures with the median lying close to 40°C for the bio-energy reactors containing livestock manure.

#### 4 pm temperature profile

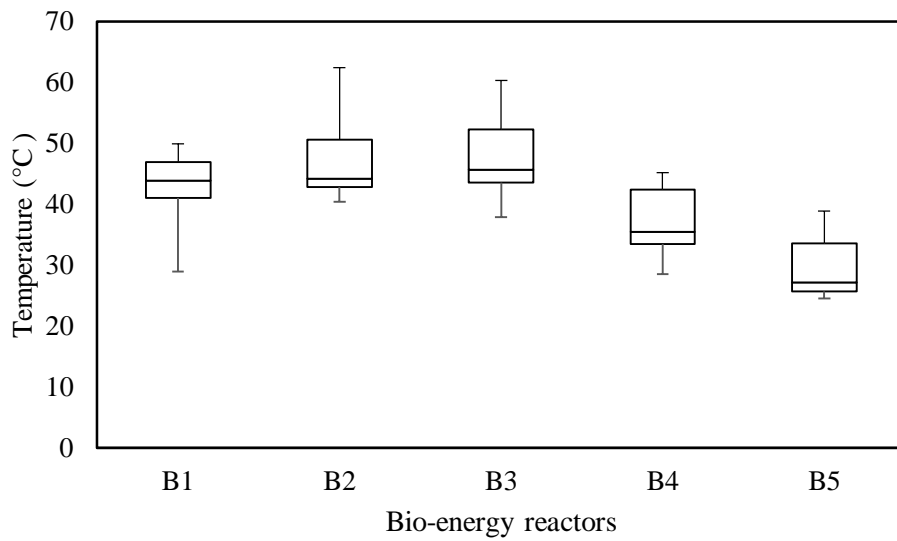
Analysis of 4 pm temperature profile suggests that B2 and B3 have variable higher temperatures than B1. Despite this, the medians for B1, B2 and B3 are very similar and range between 42.3°C and 42.8°C (Fig. 2.14). In addition, an overall increase of medians at 4 pm was noted compared to 12 pm temperatures suggesting that the temperatures began to increase at 4 pm.



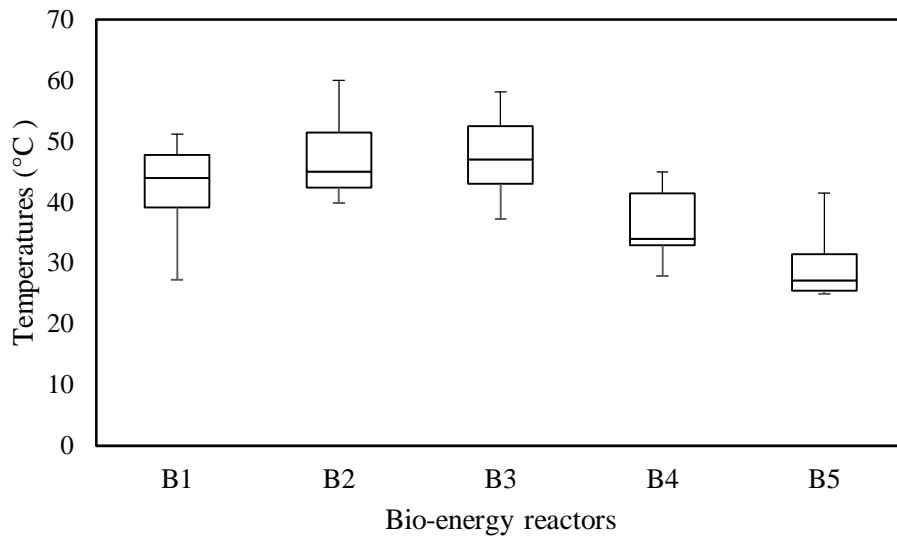
**Fig 2. 14: Box and whisker plots of 4 pm temperature for all the reactors.** Bars start at the lower quartile and end at the upper quartile with the black line in the middle representing the median. An increase in the upper quartiles from the 12pm temperatures was noted across all the bio-energy reactors.

### 8 pm-4 am temperature profile

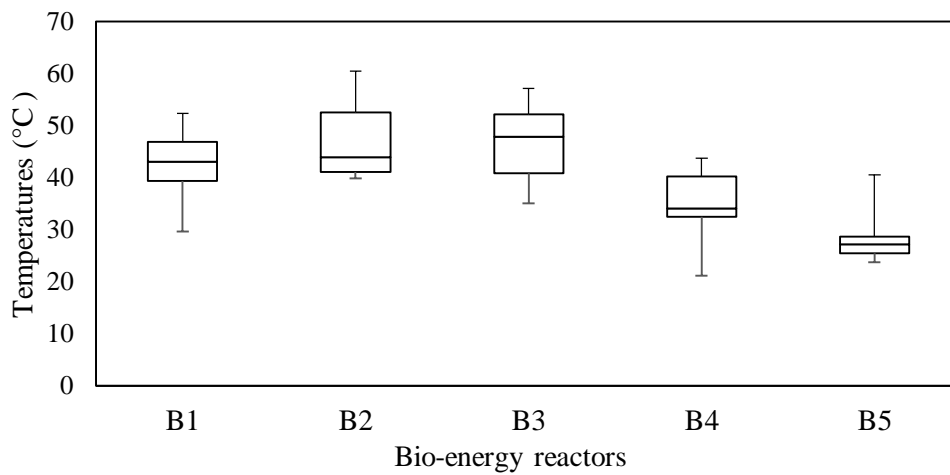
In the night readings, the temperatures assessed between 8 pm and 4 am are interestingly higher than the day time readings for all the bio-energy reactors as shown in Figs.2.15-2.17. In addition, B4 and B5 maintained considerably lower temperatures compared to the bio-energy reactors with cattle or chicken manure. However, B5 had a constant median value from 8 pm to 4 am of 27.2°C. Additionally, B3 (plastic bio-energy reactor) had the highest median values throughout the night-time recordings from 8 pm to 4 pm compared to B1 and B2 and continued to increase reaching 47.8°C at 4 am.



**Fig 2. 15: Box and whisker plots of 8 pm temperature for all the reactors.** Bars start at the lower quartile and end at the upper quartile with the black line in the middle representing the median. The temperature recordings in all the bio-energy reactors show a relatively steady increase except for B5.



**Fig 2. 16: Box and whisker plots of 12 am temperature for all the reactors.** Bars start at the lower quartile and end at the upper quartile with the black line in the middle representing the median. Temperatures recorded were noted to have a steady increase with the medians of B1, B2 and B3 reaching above 45°C. However, although B4 temperatures increased slightly, B5 median temperature did not increase.

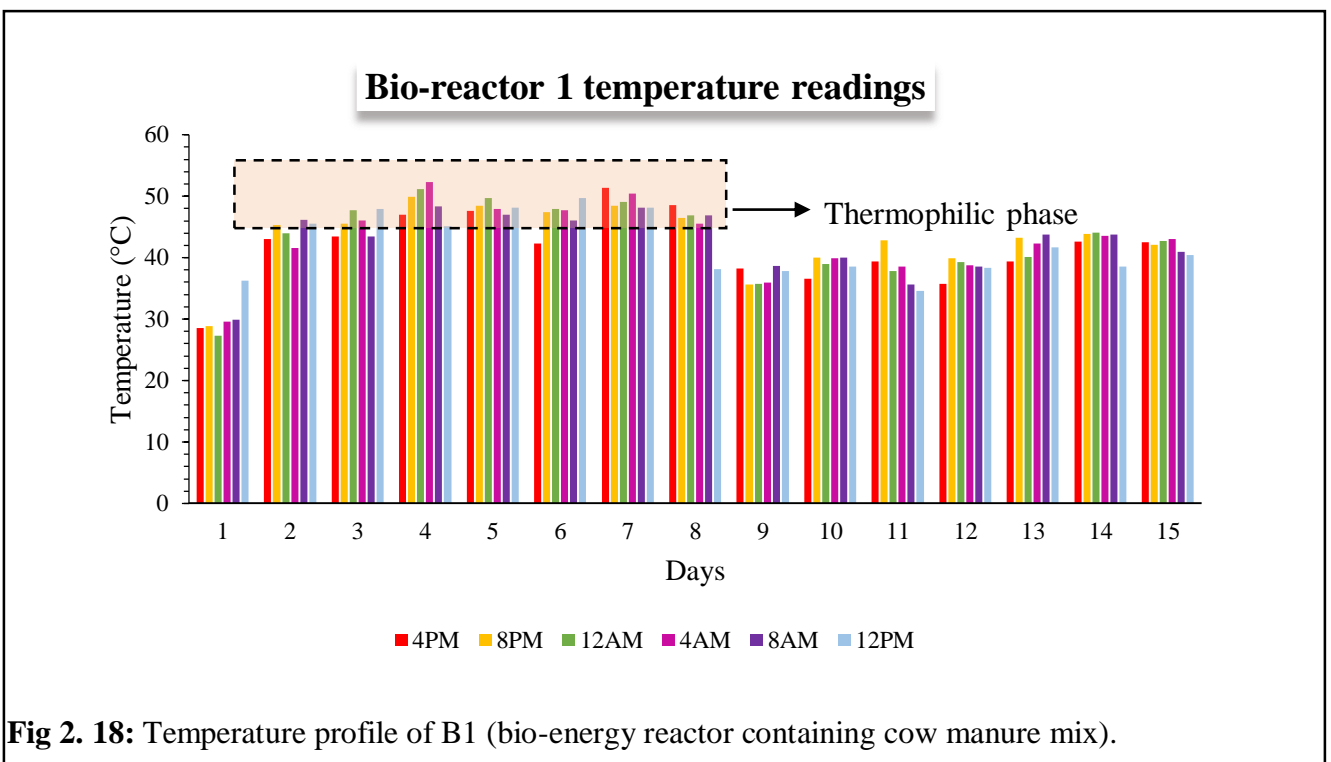


**Fig 2. 17: Box and whisker plots of 4 am temperature for all the reactors.** Bars start at the lower quartile and end at the upper quartile with the black line in the middle representing the median. B3 median temperatures increase and are slightly below 50°C whereas, B1 and B2 median temperatures decline below 45°C. In addition, B4 and B5 remain with relatively lower median temperatures than the bio-energy reactors containing livestock manure.

### 2.4.7 Thermophilic conditions in the bio-energy reactors

#### B1 analysis

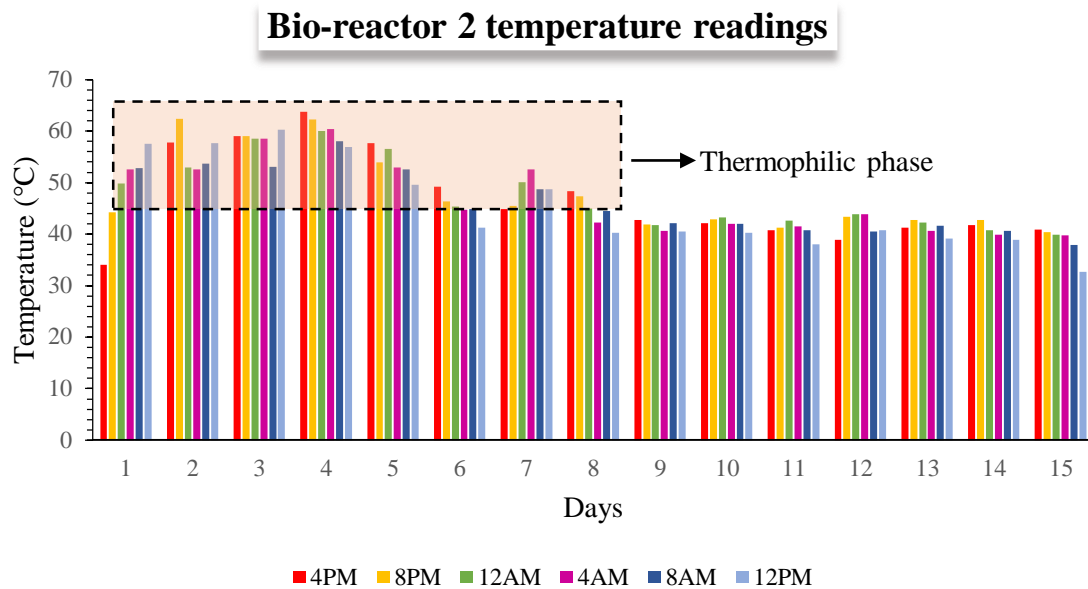
Thermophilic temperatures in the bio-energy reactor with cattle manure mix (B1) began on day 2. The thermophilic phase begins from 45°C and above. They were recorded at 8 am and lasted for one week. Thereafter, the mesophilic phase began and temperatures ranged between 34°C and 44.1°C. In addition, B1 was the only bio-energy reactor that showed the potential to increase temperatures further after week 2 as the temperatures had begun to gradually increase thereafter. The highest temperature recorded in B1 was 52.3°C on day 4 at 4 am as shown in Fig. 2.18.



**Fig 2. 18:** Temperature profile of B1 (bio-energy reactor containing cow manure mix).

#### B2 analysis

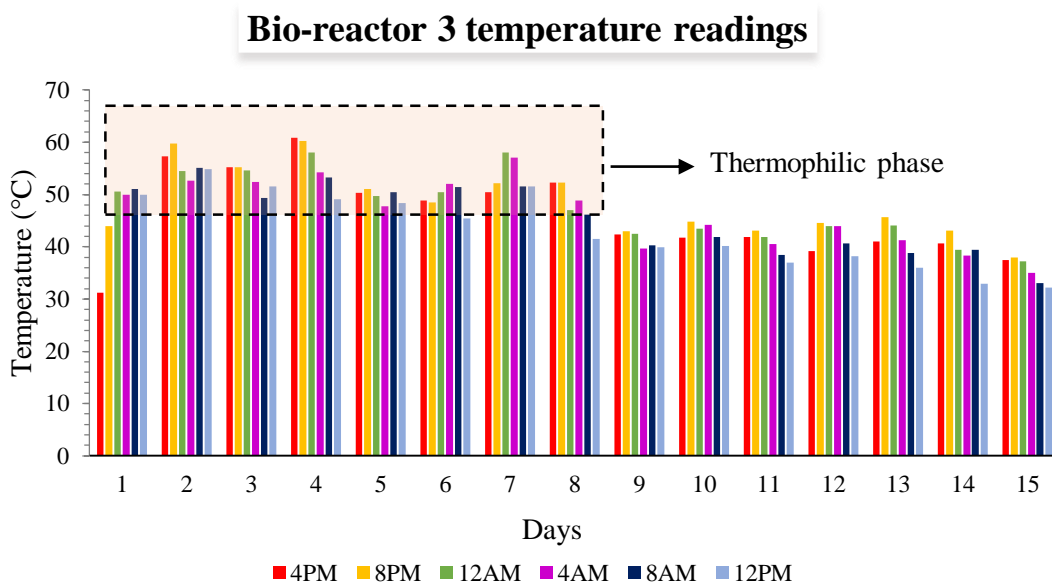
The bio-energy reactor containing chicken manure mix (B2) attained thermophilic conditions on the first day of the experiment at 8 pm and they lasted for eight days as shown in Fig. 2.19. The highest temperatures observed in B2 was 63.7 °C and it was the highest compared to all the bio-energy reactors. In the final week of the experiment, temperatures ranged between 32.7°C and 43.9°C. Interestingly, there was a very strong negative correlation between temperature and pH.



**Fig 2. 19:** Temperature profile of B2 (bio-energy reactor containing chicken manure mix).

### B3 analysis

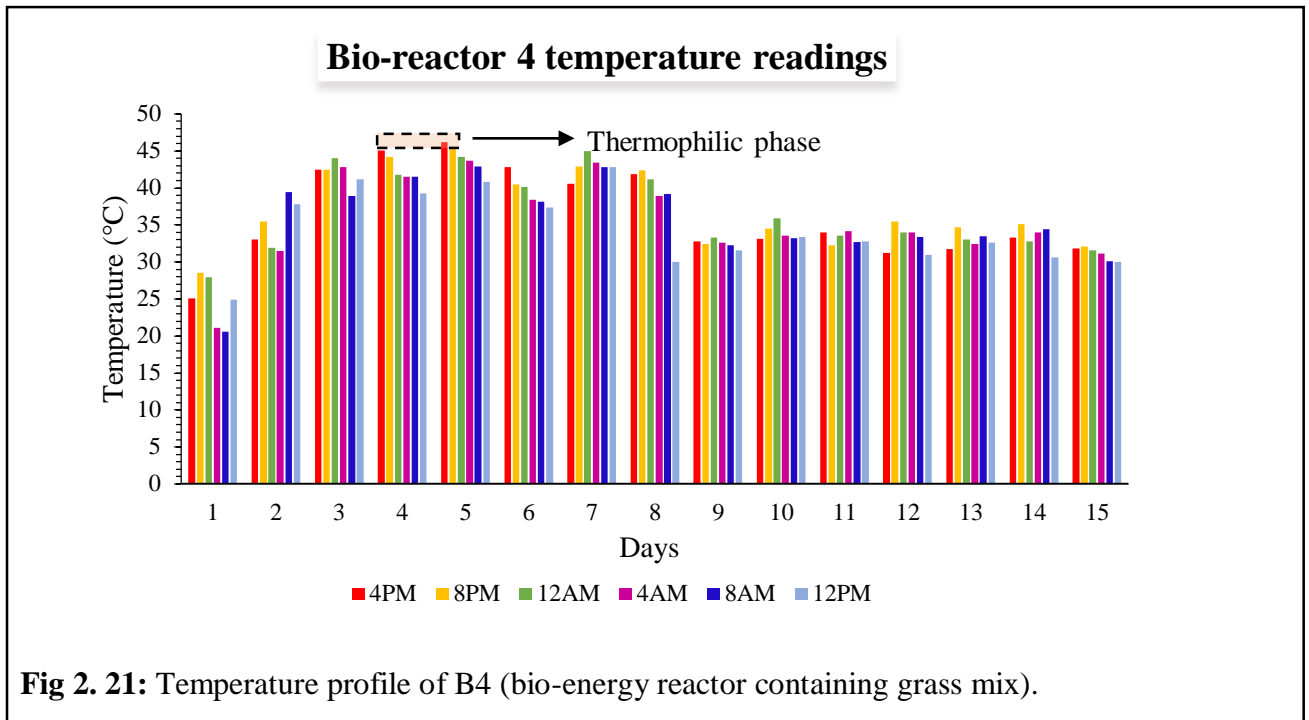
Thermophilic conditions in the plastic bio-energy reactor containing chicken manure mix (B3) began on the first day. They were recorded at 12 pm and lasted for eight days. The highest temperature recorded in B3 was 60.3°C as shown in Fig. 2.20. In the final week, temperatures ranged between 32.2°C and 45.7°C. In addition, there was a strong positive correlation between temperature and moisture content.



**Fig 2. 20:** Temperature profile of B3 (plastic bio-energy reactor containing chicken manure mix).

## B4 analysis

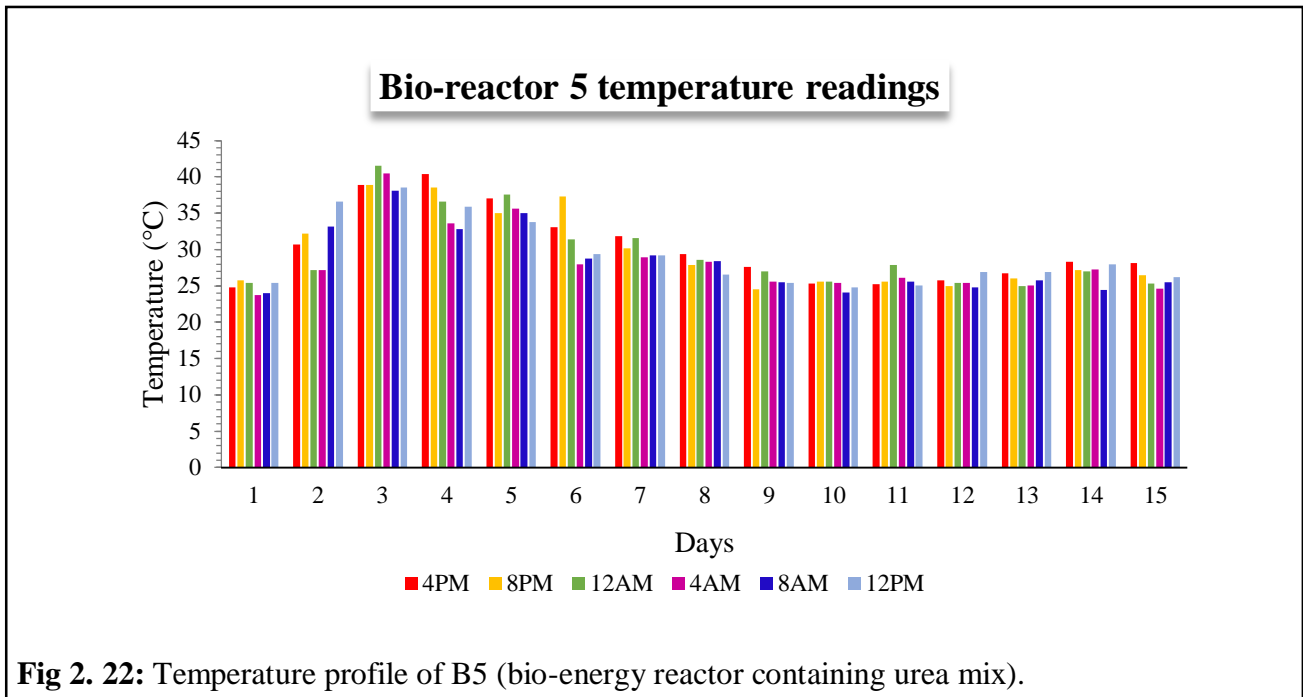
In the bio-energy reactor containing the grass mix (B4), thermophilic conditions began at 4 pm on day four and only lasted for two days. The highest temperature recorded in B4 was 46.2°C as shown in Fig. 2.21. Thereafter, temperatures ranged between 30°C and 45°C. There was a strong positive correlation between the C/N ratio and temperature.



**Fig 2. 21:** Temperature profile of B4 (bio-energy reactor containing grass mix).

## B5 analysis

The bio-energy reactor containing the urea mix (B5) failed to attain thermophilic conditions. In addition, it recorded the lowest temperatures in all the bio-energy reactors. Despite this, it showed an increasing temperature pattern similar to thermophilic rise in temperatures as observed in all the bio-energy reactors (Fig. 2.22). This pattern began on the second day and lasted three days. The highest temperature achieved in B5 was 41.5°C.



**Fig 2. 22:** Temperature profile of B5 (bio-energy reactor containing urea mix).

The highest temperature reading (63.7°C) in all the bio-energy reactors was obtained in B2-bioreactor with chicken manure. Table. 2.2 shows the summary of the descriptive statistics for all the bio-energy reactors. Additionally, the temperature means from the chicken and cattle manure bio-energy reactors ranged between 41.75°C to 48.37°C whereas the means from B4 and B5 never reached 40°C.

**Table 2. 2:** Summary of descriptive statistics for the temperature profiles.

Time (Hours)	B1	B2	B3	B4	B5	AT
08:00	42,49±5.21	46,23±6.30	45,39±6.77	35,53±5.83	28,35±4.46	19,55±1.85
12:00	41,92±5.00	45,49±8.83	43,23±7.33	34,41±5.15	29,25±4.63	26,04±1.97
16:00	41,75±5.79	46,87±8.76	46,04±8.27	36,34±6.25	30,21±5.09	26,23±2.18
20:00	43,2±5.51	47,75±7.70	48,37±6.57	37,22±5.25	29,75±5.25	24,4±2.63
00:00	42,83±6.42	47,5±6.70	47,7±6.61	36,69±5.48	29,54±5.18	19,15±1.64
04:00	42,87±5.88	46,98±7.15	46,53±6.63	35,55±6.03	28,35±4.68	17,85±1.42

Mean and standard deviation of temperatures recorded during the 15-day biodegradation process at four hour intervals in (A) bio-energy reactor containing cattle manure mix, (B) bio-energy reactor containing chicken manure mix, (C) plastic bio-energy reactor containing chicken manure mix, (D) bio-energy reactor containing grass mix and (E) bio-energy reactor containing urea mix.

The fluctuation between the daytime and the night-time temperatures (Fig 2.18 to Fig 2.22) was based on readings from the undisturbed bio-energy reactors. As indicated in the experiment procedure, the bio-energy reactors were turned periodically. After the turning of the bio-energy reactors at 8 am, a subsequent general decrease in the bio-energy reactor temperature readings at 12 pm was of great interest. However, this was followed by a sharp corresponding increase of temperatures in the following daytime and night-time time readings. This trend was however not observed in B5 where the 12 pm temperature readings were notably higher than 8 am temperatures including the days when turning occurred.

## 2.5 Discussion

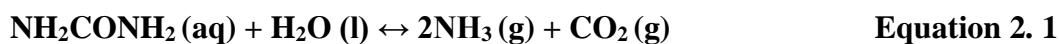
Thermophilic conditions (above 45°C) that were observed from the first reading of the biodegradation process in Bio-energy reactors B2 and B3 (chicken manure mix and plastic reactor with chicken manure mix) suggest high thermophilic bacterial activity. As a result, fungal species were only identified towards the end of the experiment during mesophilic conditions (see Appendix II, Table 6). *Penicillium* spp. was identified in both reactors on days 14 and 15. The very strong correlation ( $r = -0.94$ ) between pH and temperature indicates higher temperatures were observed in increasing acidic conditions. This suggests that thermophilic bacteria thrive in acidic conditions and metabolize causing high temperatures (Jin and Kirk, 2018). The night time temperatures for B3 were higher than that of B2 and this was likely caused by high microbial respiration occurring as a result of the MC retained by the plastic bio-energy reactor as noted by the strong positive correlation between MC and temperature ( $r = 0.71$ ). Whereas in B2 (metal bio-energy reactor), the correlation was found to be moderately positive between MC and temperature ( $r = 0.49$ ). The moderate correlation was likely caused by MC losses due to evaporation in the metal bioreactor. Furthermore, the plastic material used for the bio-energy plastic reactor has a thickness of 4mm which does not permit high heat losses hence moisture was not easily evaporated. However, there was a general increase in moisture content that was observed after turning all the bio-energy reactors (B1-B5) which could have been due to enhanced microbial respiration that could have occurred as a result of substrate leachate being reabsorbed into the microbial growth media during turning. The correlation between MC and C/N in B3 and B2 ( $r = 0.70$ ,  $r = 0.40$  respectively) suggest that the increased microbial respiration due to higher moisture content in B3 (plastic bio-energy reactor) further increased the ease of availability of nutrients for microorganisms and as they metabolized they emitted more heat. However, in B2 (metal reactor) the evaporative losses could have caused lower microbial respiration and resulted in a correspondingly lower C/N ratio.

Bio-reactor 1 (bio-energy reactor with cattle manure mix) was noted to have the highest overall frequency of fungal occurrence that were identified compared to the other bio-energy reactors (Fig 2.6). The fungal species identified in B1 at the start of the biodegradation process included; *Alternaria* spp., *Aspergillus* spp. and *Penicillium* spp. This indicates that these fungi thrive in mesophilic conditions. Mesophilic conditions lasted longer in B1 (1day) than in B2 and B3 (chicken manure mix) where thermophilic conditions began within four hours of the experiment. In addition, the pH in B1 (7.5) fell within the optimum pH range for *Penicillium* spp i.e pH of (5-9). (Dhakar *et al.*, 2013). During thermophilic conditions, *Aspergillus* spp. was identified (Appendix II, Table 6). This could have been a result of its thermo-tolerance (Mehboob *et al.*, 2014). *Aspergillus* spp. has an optimal growth temperature range of 37°C to 42°C. In addition, there was a positive correlation ( $r = 0.64$ ) between temperature and C/N ratio indicating that as the temperatures increased, more compounds were degraded resulting in more nutrient availability. *Penicillium* spp. was noted at the final stages of the biodegradation process. This trend was also noted in B2 and B3. Furthermore, it was interesting to note that the growth media composition ratios were equal for B1, B2 and B3 with the major difference being in the type of livestock manure used (Cattle manure for B1; Chicken manure for B2 and B3). This suggests that growth media composition is an important factor to be considered when biodegradation is to be used for heat recovery purposes due to the temperatures and microbial community differences in the bio-energy reactor contents.

Although all the bioreactors attained thermophilic temperature, B4 (bio-energy reactor with grass mix), cannot be used for heat recovery purposes as the thermophilic temperatures lasted for two days which may not be sufficient to sanitize the compost. In addition, the heat extraction in this reactor could result in slowing down or stopping the biodegradation process as the temperatures are relatively lower than the thermophilic temperatures achieved in the bioreactors with animal manure. The fungal species observed during the thermophilic conditions were likely due to lower day time temperatures as a result of temperature fluctuations occurring throughout the day during the biodegradation process. The low temperatures in B4 were most likely due to the lower nitrogen levels of green grass compared to animal manure. In addition, the MC in the bio-energy reactor was considerably high (65.67%) compared to that of B1, B2 and B5 which could have led to optimum moisture content conditions for *Alternaria* spp (Bullerman, 2003). Furthermore, although the temperatures may not have been optimum, *Penicillium* spp. was identified towards the end of the study and this was possibly due to the optimum pH ranges.

*Alternaria* spp. was the only fungal species identified in B5 (urea mix bio-energy reactor) at the beginning of the biodegradation process. *Alternaria* spp requires high moisture contents with optimum temperatures of up to 35°C and above and an optimum pH of 6.5 (Bullerman, 2003;

Hubballi *et al.*, 2010; Bailey, 2014). The moisture content requirements were met at the beginning of the experiment including the slightly acidic pH. However, urea volatilizes and produces ammonia which has antimicrobial properties (Veverka *et al.*, 2007). As a result, the presence of the *Alternaria* spp. was most likely due to the sample being collected before homogenization of the microbial growth media hence the antimicrobial properties of ammonia had not yet taken effect. Extremely low temperatures ranging between 23.7°C to 41.5°C were observed in B5 that could not reach thermophilic temperatures. The low temperatures can be attributed to the addition of urea in the microbial growth media mix which resulted in low microbial populations from the antimicrobial properties of ammonia. As the water was added to the microbial growth media, urea was dissolved resulting in a highly endothermic reaction. The overall equation for the decomposition of urea is shown in Equation. 1 (Gargurevich, 2016). However, the reaction is a two-step process as shown by Equations. 2 and 3 (Yim *et al.*, 2004; Gargurevich, 2016). The second step in the decomposition of urea is slightly exothermic and produces an acid. As a result, it is possible that fungi that break down the large carbon compounds for use by bacteria are unable to thrive due to the highly acidic conditions. The final step of the reaction is highly endothermic and this could further lower the temperatures noted in the reactor. These conditions are unsuitable for thermophilic bacteria therefore B5 is unsuitable for heat recovery purposes. Furthermore, all the bio-energy reactors had *Penicillium* spp. during the maturation phase of the biodegradation process except B5 (urea mix bio-energy reactor) possibly due to the acidic conditions and antimicrobial properties of ammonia that is released during urea decomposition. In addition, the fungal communities that were identified for B1, B2 and B3 for sample 6 (day 14), which were sampled immediately after turning the biomass suggest that fungal communities would be present in pockets in the bio-energy reactor thus, homogenizing the biomass is essential to obtain efficient biodegradation.



$$\Delta H = +113\text{kJ/mol}$$

Thermal decomposition of urea produces ammonia and isocyanic acid (Tischer *et al.*, 2019).



$$\Delta H = -23\text{kJ/mol}$$

Ammonium carbamate is produced which leads to the formation of ammonia and carbon dioxide.



$$\Delta H = 136\text{Kj/mol}$$

Although the bacterial communities were not identified to species level, the stages in which these bacterial communities were noted (mesophilic and thermophilic) is similarly in agreement with trends observed by other authors (Pasupathi and Devendrian, 2018; Wei *et al.*, 2018; Zhu *et al.*, 2019). The high temperatures noted in B1 after the thermophilic stage could also be due to enhanced respiration that occurs as a result of improved nutrient availability in the growth media. Easily degradable carbohydrates in microbial growth media material such as leaves would have been biodegraded causing high-temperature values that shorten the thermophilic stage. However, sawdust has a high lignin and cellulose content that takes longer to degrade and this assists in ensuring that there is a steady supply of carbohydrates over a longer period i.e. throughout the biodegradation process (Asadu *et al.*, 2018).

The interesting finding that the daytime temperatures were lower than the night-time temperatures could be due to the latent heat of vaporization and the specific heat capacity of biomass. As the ambient temperatures heat the biomass, the moisture that is present in the biomass is evaporated through the latent heat of vaporization and, as a result, a cooling effect occurs in the biomass due to the phase change of the moisture (Kirkham, 2014). Biomass has a specific heat capacity which can range above  $2.71 \text{ kJ}^{-1}\text{kg}^{-1}\text{K}^{-1}$  (Briški *et al.*, 2007; Iwabuchi, 2009; Irvine *et al.*, 2010). This specific heat capacity could mean that when the biomass is heated during the day by the ambient temperatures, it absorbs the heat and slowly dissipates it resulting in higher temperatures recorded at night. In addition to the heat produced by microorganisms, biomass is self-insulating hence the heat absorbed from ambient conditions would not be easily lost (Walther *et al.*, 2016; Aziz and Mustafa, 2018; Gurtler *et al.*, 2018).

After turning the bio-energy reactors for aeration at 8 am, the 12 pm temperature readings were notably lower but the readings after the 12 pm readings subsequently increased. This could be a result of the air that would have been introduced during aeration releasing the heat as latent heat (Zhao *et al.*, 2017; Smith and Aber, 2018). Another factor to be considered for the decrease in temperature is that the turning of the bio-energy reactor kills microbes by disrupting the biochemical reactions occurring that require oxygen thereby restarting the biodegradation process (Misra *et al.*, 2003; Román *et al.*, 2015). However, turning so as to kill the microbes is usually employed to mitigate the overheating of the biomass pile (Román *et al.*, 2015).

The temperatures observed in these bio-energy reactors would suggest that substrates consisting of animal manure are more suitable for heat recovery and that poultry manure emits more heat than cow manure. Therefore, poultry manure would be more suitable for heat recovery as relatively higher temperatures were obtained from bioreactors containing it. However, as the temperature profile of B1 showed an unusual gradual increase in temperature towards the end of the experiment,

a microbial growth media mix consisting of both cattle and poultry manure should be analysed for heat recovery purposes. In addition, the nutrient availability in cattle manure was also increasing with days from the breaking down of carbohydrates and other nutrients thereby making them easily accessible for other microorganisms. The shelf life determined for the heat recovery is 12 days beginning from day 3 of the biodegradation process so as to inactivate harmful pathogens. Overall, it was noted that pH, C/N ratio and moisture content play an important role in microbial communities and must be carefully managed so as to obtain thermophilic conditions that are necessary for aerobic biodegradation. A significant finding was that temperature profiles in the bio-energy reactors do not only change per day during biodegradation but, they change throughout the day with night-time temperatures recorded as being higher than the day-time temperatures.

## CHAPTER THREE

### DESIGN AND DEVELOPMENT OF A SOLAR-BIO-ENERGY HYBRID FRUIT DRYER

#### 3.1 Introduction

The drying efficiency of solar fruit dryers is considered to be unreliable because of their total dependence on sunshine hours (Tiwari, 2016). As a result, the effective drying efficiency of closed chamber solar fruit dryers without the supplementary heat is relatively reduced compared to that of the traditional open sun drying. Hybrid solar dryers commonly use varying supplementary heat sources that include; gas, firewood and charcoal. However, these may no longer be appropriate because of the recent global climate change challenges that have led to significant interest in technology that utilizes renewable energy. Renewable energy sources include; solar energy, wind energy and heat recovery from microbial respiration during substrate biodegradation (Smith and Aber, 2018). Solar energy and wind energy have been widely used as renewable energy whereas bio-energy from the biodegradation process has not yet been fully utilized (IRENA, 2015). Although heat recovery from the biodegradation process has been used in various agricultural processes, it has been mostly limited to; heating buildings, hotbeds for crop production, greenhouses and hot water use (Sokolovs *et al.*, 2015; Zhao *et al.*, 2017; Smith *et al.*, 2017).

Hybrid solar dryers using renewable energy have focused mainly on burning the biomass and extracting the heated gases for drying (Tibebu *et al.*, 2016). However, the burning of biomass poses threats to the environment through the release of pollutant emissions such as Nitrogen oxides, Sulphur oxides and Carbon monoxide (Kar and Keles, 2016). The use of energy from woody biomass can also contribute to deforestation. Technology that recovers the bio-energy from substrate biodegradation that would have been lost to the environment or surroundings has not been thoroughly investigated and developed. This technology would have the added advantage of providing farmers with bio-fertilizer through the production of compost. Therefore, the main objective of this study was to design and develop a solar-bio-energy hybrid fruit dryer.

#### 3.1.1 The specific objectives included:

- i. Using bio-energy from the biodegradation process and solar energy for the drying process.
- ii. The comparison of the solar-bio-energy hybrid drying temperatures to the traditional open sun drying temperatures.

### 3.2 Materials and methods

#### 3.2.1. Experiment description

The experiment and analysis of the samples were carried out at the North-West University Molelwane Farm laboratories 25°40.459'S, 26°10.563'E. Ambient temperatures in Mafikeng range between 27°C to 37°C in summer and -3°C to 25°C in winter.

#### 3.2.2. Design conceptualization

The solar-bio-energy hybrid fruit dryer was designed to have increased temperatures in the drying chamber due to the hot air flowing through the solar collector and bioreactor. The series connection of the bioreactor and the solar collectors increases the drying air temperatures through heat radiation in the solar collector and the air is heated further when it exits the drying chamber and passes through the bioreactor where it is heated through radiation and conduction. The design parameters that were taken into consideration included; environmental conditions of Mafikeng, physical properties of banana and Kei apple, local availability of materials to be used for construction, previous reported solar dryer designs in literature review, ergonomics and total production cost. The design procedure was carried out using a modified design procedure (Khandani, 2005; Khurmi and Gupta, 2005). The control experiment was open sun drying.

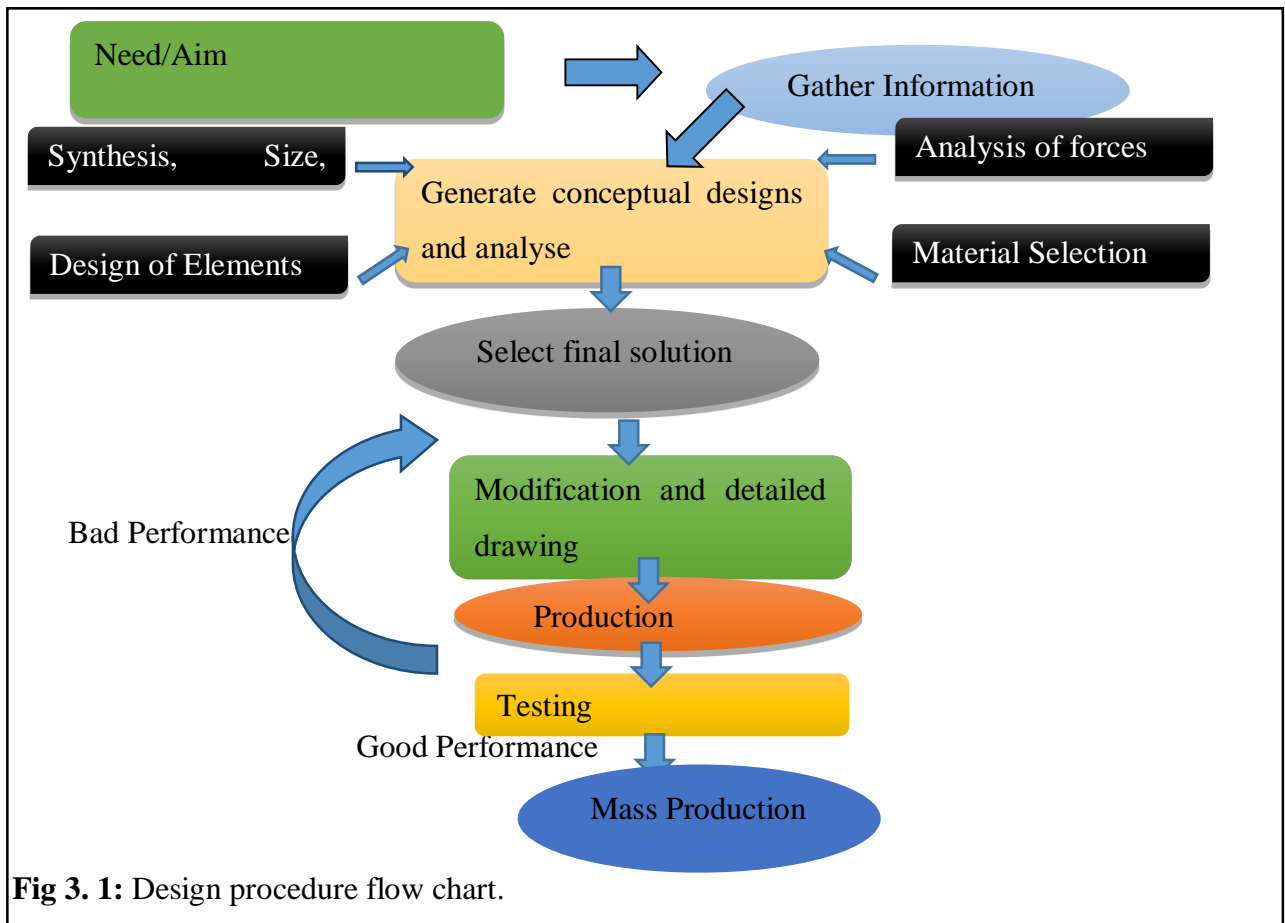
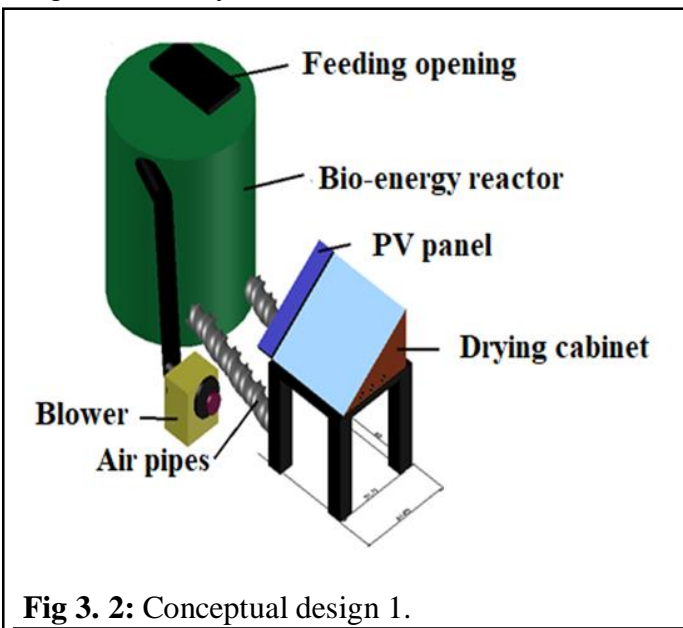
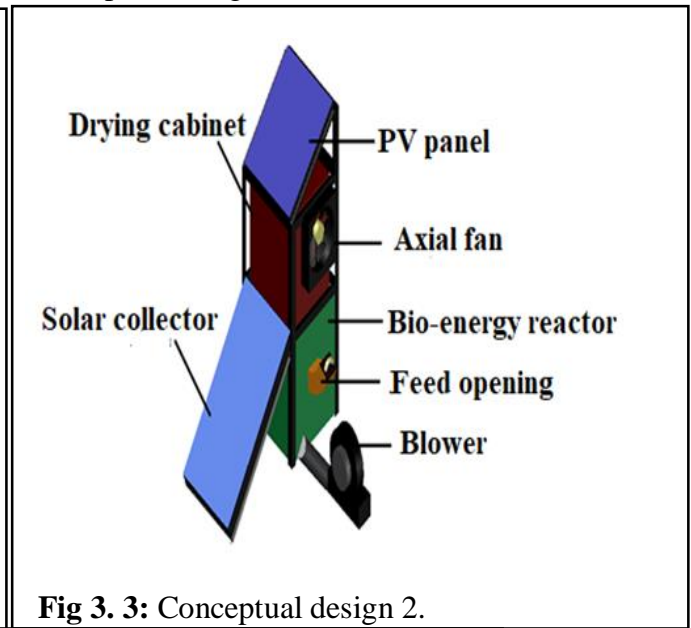


Fig 3. 1: Design procedure flow chart.

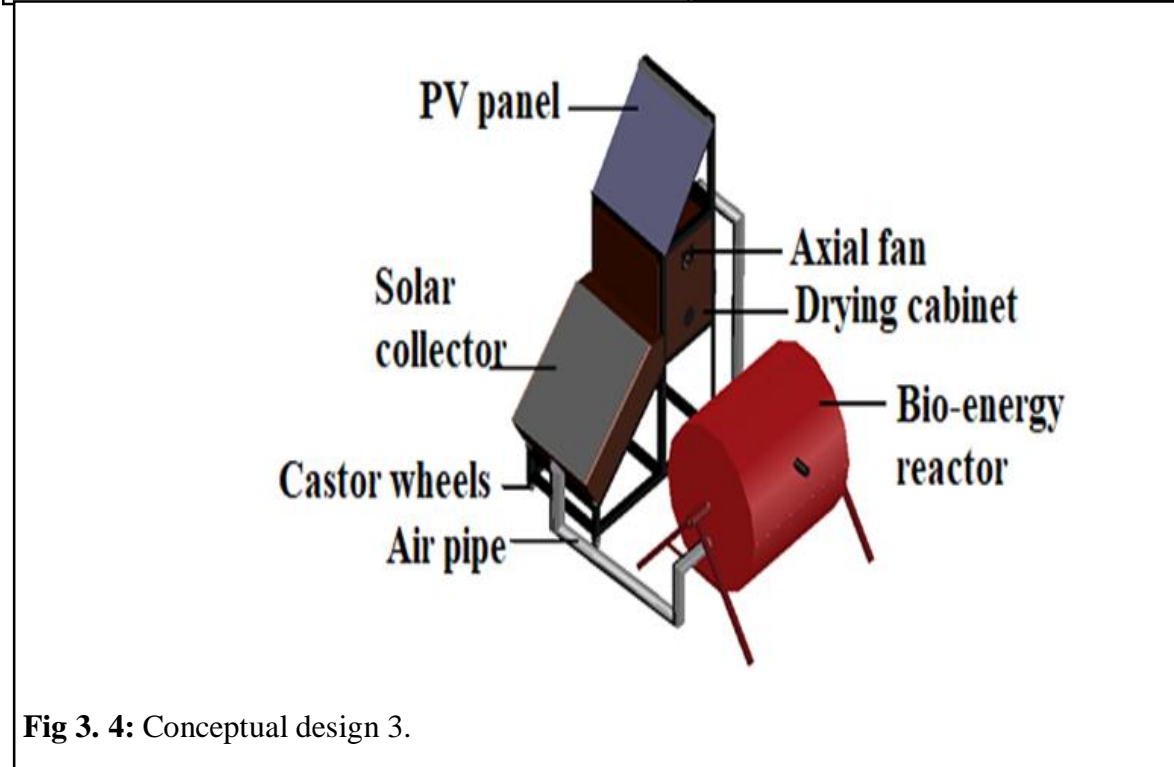
Based on the review of literature, three conceptual designs were generated as shown in Fig 3.2 to Fig 3.4 and they were assessed to select the final best conceptual design.



**Fig 3. 2:** Conceptual design 1.



**Fig 3. 3:** Conceptual design 2.



**Fig 3. 4:** Conceptual design 3.

### Conceptual design 1

This design has a direct drying chamber connected in series with a vertical bioreactor. A photovoltaic panel supplies power to a blower that aerates the biomass in the bioreactor. The photovoltaic panel also supplies power to exhaust fans that push the air through the bioreactor. The main advantage of this design is the large bioreactor which is able to supply relatively large amounts of heat. The main disadvantage of this system is that the excessive amount of heat that is generated including the short wave radiation from the drying chamber can cause case hardening of

the products, where the surface dries and further drying cannot occur. In addition, excessive heat can cause discoloration of the products thereby reducing the quality of the dried products.

### **Conceptual design 2**

This design has an indirect drying chamber connected in series with a bioreactor. It has a photovoltaic panel that supplies power to a blower and axial fan. The blower aerates the biomass in the bioreactor. The main advantage of this design is that it is compact and it has relatively fewer attachments. However, it is costly to produce and maintain.

### **Conceptual design 3**

This design has an indirect drying chamber connected in series with a bioreactor. It has a photovoltaic panel that supplies power to axial fans. The biomass in the bioreactor is aerated manually by turning the bioreactor. The main advantage of this design is that it is relatively less costly to produce and it is easy to maintain. However, it has a relatively lower efficiency compared to conceptual design 2.

#### **a) Best design selection**

To select the best conceptual design, key factors in the three conceptual designs were compared. The key factors include the cost of production, operability, ease of maintenance, reliability, efficiency, ease of manufacturing, safety and uniform drying. The conceptual design with the highest total points per factor was then selected as the final best conceptual design.

Of the factors that were considered in the design of the solar-bio-energy hybrid dryer, the cost of production was the major factor. The cost of production was categorized as follows: expensive, moderate or least expensive. Whilst operability, ease of maintenance, reliability, efficiency, ease of manufacturing, safety and uniform drying were rated as high, medium or low. The ratings were such that total costs carried 40% for least expensive, 20% for moderate and 10% for most expensive while the rest of the factors carried 10% for high, 5% for medium and 2.5% for low. A desk evaluation assessment was carried out and the summary assessment of the three conceptual designs is shown in Table 3.1.

**Table 3. 1:** Desk evaluation summary assessment of the three conceptual designs.

<b>Design factor</b>	<b>Conceptual design 1</b>	<b>Conceptual design 2</b>	<b>Conceptual design 3</b>
Total costs (%)	20	10	20
Operability (%)	5	2.5	10
Easiness of maintenance (%)	5	2.5	10
Reliability (%)	2.5	10	5
Efficiency (%)	5	10	5
Ease of manufacturing (%)	10	2.5	5
Safety (%)	5	5	10
Uniform drying (%)	5	10	10
Total Points (%)	57.5	52.5	75

The assessment of conceptual designs indicates that conceptual design 3 is the most appropriate selection for the solar-bio-energy hybrid fruit dryer as it scored 75% total points.

### **3.2.3. Sizing of the main components**

The components of the hybrid solar dryer included: solar collector, bioreactor unit, drying chamber, photovoltaic panels, fans and battery. The solar-bio-energy hybrid dryer was to be mobile/portable in order to increase ease of operability. To assist in the sizing of the components, various equations, ambient conditions data and psychrometric charts were used. Table 1 in Appendix IV shows the values for the design parameters used to size the dryer components.

#### **a) Flat plate solar collector**

The solar collector housing was constructed from plywood as it is a good insulator. In addition, it was painted with a dark oak wood exterior sealer to protect it from harsh weather conditions. The inside of the housing was insulated with rock-wool and lined with aluminium foil to avoid heat losses as the use of insulation increases solar collector performance (Fig 3.5). The absorber sheet is galvanized iron sheet that was painted black to increase solar radiation absorption. A 4mm glass sheet was selected for the glazing of the solar collector as it has been found to improve the

performance of solar air collectors and it has minimal convective heat losses (Bakari *et al.*, 2014). The distance between the absorber plate and the glass cover is 25mm. The solar collector is tilted at an angle of 30° at a north-south orientation (Le Roux, 2016).

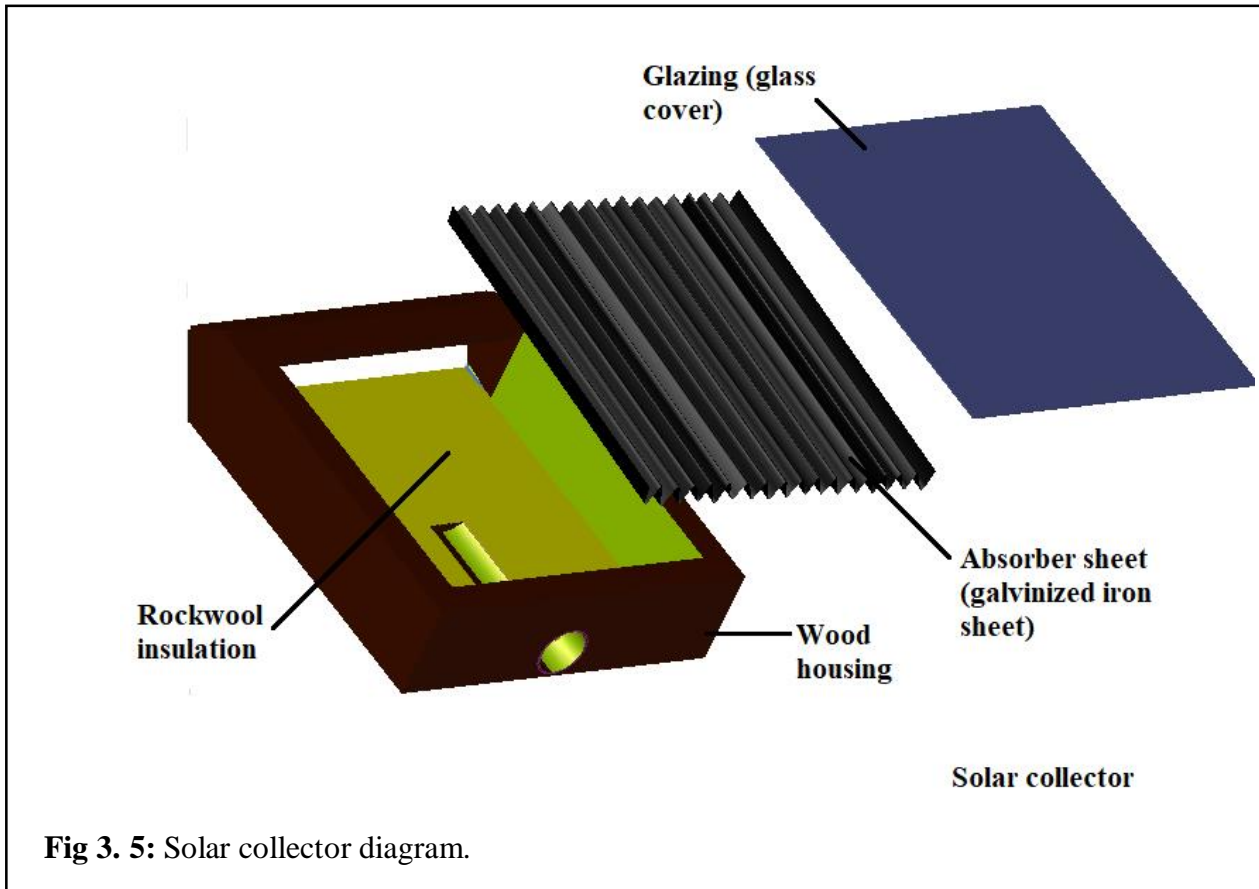


Fig 3. 5: Solar collector diagram.

The amount of moisture to be removed was calculated using

$$M_w = \frac{w_w (M_i - M_f)}{100 - M_f} \quad \text{Equation 3. 1}$$

Where  $W_w$  is the initial mass of product to be dried (kg),  $M_i$  is the initial moisture content of the product (% wet basis) and  $M_f$  is the final moisture content of the product (% wet basis)

The final relative humidity (ERH) was calculated using the sorption isotherms equation

$$ERH = 100a_w \quad \text{Equation 3. 2}$$

Where  $a_w$  is calculated using:

$$a_w = 1 - e^{[-e^{(0.914 + 0.539 \ln M)}]} \quad \text{Equation 3. 3}$$

Where  $a_w$  is the water activity and  $M$  is the moisture content dry basis (kg water/kg dry solids)

$M$  is calculated using:

$$M = \frac{M_f}{100 - M_f} \quad \text{Equation 3. 4}$$

Where  $M_f$  is the final moisture content of the product.

The average drying rate  $d_r$  [kg/s] was calculated from the mass of moisture content removed and the time it took to dry the product as shown in equation 7.

$$d_r = \frac{m_r}{\tau_d} \quad \text{Equation 3. 5}$$

Where  $m_r$  is the mass of moisture removed [kg] and  $\tau_d$  is the drying time [s].

To increase collector efficiency an aspect ratio of 2:1 was selected

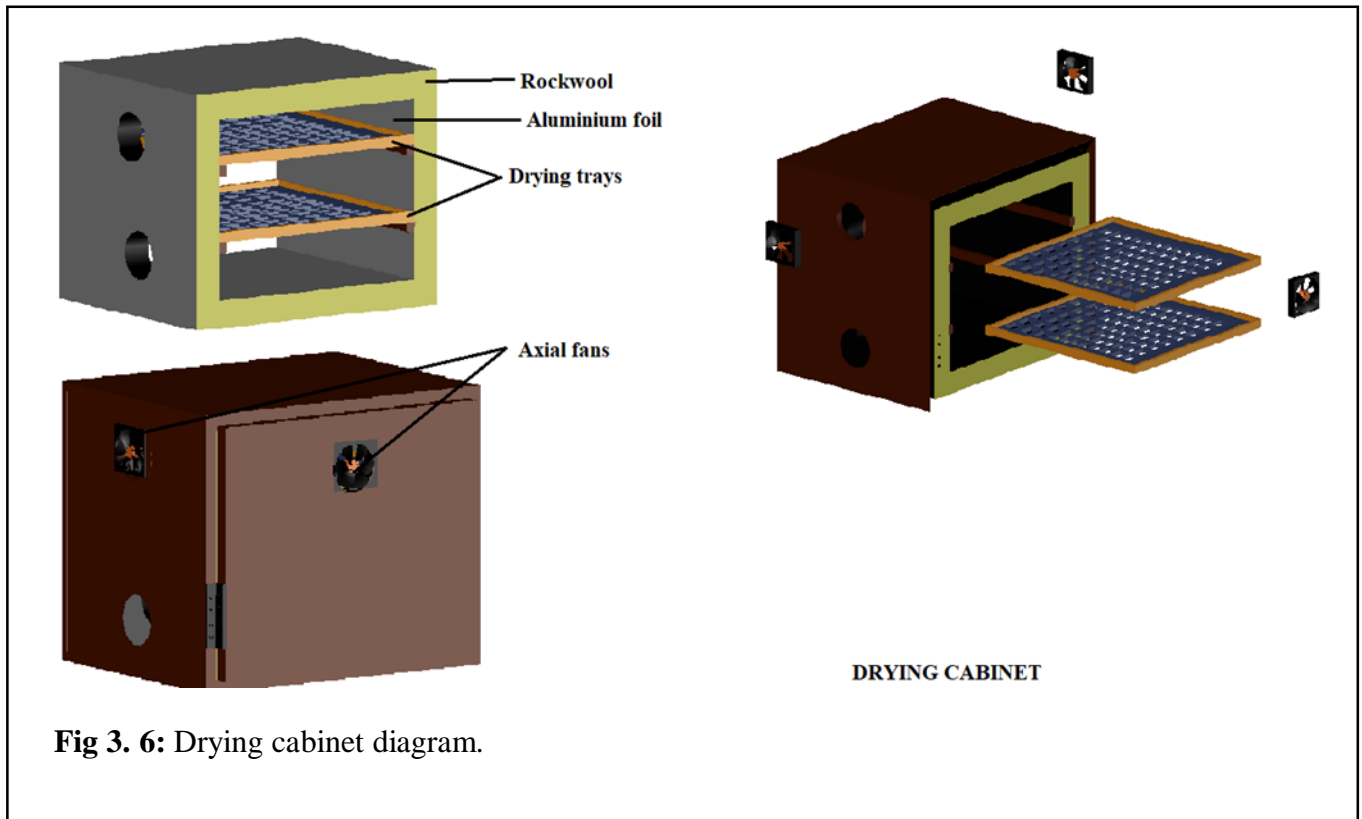
Aspect ratio is expressed as:

$$\text{Aspect ratio} = \frac{\text{collector length}}{\text{collector width}} \quad \text{Equation 3. 6}$$

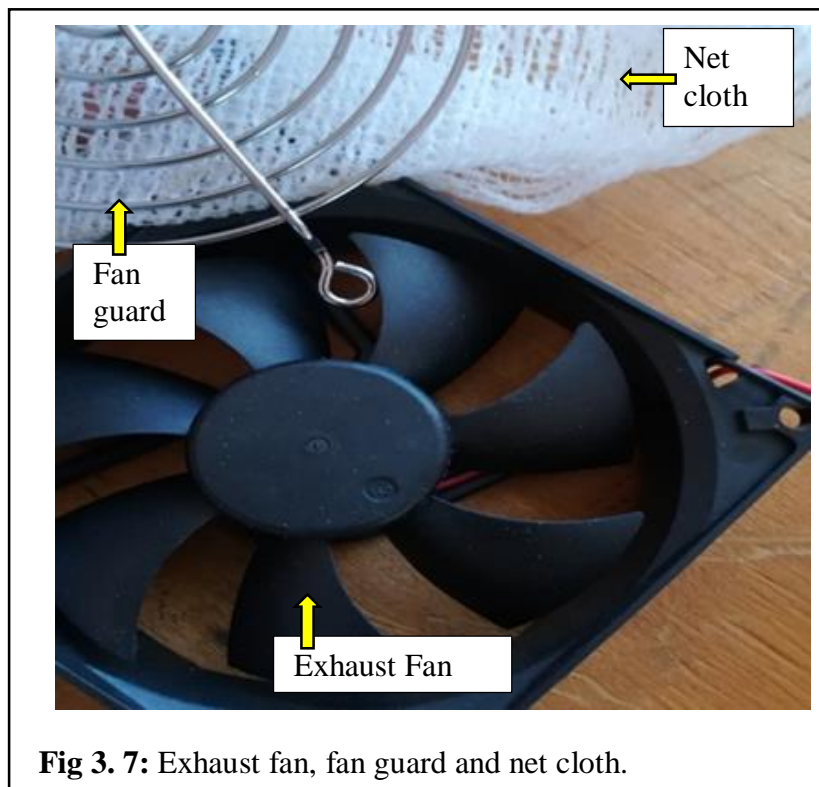
Based on the aspect ratio the resulting solar collector area is 0.72 m<sup>2</sup>.

#### **b) Drying chamber**

The drying chamber interior and exterior was constructed from plywood as it is a good insulator. In addition, it was painted with a dark oak wood exterior sealer to protect it from harsh weather conditions. The inside of the drying chamber was insulated with rock-wool and lined with aluminium foil to avoid heat losses (Fig 3.6). Furthermore, the door and all other openings were lined with weather stripping to minimize heat losses. Two trays made from steel mesh were placed in the drying chamber at 0.2 m apart. The exhaust fans were located in the drying chamber. To ensure effective drying three exhaust axial fans were used to produce a uniform mass air flow rate. The three fans were also selected based on their relatively low costs compared to in-flow fans and centrifugal blowers. The inlet and outlet openings were covered with a net cloth to ensure that no insects came into contact with the food products as shown in Fig 3.7.



**Fig 3. 6:** Drying cabinet diagram.



**Fig 3. 7:** Exhaust fan, fan guard and net cloth.

In addition, all openings had caps in order to close the openings when the dryer is not in use as shown in Fig 3.8. This increases the durability of the dryer by minimizing the risk of rodents or pests entering the dryer causing damage to the dryer interior. Equations used to calculate the size of the drying cabinet and fan design and solar panel system are shown in Appendix IV, Table 2.



**Fig 3. 8:** Air inlet sealed with cap.

### c) Bioreactor unit

The bioreactor was assembled horizontally on stands at 500 mm from the ground. The bioreactor had 10 mm diameter openings with a spacing of 100 mm and 450 mm on the periphery of the bioreactor for air circulation and leachate drainage. The bioreactor was primed with red oxide paint to prevent rusting and a handle was attached for turning. The unit had a square opening of 300 mm by 300 mm for feeding the bio-waste. In addition, the opening can be securely closed to prevent spilling of the substrate when aerating the biomass. The bioreactor unit had a galvanized iron pipe running through it that was connected to the insulation duct pipes for air circulation and heat transfer from the biodegradation process as shown in Fig 3.9. Despite copper pipes having a higher heat conductivity, a galvanized iron pipe was chosen as a cheaper alternative to copper. The pipe was sealed with silicone sealant to ensure that there were no leakages that could cause pathogen contamination.



**Fig 3. 9:** Galvanized iron pipe at the centre of the bioreactor.

Structural analysis for the frame that was used to support the drying chamber, photovoltaic panels and solar collector (see Appendix IV, Table 2). The component materials and value summary is shown in Table 3.3.

**Table 3. 2:** Component material and specifications.

Component	Material	Specifications
Flat plate solar collector	Wood	1.2*0.6 m 0.2 m depth of collector housing
	Glass	1.2*0.6*0.04 m
	Rockwool insulation	0.08 m thick
	Galvanized iron sheet	0.01*1.2*0.6 m
Bioreactor unit	Recycled metal drum	0.876*outside diameter 0.597 m length
Drying chamber	Wood	0.595*0.595 m
	Rockwool	0.06 m thick
	Aluminium foil	0.595*0.595 m
Air circulation	Direct current fans	12 V
	Battery	12 V Deep cycle gel
	Solar panel	100 W
	Insulated duct piping	10 m* inside diameter 0.1 m
	Galvanized iron pipe	1 m* inside diameter 0.1 m

### 3.2.4 Experimental procedure

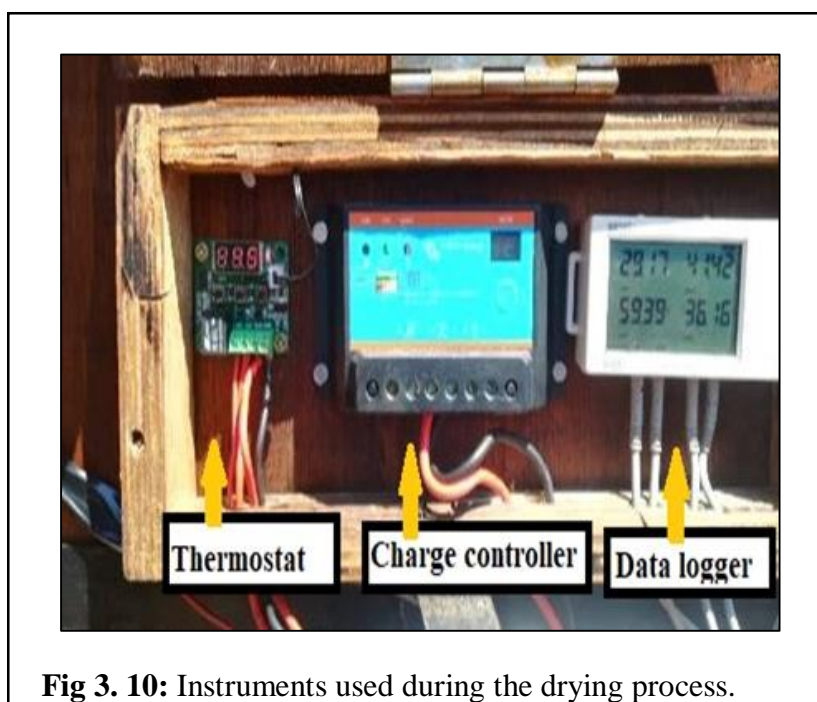
The bio-waste used in this study was selected from the bio-energy reactor which presented the highest temperatures in the previous experiment (Chapter two). This was the bio-energy reactor with chicken manure mix in the steel bio-energy reactor. Bio-waste was homogenized with various organic material including: chicken manure, grass clippings, dry leaves and sawdust with a total mass of 60 kg. The insulated pipe was connected to the bio-energy reactor three days after the biodegradation thermophilic process had begun. The thermophilic process was marked by

temperatures in the bio-energy reactor exceeding 45°C. This was done to eliminate airborne pathogen contamination and to avoid reducing the efficiency of the biodegradation process.

Air at ambient temperatures enters the inlet opening and is heated in the solar collectors. The hot air dries fruit in the drying chamber then is pushed out of the exhaust pipe and passes through the bioreactor unit where it is reheated and forced to the drying chamber. Moisture that is removed is absorbed by food grade desiccants placed in the solar collector and drying chamber.

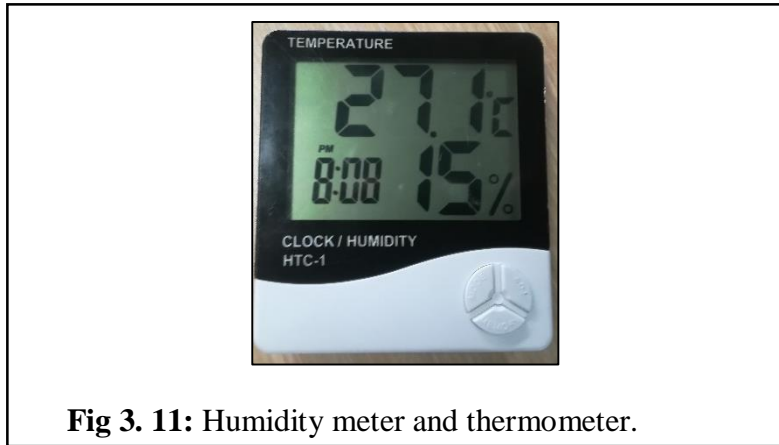
### 3.2.5 Analysis of the solar-bio-energy hybrid fruit dryer performance

The temperature was recorded by a Hobo UX 4 channel analogue data logger for the four temperature sensors that were placed in the following conditions in the dryer: one sensor was placed in a shaded area under the dryer to record ambient temperatures. Other sensors were placed inside the solar collector and in the inlet and outlet openings. A W1209 digital thermostat was set to switch on the fans at 15°C to maintain temperatures above this level of heating of the air that occurred in the solar collectors. The data logger and the digital thermostat are shown in Fig 3.10.



**Fig 3. 10:** Instruments used during the drying process.

A digital scale balance was used to determine the moisture content of the products during the drying process. A digital humidity meter was used to determine the relative humidity in the dryer and for ambient conditions (Fig. 3.11).



**Fig 3. 11:** Humidity meter and thermometer.

### a) Dryer efficiency

Solar dryer efficiency was calculated based on solar collector efficiency. It is expressed using:

$$\eta_{ds} = \frac{mC_p\Delta T}{AcI_s} \quad \text{Equation 3. 7}$$

Taking the energy supplied by the bioreactor, the Solar-bio-energy hybrid dryer efficiency is calculated using equation (Genobiagon Jr and B. Alagao, 2019)

$m$  is the mass flow rate of air calculated as:

$$m = \rho VA$$

Therefore the Total efficiency is calculated as:

$$\eta_h = \frac{m_w L}{AcI_s + P_w} \quad \text{Equation 3. 8}$$

Where  $C_p$  is the specific heat capacity of air,  $\Delta T$  is change in temperature,  $Ac$  is solar collector area,  $I_s$  is solar insolation,  $\rho$  is density of air,  $V$  is the volume of air required to dry the fruits,  $m_w$  is the mass of moisture removed,  $L$  is the latent heat of vaporization of water,  $P_w$  is the bio-energy input.

The effectiveness factor of the solar-bio-energy hybrid dryer was calculated using:

$$\text{Effectiveness factor} = \frac{\text{drying rate in hybrid dryer}}{\text{drying rate of open sun drying}} \quad \text{Equation 3. 9}$$

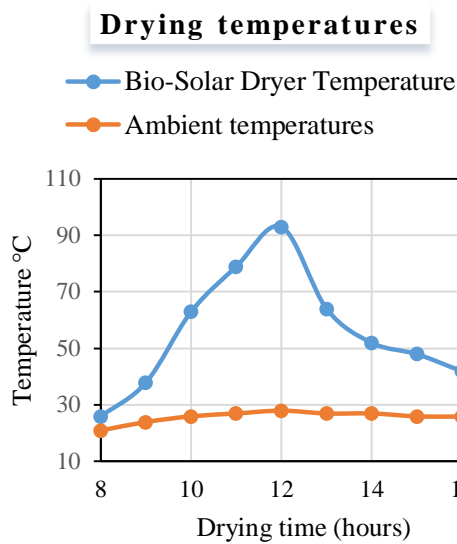
### b) Statistical Analysis

A Pearson correlation coefficient analysis was used to analyse the relationship between the solar-bio-energy hybrid dryer temperatures and ambient air temperatures in open sun drying. It was also

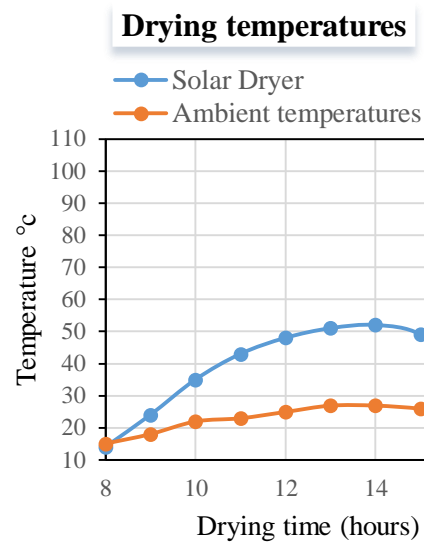
used to analyse the correlation between the relative humidity in the drying chamber and the drying rate in open sun drying.

### 3.3 Results

The temperatures obtained in the solar-bio-energy hybrid dryer from the reheating of the air reached 93°C at 12 pm whereas those obtained from the solar dryer without the bio-energy reactor had a maximum of 52°C at 2 pm. The ambient maximum temperatures ranged between 27-28°C between 11 am and 2 pm. As a result, open sun drying would take between three to five hours longer to reach the required moisture content levels based on the drying temperatures. Temperature variations from the solar-bio-energy hybrid dryer and open sun drying (ambient temperatures) on a selected sunny day are shown in Fig 3.12 for Solar-bio-energy hybrid dryer and Fig 3.13 for the solar dryer when not connected to the bioreactor unit.



**Fig 3. 12:** Solar-bio-energy hybrid dryer.

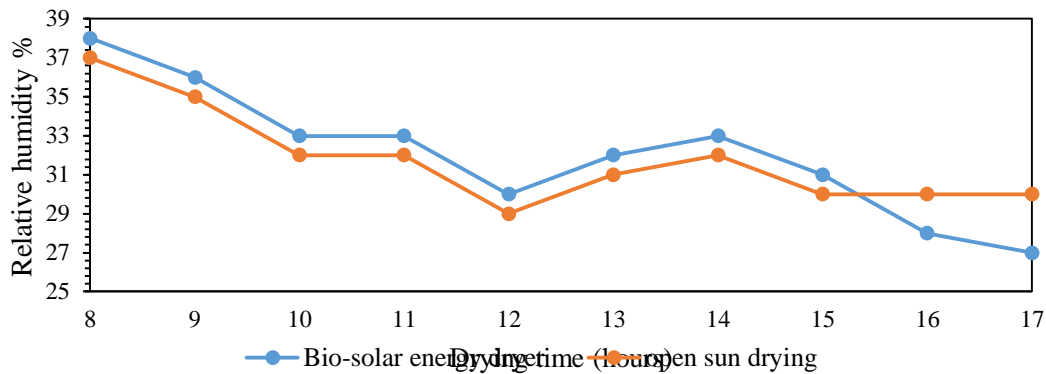


**Fig 3. 13:** Solar dryer- without bioreactor.

The thermal efficiency of the dryer without the bio-energy reactor was 36.02% and that of the solar-bio-energy hybrid dryer was 35.99% (Equation 3.7 and Equation 3.8) as a result of low convective heat transfer occurring in the solar collector and heat losses in the drying system. Using Equation 3.9, the factor of effectiveness of the solar-bio-energy hybrid dryer compared to open sun drying was 60%.

The relative humidity in the drying chamber was relatively higher than that of open sun drying in the first eight hours of the drying process as shown in Fig 3.14. However, in the final stages of the

drying process, the relative humidity in the drying chamber decreases considerably compared to that of open sun drying



**Fig 3. 14:** Relative humidity in solar-bio-energy hybrid drying chamber and open sun drying. There was no significant statistical difference in relative humidity at  $P \leq 0.05$ .

The fruits dried using the traditional open sun drying were shrivelled and discoloured compared to the ones dried in the solar-bio-energy hybrid fruit dryer.

### 3.4 Discussion

The relatively high temperatures noted in the solar-bio-energy hybrid dryer that ranged between 52-93°C from 12 pm until 2 pm indicate that bio-energy is effective in increasing temperatures considerably. A negative correlation  $r = -0.66$  was established between the drying rate in the solar-bio-energy hybrid dryer and ambient air temperatures. The negative correlation can be explained by the process known as case hardening where excessive heat introduced to the fruit limits the drying effect of the air. The outer layer of the fruit dries and hardens leaving the inner layers moist. As a result, the drying process is stopped despite the continuous introduction of hot air.

The relative humidity in the drying chamber that was found to be relatively higher than that of open sun drying was likely caused by the increased moisture-holding capacity of the heated air. As the hot air passes through the fruit it carries off moisture from the fruit as a result, the relative humidity increases. The increased relative humidity may have contributed to the steady drying rate. However, in the final stages of the drying process, the relative humidity in the drying chamber decreases considerably compared to that of open sun drying (Fig 3.14). The decrease can be explained by the steady removal of moisture in the drying chamber resulting in the decline of relative humidity.

There was a strong positive correlation between the relative humidity in the drying chamber and the drying rate ( $r = 0.90$ ). This correlation indicates that moisture content removal of the drying air increases the relative humidity in the drying cabinet.

There was a strong positive correlation ( $r = 0.84$ ) between the drying rate of the solar dryer without the bioreactor unit and ambient air temperatures. This indicates that this solar dryer relies strongly on ambient air temperatures whereas the solar-bio-energy hybrid dryer had a negative correlation with ambient temperatures as noted above. Furthermore, this suggests that the solar-bio-energy hybrid fruit dryer is capable of drying fruit when ambient temperatures are low i.e. cloudy weather or at night. In addition, the relatively higher temperatures noted in the solar-bio-energy hybrid fruit dryer (Fig 3.12 and Fig 3.13) would result in a faster drying rate compared to the dryer without the bioreactor unit.

In summary, the solar-bio-energy hybrid utilizes heat emitted from the biodegradation process. This heat energy, if not harnessed, would otherwise have been lost to the environment (Smith *et al.*, 2017). The additional benefit of this Hybrid Bio-Solar dryer unit is the residual organic material that remains in the bioreactor after heat energy generation. This organic matter can be used as a bio-fertilizer. This type of dryer, therefore, promotes optimum utilization of farm biomass. The design of the hybrid bio-solar dryer demonstrates opportunities for the development of renewable energy technologies that can assist farmers in energy-intensive agro-processing operations. With such technologies, farmers can reduce post-harvest losses and food insecurity.

## CHAPTER FOUR

### SENSORY EVALUATION OF DRIED BANANA AND KEI APPLE-BANANA- BLEND FRUIT ROLL

Dried fruit products are nutritious and can be stored for long periods of time. However, the quality of the food product is an important aspect that can determine overall acceptance of the product. In this study, dried banana and Kei apple banana fruit roll product types were evaluated hence the study as divided into two sections. The banana had four pre-treatments and the Kei apple banana blend fruit roll had three proportions.

#### (A) Sensory evaluation for dried banana

##### 4.1 Introduction

Banana (*Musa* spp) is a tropical fruit that is considered a vital food source in Africa, Southeast Asia and Central America (Mba, 2013). It is rich in carbohydrates, potassium, magnesium, phosphorus, iron, vitamins C and carotene (Elayabalan *et al.*, 2017). However, banana is a climacteric fruit, that is, it continues to ripen after being harvested. This ripening is caused by ethylene which is a plant hormone that stimulates the production of amylase enzyme that degrades starch into sugars (Goddard *et al.*, 2015). Furthermore, ethylene also causes pectinase to act on pectin in the pulp resulting in softened tissues (Elayabalan *et al.*, 2017). This continued ripening of the banana after harvesting leads to increased post-harvest losses for smallholder farmers. Smallholder farmers play a significant agricultural and food security role in developing countries through the production of fruits and vegetables at a household level (Gollin, 2014). However, the lack of appropriate storage facilities and technologies coupled with poor marketing and transportation conditions increase postharvest losses that smallholder farmers incur (Pandya and Chandra, 2014).

Drying is a value addition processing technology that can reduce post-harvest losses. The drying of banana is an inexpensive technology that extends the shelf life of the highly perishable fruit. Furthermore, drying reduces the volume of the product which results in ease of transportation (Sontakke and Salve, 2015). In addition, spoilage from biochemical reactions occurring due to respiration and moisture content in the fresh fruit is reduced. However, the quality of the dried banana is important for consumer acceptance. Factors that contribute to accepted quality include; colour, texture, sweetness (Belayneh *et al.*, 2013; Aridi *et al.*, 2016). In this study, the drying of banana fruit was carried out in a solar-bio-energy hybrid dryer. This dryer utilizes solar energy and

bio-energy from the biodegradation process for increased drying rates and a continuous drying process. The main objective of this study was therefore, to determine the most consumer acceptable pre-treatment method of the fruit dried in the solar-bio-energy hybrid fruit dryer.

#### **Specific objective:**

- i. To determine physicochemical differences between fruit dried using traditional open sun drying and fruit dried in the solar-bio-energy hybrid dryer.

## **4.2 Materials and methods**

### **4.2.1 Experiment description**

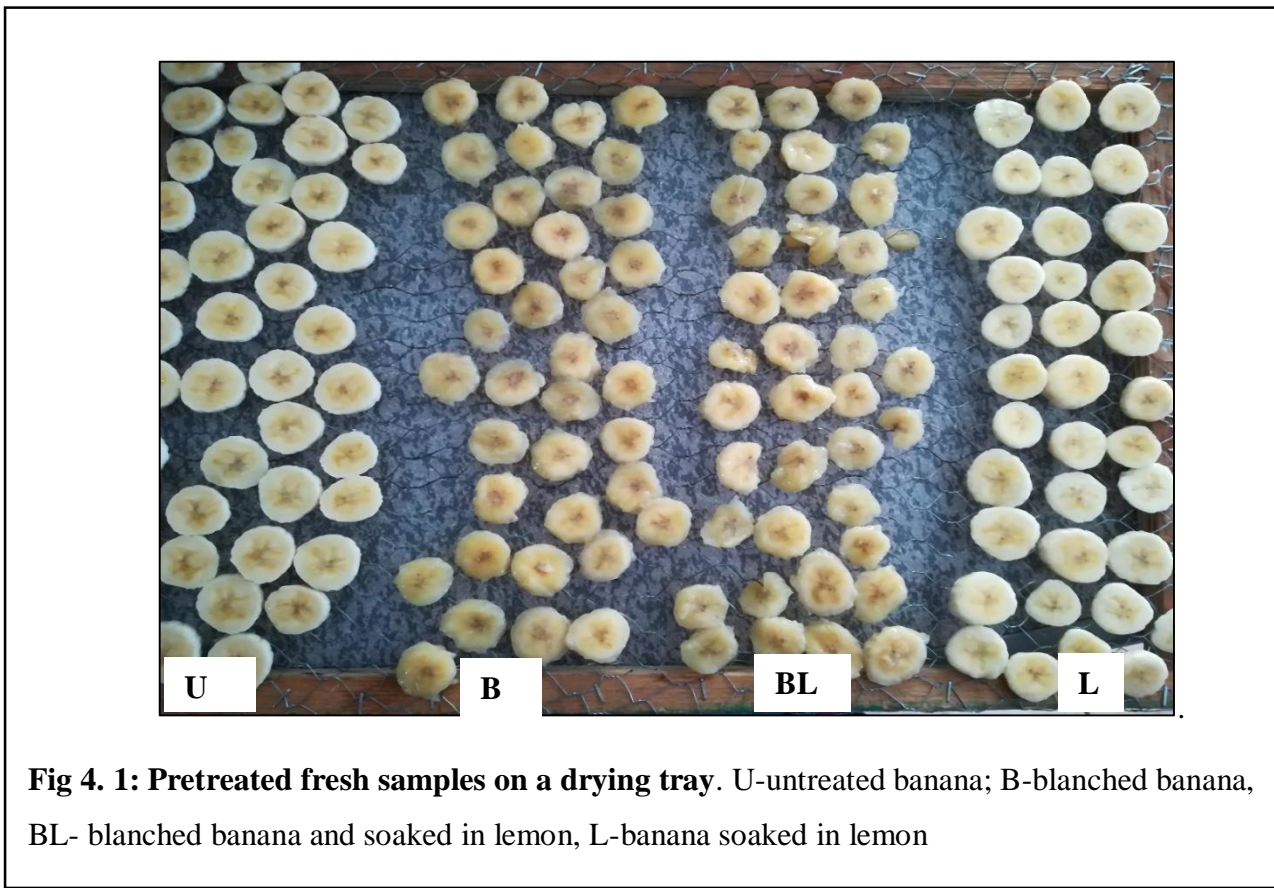
The experiment was carried out in Mafikeng and analysis of the samples was carried out at the North-West University Molelwane Farm laboratories 25°40.459'S, 26°10.563'E. Ambient temperatures in Mafikeng range between 27°C to 37°C in summer and -3°C to 25°C in winter.

### **4.2.2 Experimental procedure of pretreating and drying the banana fruit**

Ripe bananas that were visually assessed for blemishes and spoilage were purchased from a local supermarket. A composite sample was washed, hand-peeled and cut into 4mm disks using a sharp knife. The disks were measured using a vernier calliper. The disks were weighed to 100g per sample and placed on a tray. There were four pretreatments that were used in this study namely; the (i) untreated samples (control), (ii) blanched samples, (iii) blanched and soaked in lemon samples and (iv) soaked in lemon only samples. Blanching is a process where fruit is dipped in hot water for a short period of time of 30 seconds to ten minutes inactive or slow down enzyme activity. Lemon has high vitamin C content and acidity therefore it is used to preserve nutrients in food products. The pretreatment procedure is shown in Table 4.1 and the layout of the pretreatment samples is shown in Fig 4.1.

**Table 4. 1:** Pretreatment procedures.

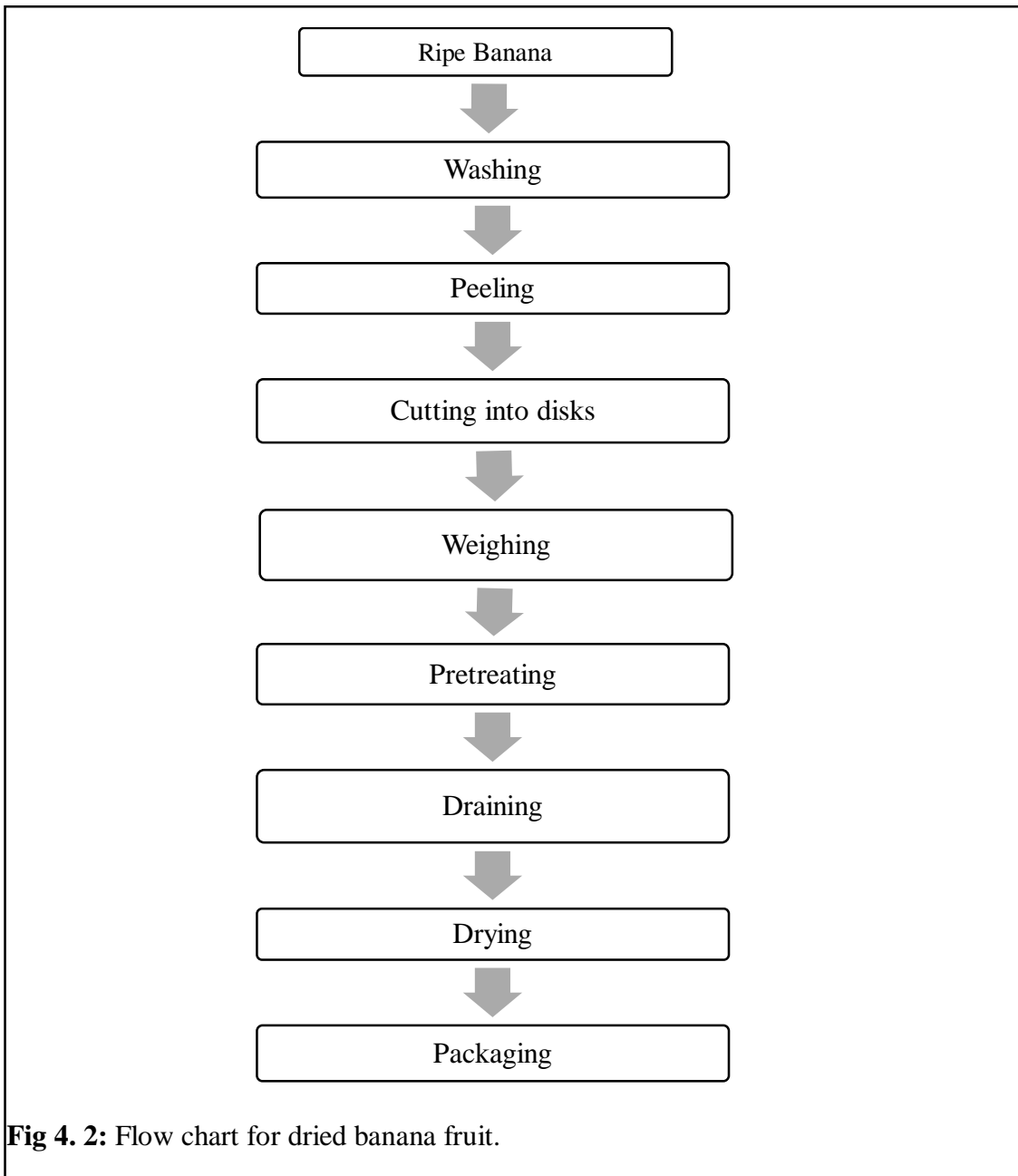
	<b>Untreated-control (KLM)</b>	<b>Blanch (HTS)</b>	<b>Blanch and lemon (GRF)</b>	<b>Lemon (JPY)</b>
<b>Procedure</b>	30 g disk samples were weighed and no treatment applied to them	30 g disk samples were placed in hot water (80°C) for 30s to ensure product firmness is not compromised. The fruits were then dipped in an ice bath for 30seconds to stop the blanching process	30 g disk samples were blanched using the procedure for Blanch thereafter, the disks were drained of water and dipped in lemon following the procedure for lemon	30 g disc samples were dipped in 50% v/v lemon juice for 2,5mins and the samples drained of the juice



**Fig 4. 1: Pretreated fresh samples on a drying tray.** U-untreated banana; B-blanched banana, BL- blanched banana and soaked in lemon, L-banana soaked in lemon

The pretreated samples were then placed on a drying tray and placed inside the hybrid dryer. Temperatures in the drying chamber had an average of 49°C whereas average ambient temperatures were 19°C. This pretreatment procedure was similarly done for the open sun drying and the drying tray was placed in an unshaded were the bananas were left to dry.

MC was recorded hourly for the duration of the 10-hour drying process for both fruits dried in the solar-bio-energy hybrid dryer and those dried using open sun drying. The flow diagram of the experimental procedure is shown in Fig 4.2.



**Fig 4. 2:** Flow chart for dried banana fruit.

### 4.2.3 Analysis

#### a) Sensory evaluation

A sensory preference evaluation was performed using a 5-point Hedonic scale. The preference criteria included; appearance, sweetness, texture and overall acceptability. The overall acceptability included the aroma of the dried bananas. Twenty-two (22) semi-trained randomly selected panellists comprising of local community church members were asked to assess three-digit coded samples and rate them using a Hedonic rating test (**1-dislike it a lot; 2-dislike it a little; 3-I neither like nor dislike it; 4-I like it a little; 5-I like it a lot**). The panellists were asked to rinse their mouths in between samples with the provided distilled water. Furthermore, the panellists were further asked to indicate their preferred order of the samples and their intent to purchase the products (see Appendix VI for Sensory evaluation scorecard).

#### b) Analysis of total soluble solutes

Samples of banana fruit were washed and manually peeled. 30g of the fruit was blended with 95ml distilled water for 2 minutes using a hand blender shown in Fig 4.1. The juice was then tested for TSS using a digital refractometer (Atago pocket refractometer, PAL-1,0-53%). TSS was read as Brix that is equal to TSS %. Data was collected in triplicate.

#### c) Analysis of pH and titratable acids

The pH method was used to determine titratable acids (OECD, 2018). The pH was determined using a pH meter (PHS-25C Microprocessor Bante Instruments). Samples of the banana were prepared by measuring 30 g of the fruit which were blended with 90 ml distilled water for 2 minutes using a hand blender. The juice mixed with 50 ml distilled water and the pH recorded. The mixture was titrated with 0.1 M sodium hydroxide to the endpoint pH of 8.1.

Acid ratios were determined using Equation 4.1 and the acid factors in Table 4.1 (OECD, 2018).

$$\% \text{ acid} = \frac{\text{Titre} * \text{acid factor} * 100}{10}$$

**Equation 4. 1**

**Table 4. 2:** Acid factors for different acids.

<b>Acid</b>	<b>Acid factor</b>
Citric acid	0.0064 (Citrus fruits)
Malic acid	0.0067 (Apples)
Tartaric acid	0.0075 (Grapes)

**d) Analysis of moisture content (MC)**

The moisture content (MC) of the samples was determined using the oven-dry method where initial samples were weighed then dried for 4 hours at 70°C. The dried sample was re-weighed and MC expressed as a percentage of the dried sample. Data was collected in triplicate.

**e) Analysis of total phenol content**

Total phenolic content was determined using Folin Ciocalteu reagent. To prepare the extract, 0.2 g of the ground fruit was dissolved in 10 ml 50% v/v methanol and the mixture vortexed at 2000 rpm for 2 min. The reaction mixture consisting of a total volume of 2ml was made up of 450 µl distilled water, 250 µl of 1 N Folin-Ciocalteu's phenol reagent, 1250 µl of 2 % sodium carbonate and 50 µl of the fruit sample. The mixture was briefly mixed in a vortex mixer (IKA, vortex 3) for 6 s and incubated at room temperature for 40 minutes. The absorbance was measured at 725 nm using a spectrophotometer (Spectrum, UV 300 series, Spectrophotometer) against the reagent blank. The reagent blank was prepared using 450 µl distilled water, 250 µl of 1 N Folin-Ciocalteu's phenol reagent, 1250 µl of 2 % sodium carbonate and 50 µl methanol 50% v/v. A Gallic acid equivalent (GAE) standard curve was used to convert the measured absorbance readings into phenolic compounds concentrations per gram of extract. The phenolic content was reported as mg gallic acid equivalents (GAE)/g DW. The samples were conducted in triplicate.

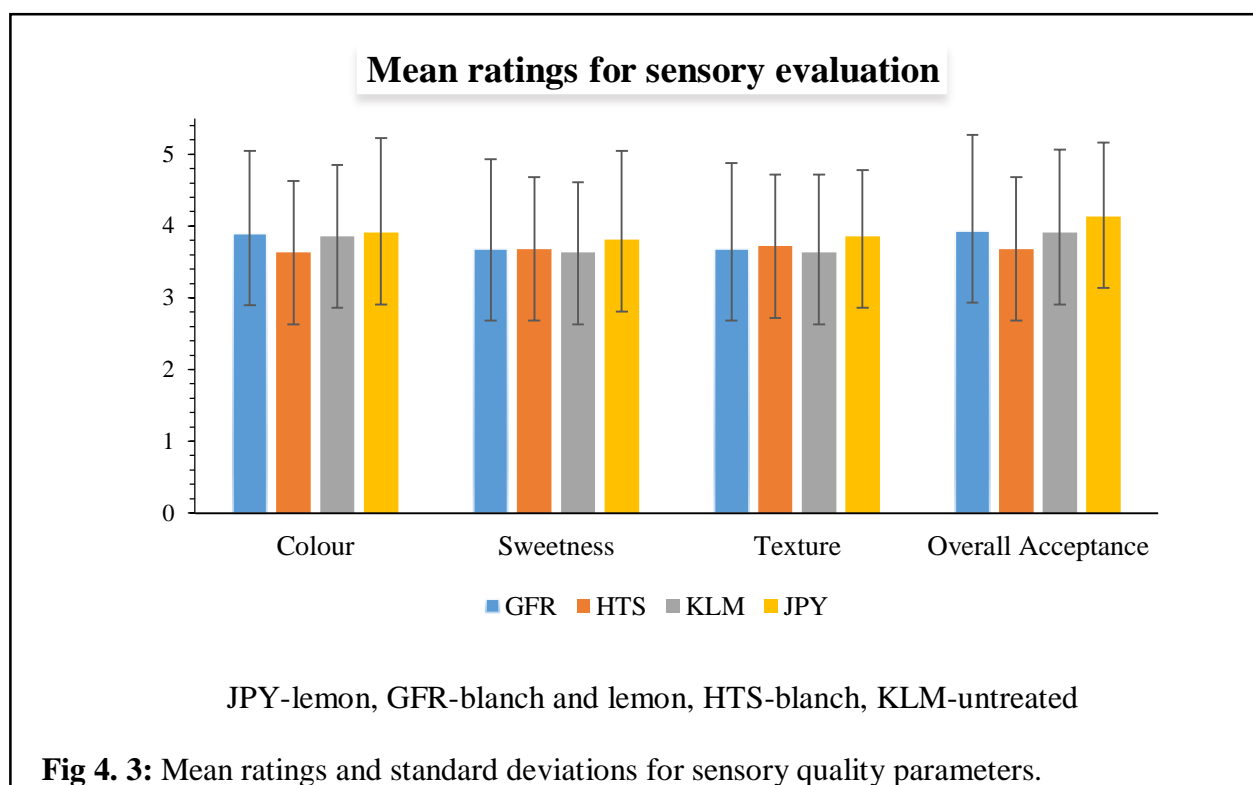
**f) Statistical analysis**

The collected data on sensory evaluation i.e. colour, texture, sweetness and overall acceptability were subjected to Analysis of Variance (ANOVA) using GenStat software package version 17.1.

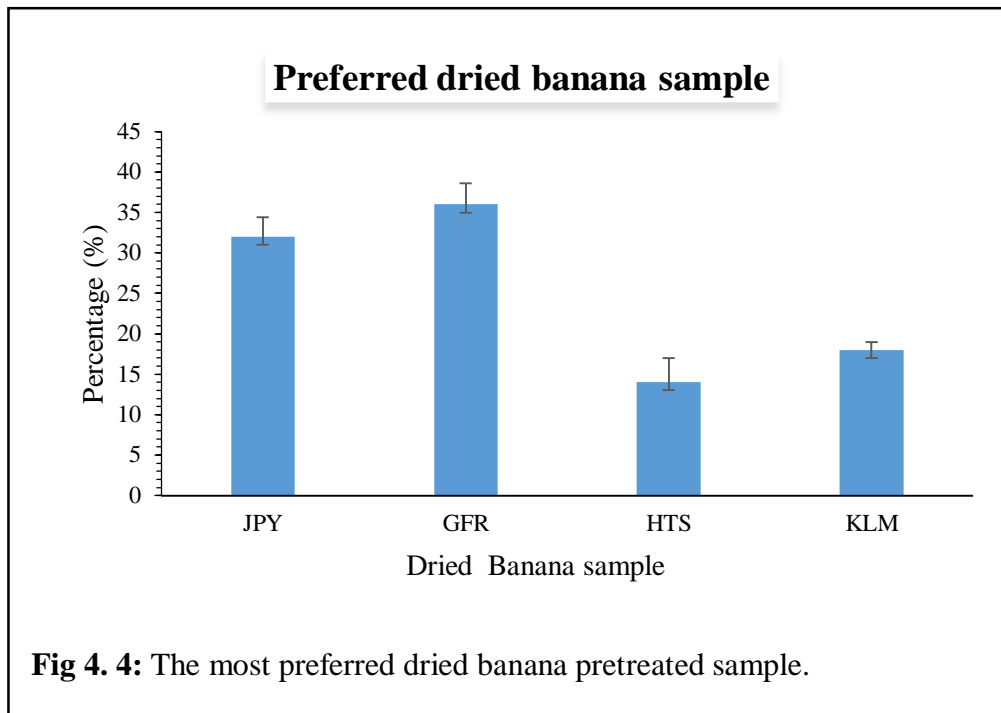
## 4.3 Results

### 4.3.1 Effect of pre-treatment on sensory characteristics

The mean value for the colour in all the banana treatments was  $3.82 \pm 1.24$ . The highest score for colour was 3.9 from both GFR (Blanch and lemon treated) and JPY (lemon only). The mean sweetness for all the banana samples was  $3.7 \pm 1.2$  and JPY had the highest score of 3.8 whereas HTS (blanch) had the lowest score of 3.63. JPY scored the highest in overall acceptance with 4.14 when the mean for all the pre-treatments was 3.92. There was no significant difference between the ratings for colour, sweetness, texture and overall preference for the different pre-treatments ( $P \leq 0.05$ ) (see Appendix VI).



However, amongst the pre-treatments, 36% preferred GRF (Blanch and lemon treated) and only 13% preferred HTS (Blanch) as shown in Fig 4.4. Furthermore, 63% of the panellists stated that they would purchase JPY if it was on the market and 59% said that they would purchase KLM or HTS. Despite GFR being the most preferred pre-treatment, only 36% said they would purchase GFR.



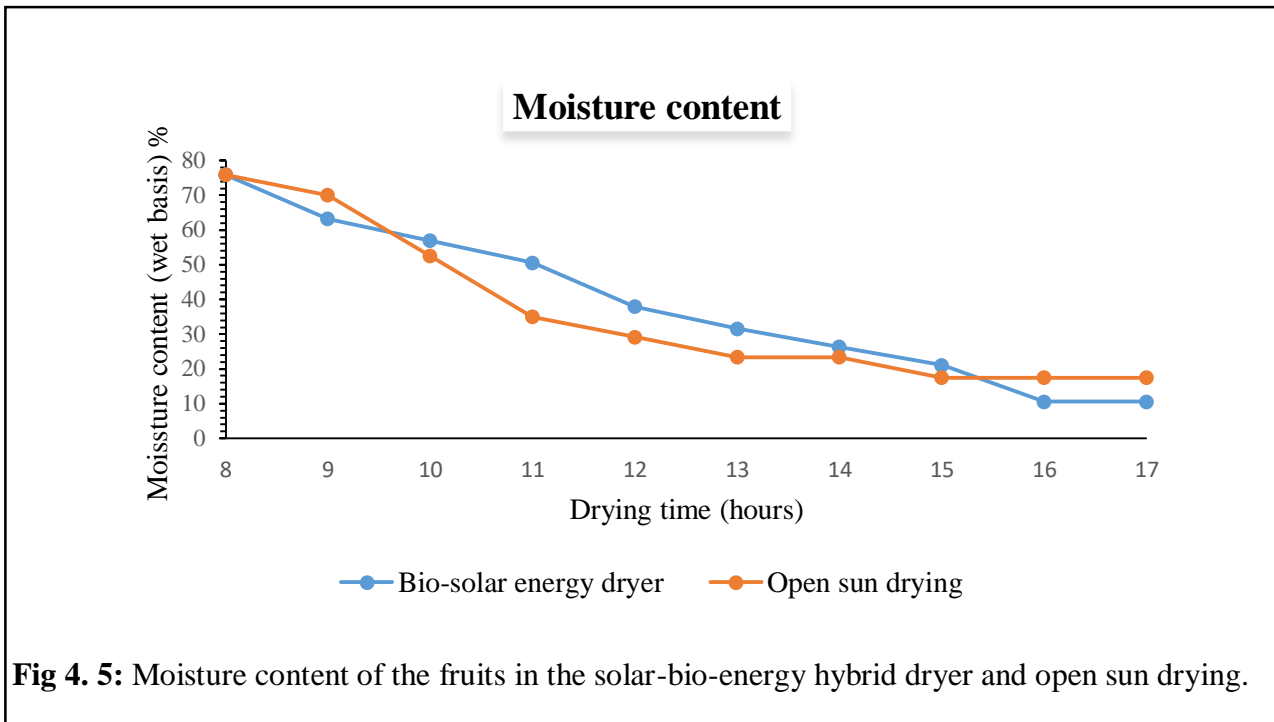
### Sensory evaluation summary

Panellists were asked to comment on the samples that they tasted and rated. Most of the panellists said that the bananas had a good colour and appearance to be without defects. In addition, they had a fair amount of sweetness.

#### 4.3.2 Effect of pretreatment and drying method on drying rate

Statistical analysis of the pre-treatments; JPY(lemon,) GFR (blanch and lemon), HTS(blanch), KLM (untreated) and the two drying methods which were solar-bio-energy hybrid drying and open sun drying showed that the pre-treatments did not have a significant difference on the drying rate at  $P \leq 0.05$ .

Initial moisture content (wet basis) was found to be 75.91% for untreated banana. At average ambient temperatures of 23.23°C and initial relative humidity 37%, the final moisture content of the fruits with the Solar-bio-energy hybrid dryer reached 10.54% compared to 17.5% from open sun drying as shown in Fig 4.5.



**Fig 4. 5:** Moisture content of the fruits in the solar-bio-energy hybrid dryer and open sun drying.

The fruits dried using the traditional open sun drying way were shrivelled and had relatively higher discoloration compared to the ones dried in the solar-bio-energy hybrid as shown in Fig 4.6. In addition, the fruits dried in the solar-bio-energy hybrid dryer had a glossy surface.



**Fig 4. 6:** Open sun-dried fruit.



**Fig 4. 7:** Solar-bio-energy hybrid dried fruit.

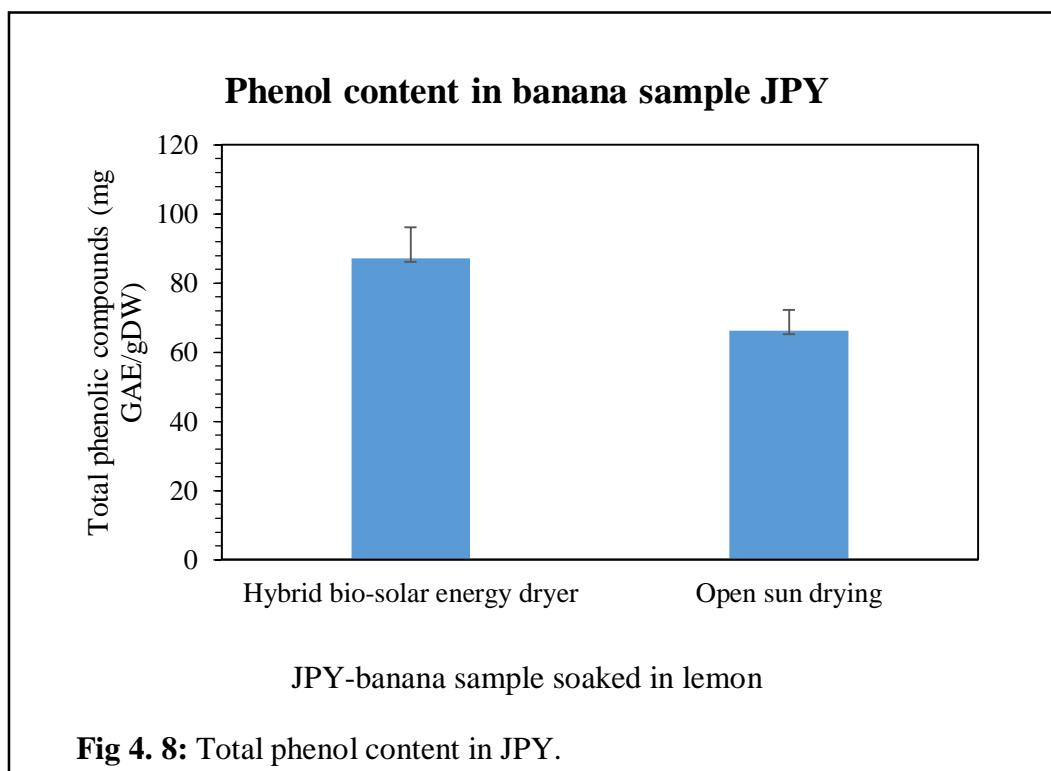
### 4.3.3 Physicochemical properties assessed for dried banana

The drying process increased the pH value of the banana fruit from 5.2 to 5.8. However, the total acidity in the fruits decreased in value as shown in Table 4.3.

**Table 4. 3:** The physicochemical properties of untreated banana fruit.

	Moisture content (%)	TSS %	pH	Citric acid %	Malic acid %	Tartaric acid %
Before drying	75.91	16.4	5.2	0.0192	0.0225	0.0201
After drying	10.54	57.8	5.8	0.0120	0.0135	0.0115

JPY was selected for the determination of phenol content as it had the highest overall sensory evaluation score. The data revealed that there was relatively higher phenol content in the fruit dried in the solar-bio-energy hybrid dryer than in the fruit dried in the open sun. Fig 4.8. shows the total phenolic content of the fruits using different drying methods.



#### 4.4 Discussion

Although GFR (Blanch and lemon) had the highest first preference rating of 36% (Fig 4.4), it did not have a high certainty for purchase of intent compared to JPY. This could be possibly due to the sweetness score of JPY (76%) compared to the slightly lower score of GFR (74%) (Fig 4.3). In addition, GFR had a relatively lower texture and overall acceptance value compared to JPY. This

suggests that the consumers would certainly buy dried products with better texture and overall acceptance although these products may be sweeter than they like. Furthermore, GFR and JPY had equal scores on colour as they were both dipped in lemon which is used to minimize oxidation of polyphenols that lead to the browning of fruits. Therefore, the main difference in the texture and overall acceptance was from the blanching in GFR. HTS had the lowest rating in colour (72%) and overall acceptability (74%) and as a result, it was the least preferred. The lower rating in colour for HTS was as a result of blanching. Blanching can cause structural changes through the breaking down of tissues and cell walls and have negative effects on heat-sensitive nutrients such as vitamin C and colour of products (Xiao *et al.*, 2017).

After the drying process, the pH of the fruit increased from 5.2 to 5.8 and the total acids were reduced. This suggests that the high temperatures in the dryer and moisture removal could have had an effect on the acids lost. However, total phenolic compounds were relatively higher in fruits dried in the solar-bio-energy hybrid dryer than in fruits dried using open sun drying. This suggests that the high heat and drying rate in the solar-bio-energy hybrid dryer may not cause high losses of phenolic compounds in fruits compared to open sun drying (Madrau *et al.*, 2009). In addition, it is possible that longer drying rates in open sun drying expose the nutrients to oxygen for longer periods therefore, polyphenol oxidase has a longer time to oxidize the phenol compounds in open sun drying.

The rapid decline of moisture content noted for open sun drying leads to undesirable non-uniform dried product. The solar-bio-energy hybrid dryer has a steady moisture content decline which allows uniform drying and results in good quality dried fruit (Fig 4.5.). The moisture removal efficiency of the Solar-bio-energy hybrid fruit dryer was found to be higher than that of open sun drying. This efficiency is indicated by the final moisture content of the fruits with the Solar-bio-energy hybrid dryer reaching 10.54% compared to 17.5% from open sun drying.

In summary, GFR was the most preferred banana treatment. The highest contributing factors to the acceptability appeared to be colour and sweetness. The fruits dried in the solar-bio-energy hybrid dryer had relatively higher phenolic compounds compared to fruits dried using open sun drying. In addition, the use of the solar-bio-energy hybrid dryer had a significant difference in the drying rates of the fruits (see Appendix for ANOVA table).

## (A) Sensory evaluation for Kei Apple banana blend fruit roll

### 4.5 Introduction

Indigenous food crops have been widely promoted as adaptive strategies towards reduced rainfall occurring because of climate change. Among many other indigenous fruit and vegetable crops, Kei apple is receiving increased interests (Omotayo *et al.*, 2018). This is because of its rich nutritional and medicinal properties that has been highly acknowledged (NRC, 2008; Omotayo *et al.*, 2018; Aremu *et al.*, 2019). Furthermore, the resultant droughts and extreme temperatures increase food insecurity through; reduced food availability, poverty and reduced access to nutrient-rich foods (Affognon *et al.*, 2015). As a result, there is a peaked research interest towards the utilization of indigenous plants to mitigate food shortages amidst the growing global population (Kucich and Wicht, 2016).

Kei-apple (*Dovyalis caffra* L.) is an indigenous plant that can thrive in arid and semi-arid conditions (Chaka and Osano, 2019). This drought-resistant plant is indigenous to southern Africa (Aremu *et al.*, 2019). Kei-apple is rich in carbohydrates, antioxidants, iron, zinc, cobalt and other bio-minerals (Loots *et al.*, 2006; Chaka and Osano, 2019). Furthermore, it has a variety of medicinal uses due to its anti-inflammatory and pain relieving properties are related to alleviating rheumatism (Aremu *et al.*, 2019). Despite this, Kei apple is not widely accepted due to its sour unpalatable taste hence, it is incorporated with other foods and processed to form products which include; sweets, jellies, beverages and jams (NRC, 2008; Van Wyk, 2011). In jams and jellies, Kei-apple is mostly used for its high pectin content (NRC, 2008). Pectin is made up of complex heteropolysaccharides consisting of 1,4 linked galacturonic acid units and methyl esters of varying sugar (Mudgil, 2017; Kaur *et al.*, 2018). It forms gels at low pH in the presence of cations and co-solute such as sugars (Donald, 2001). In acidic conditions, the gel is formed when the carboxyl groups are reduced lowering the electro repulsive forces between the pectin chains (Lanza, 2003; Gawkowska *et al.*, 2018). When sugar concentrations are high, intermolecular interactions in the pectin such as hydrogen bonds are enhanced (Gawkowska *et al.*, 2018). These strong hydrogen bonds stabilize the gel structure. Therefore, due to its high pectin content and nutrient composition, Kei-apple has the potential to be developed further for value addition purposes such as fruit leather where pectin is required to thicken the fruit puree and ensure flexible texture whilst retaining the shape of the fruit sheet (Diamante *et al.*, 2014).

Fruit leathers can be described as dried fruit blend sheets that are sweet, soft and have a rubbery texture (Diamante *et al.*, 2014). They can be consumed as healthy snacks or desserts. Due to their extended shelf life as a result of drying, fruit leathers enable access to nutrients of fruits which are

seasonal fruits (Shakoor *et al.*, 2015). In addition, fruit leathers are naturally high in fibre. Commercially, fruit leathers can be termed as fruit rolls, fruit bars or fruit jerky. The production of fruit leather using indigenous Kei-apple has the potential to contribute to job creation opportunities in agro-processing, improve livelihoods through access to nutritious snacks and to diversify food (NRC, 2008; Aremu *et al.*, 2019). In this study, banana fruit was selected to blend with the Kei-apple as it is locally available throughout the year and it has high nutritional value (Sidhu and Zafar, 2018). In addition, the blended fruit puree was sweetened with honey as Kei-apple is sour due to its high vitamin C content (NRC, 2008). The objective of this study was to develop a value-added product made from Kei-apple fruit that was dried using a hybrid bio-solar energy. Furthermore, the study also included sensory evaluation on three Kei-apple banana blends with different proportions. In addition, the study sought to determine the nutritional properties of the most preferred Kei-apple banana blend fruit roll.

#### **Specific objectives:**

- ii. To develop a consumer acceptable value added Kei apple banana blend fruit roll.
- iii. To compare phenolic content of fruit dried using the solar-bio-energy hybrid dryer to the traditional open sun drying.

## **4.6 Materials and methods**

### **4.6.1 Experiment description**

The experiment was carried out in Mafikeng and analysis of the samples was carried out at the North-West University Molelwane Farm laboratories 25°40.459'S, 26°10.563'E. Ambient temperatures in Mafikeng range between 27°C to 37°C in summer and -3°C to 25°C in winter.

### **4.6.2 Experimental procedure of fruit leather puree formation and drying process**

The Kei-apple fruit was sourced locally 25.8562°S, 25.6403°E i.e. trees that were historically introduced in the North West province from the Eastern Cape. The Kei-apple was washed and fruits with blemishes or worms were discarded. The fruit was boiled for 3 mins in order to separate the seeds and skin from the pulp (NRC, 2008). Ripe bananas purchased from a local supermarket were visually assessed for blemishes or spoilage. A composite sample was washed and hand peeled. The peeled banana was blended using a hand blender. The blended fruit sample was heated in low heat and allowed to simmer for 2 minutes in order to minimize enzyme activity that causes discoloration

of the product. There were three fruit leather proportions/ratios that were used in the study. These proportions for Kei apple fruit to honey and banana fruit pulp are shown in Table 4.4.

**Table 4. 4:** Pretreatment proportions.

<b>(KLM)</b>			<b>(LSC)</b>			<b>(HTS)</b>		
Kei- apple	Banana	Honey	Kei- apple	Banana	Honey	Kei- apple	Banana	Honey
100 g	50 g	20 g	100 g	80 g	20 g	100 g	50 g	5 g

The samples KLM, LSC and HTS were placed on a drying tray and placed inside the hybrid dryer. For the open sun drying, the proportions for KLM, LSC and HTS were prepared and placed on a drying tray in an unshaded area and left to dry.

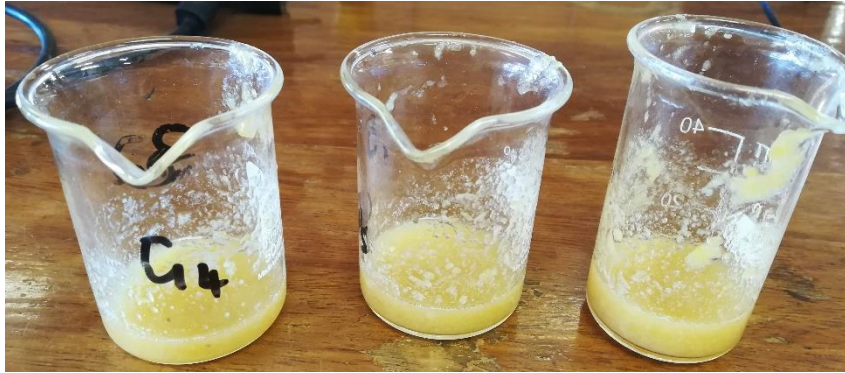
#### 4.6.3 Analysis

##### a) Sensory evaluation

The sensory evaluation was conducted as described in the first paragraph of (A) Sensory evaluation for dried banana, 4.3.1. a)

##### b) Analysis of total soluble solutes

Samples of Kei-apple fruit and banana that had been blended together were used. 30 g of the Kei-apple and banana mixture was blended with 90 ml distilled water for 2 minutes using a hand blender. 30 g samples of the Kei-apple blends are shown in Fig 4.9. The juice was then tested for TSS using a digital refractometer (Atago pocket refractometer, PAL-1,0-53%). TSS was read as °Brix that is equal to TSS %. Data was collected in triplicate.



**Fig 4. 9:** 30 g samples of the blended Kei-apple and banana fruits.

#### **c) Analysis of pH and titratable acids**

The analysis of pH and titratable acids was conducted as described in 4.2.3 c).

#### **d) Analysis of total phenol content**

The analysis of total phenol content was conducted as described in 4.2.3 e).

#### **e) Statistical analysis**

The collected data on sensory evaluation i.e. colour, texture, sweetness and overall acceptability were subjected to Analysis of Variance (ANOVA) using GenStat software package version 17.1. Mean comparison of data was interpreted using the Least Significant Difference (LSD) at 5% level of significance.

### **4.7 Results**

The proportion of LSC (100:80:20 - Kei-apple, banana, honey) scored relatively high values for colour, sweetness, texture and overall acceptance. However, there was no significant difference between KLM (100:50:20) and HTS (100:50:5) for these sensory quality parameters (Table 4.5) (see Appendix II). Furthermore, there was no significant difference between the textures for all the Kei-apple blend proportions ( $P \leq 0.05$ ). Generally, the fruit leathers had a mean colour  $4.12 \pm 0.16$  that fell between liked a little and liked a lot.

**Table 4. 5:** Sensory evaluation ratings for the different banana pre-treatments.

Sensory criteria	Colour (Mean $\pm$ SD) *	Sweetness (Mean $\pm$ SD) *	Texture (Mean $\pm$ SD) *	Overall acceptance (Mean $\pm$ SD) *
TRH	3.86 $\pm$ 1.20 <sup>a</sup>	3.09 $\pm$ 1.04 <sup>a</sup>	3.68 $\pm$ 1.24 <sup>a</sup>	3.52 $\pm$ 1.12 <sup>a</sup>
MBQ	3.86 $\pm$ 1.08 <sup>a</sup>	3.09 $\pm$ 1.13 <sup>a</sup>	3.91 $\pm$ 1.01 <sup>a</sup>	3.57 $\pm$ 1.32 <sup>a</sup>
LSC	4.63 $\pm$ 0.58 <sup>b</sup>	4.33 $\pm$ 0.79 <sup>b</sup>	4.27 $\pm$ 0.70 <sup>a</sup>	4.33 $\pm$ 0.91 <sup>b</sup>

\*Means with the same letters in a column are not significantly different at  $P \leq 0.05$ .

Eighty-one percent of the panellists said that they would certainly buy LSC, whilst 54% said they would buy TRH and 36% said that they would definitely buy MBQ. In addition, 81% said that they would definitely buy LSC, 54% would definitely buy TRH and only 36% said that they would definitely buy MBQ.

Panellists were asked to comment on the samples that they tasted and rated. Most of the panellists said that TRH was very bitter and suggested that it should be sweetened to be more palatable. Fifty-nine percent said that the fruit leathers were very tasty. In addition, some commented that the LSC should be made available soon in the market.

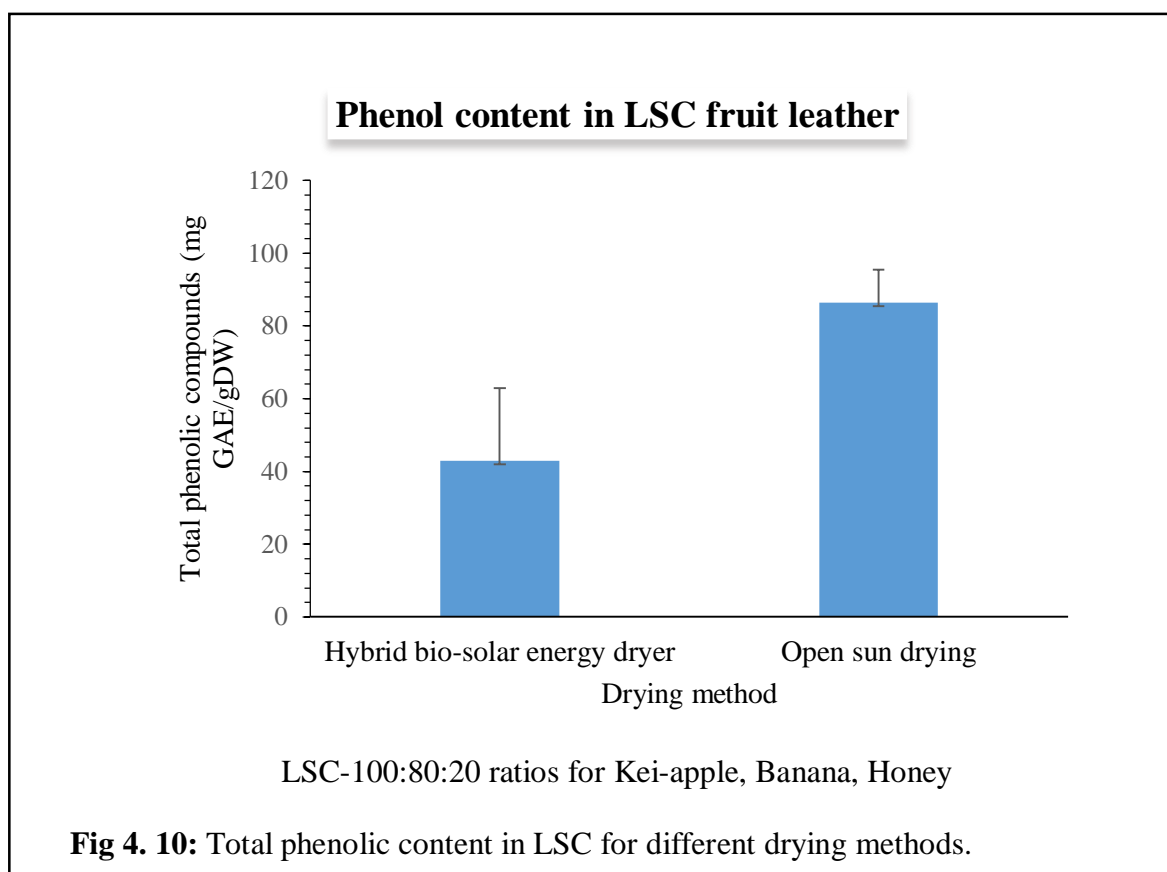
#### 4.7.1 Physicochemical properties assessed for Kei-apple blends

The pH and total acidity of the Kei-apple fruit blends did not appear to vary (Table 4.6).

**Table 4. 6:** The physicochemical properties of Kei-apple fruit blends.

	TSS %	pH	Citric acid %	Malic acid %	Tartaric acid %
MBQ	4.7	4.52	0.28	0.29	0.32
LSC	3.2	4.53	0.24	0.25	0.29
TRH	4	4.51	0.20	0.21	0.23

LSC was selected for the determination of phenol content as it was the most preferred Kei-apple blend. The data revealed that there was relatively lower phenol content in the fruit leather dried in the solar-bio-energy hybrid dryer than in the fruit leather dried in the open sun. Fig 4.10 shows the phenolic content in LSC dried in the solar-bio-energy hybrid and that dried using open sun drying.



#### 4.8 Discussion

The Kei apple banana blend LSC (100:80:20 Kei-apple, banana, honey) had relatively higher values for colour, sweetness, texture and overall acceptability compared to MBQ (100:50:20 Kei-apple, banana, honey) and TRH (100:50:5 Kei-apple, banana, honey). The banana concentration was higher in LSC and this could have contributed to the sweeter sensory characteristic values given to LSC. However, the higher banana concentration in LSC did not cause a difference in texture as there was no significant difference in the texture amongst all the treatments ( $P \leq 0.05$ ). TRH which had the highest acidity had the lowest acceptance level as the acceptance for sour or bitter fruits is relatively low (NRC, 2008). In addition, the varying Kei-apple blend proportions did not appear to have an impact on the pH as the pH range was narrow (4.51-4.53). This would suggest that the high acidity of the Kei-apple was not largely impacted by the banana and honey proportions. Furthermore, no water was added to the blends hence there was no decrease of  $H^+$  ions due to the dilution that would have resulted in increase in pH.

The relatively lower phenol content noted in fruit leather dried in the solar-bio-energy hybrid dryer compared to open sun drying was likely caused by the high heat in the dryer acting on the broken-down tissue cells and this had a negative impact on the phenol compounds (Perla *et al*, 2012, Minatel *et al*, 2017). The blending of the fruit breaks down tissue cells and increases the surface

area that the heat can act on (Minatel *et al.*, 2017). This suggests that there are higher risks of heat-sensitive nutrients being degenerated at a relatively faster rate.

In summary, a value addition fruit leather product was produced from various blending proportions of Kei-apple, banana, and honey. The most preferred Kei-apple fruit roll was LSC which scored the highest for colour, sweetness, texture and overall acceptability. The least preferred fruit leather blend was HTS which had the highest acidity and was considered too sour by some panellists. The fruit leather dried using the solar-bio-energy hybrid fruit dryer had relatively lower total phenolic content compared to fruit dried using the traditional open sun drying. This would suggest that the temperature in the solar-bio-energy hybrid were excessive for the temperature sensitive phenolic compounds in the fruit rolls. It is recommended that when drying Kei apple banana blend fruit rolls, the speed of the exhaust fans must be adjusted to carry out hot air at faster rates in order to retain heat sensitive nutrients.

## CHAPTER FIVE

### OVERALL DISCUSSION AND RECOMMENDATIONS

This study sought to develop an appropriate fruit processing technology for small scale farmers. A solar-bio-energy hybrid dryer that uses both solar and bio-energy connected in series was developed. The study revealed that temperatures recorded in the bio-energy reactor were higher in the night time compared to the day time temperatures. These variations were possibly caused by the latent heat of vaporization during the day as opposed to the night periods. As the ambient temperatures heated the biomass, moisture in the biomass may have been evaporated resulting in a temperature drop inside the biomass due to the latent heat of vaporisation. In addition, as the ambient temperatures heated the biomass during the day, the heat acquired would have been released at night due to the relatively high specific heat capacity of the biomass. Furthermore, the study revealed that growth media used in the biodegradation process had an effect on the recorded temperatures. Higher temperatures ranging between 51-63.7°C were noted in bio-energy reactors containing chicken manure or cattle manure making them suitable for heat energy utilization. These higher temperatures could have been caused by the relatively higher nitrogen content values that are often found in animal manures resulting in higher microbial metabolism (Huang *et al.*, 2017).

However, the growth medium which had chicken manure was noted to be the most suitable for heat energy extraction due to the highest recorded temperatures in the bio-energy reactor which reached up to 63.7°C. This could be due to the C/N ratio of the growth medium which favors higher microbial respiration resulting in higher heat emission. In addition, chicken manure reached thermophilic temperatures above 45°C within four hours of the experiment. However, the growth medium containing cattle manure reached thermophilic temperatures after two days and had a relatively higher microbial frequency throughout the experiment. This could have been as a result of the relatively higher pH values obtained in the bioreactor containing cattle manure which were within the optimum ranges for fungal development. In addition, the C/N ratio of the cattle manure mix showed a positive correlation with temperatures indicating that, as C/N ratio increased, the availability of the nutrients for the microorganisms increased resulting in higher microbial respiration and populations that increases the heat emitted.

The lowest temperatures were noted in the bio-energy reactor containing urea. Urea volatilizes and produces ammonia which has antimicrobial properties which result in decline of microbial populations and therefore reduced respiration resulting in reduced heat energy generation. Therefore, growth media containing urea is unsuitable for heat energy extraction.

The solar-bio-energy hybrid fruit dryer had an effectiveness factor of 60% compared to open sun drying when drying banana fruit. The drying temperatures for fruit were noted to be relatively higher than the drying rate of the solar-bio-energy hybrid on its own i.e. without the bioreactor and open sun drying (Fig 3.12 and Fig 3.13). In addition, the drying rate of the solar-bio-energy hybrid dryer was found to be relatively higher compared to open sun drying (Fig 4.4).

A sensory evaluation of the banana fruit and fruit leather dried in the solar-bio-energy hybrid dryer revealed that the banana fruit dried in the solar-bio-energy hybrid dryer had a better appearance, higher total phenolic contents and was dried at a faster rate compared to the traditional open sun drying. In addition, banana fruit pre-treated by soaking the fruit in lemon was most preferred by the panelists. Fruit leather with a ratio of 100:80:20 of Kei-apple, banana, and honey respectively were the most preferred proportion for the fruit leathers. The total phenolic contents in fruit leather dried using open sun drying were relatively higher than fruit dried using the solar-bio-energy hybrid fruit dryer. This was possibly due to the high temperatures in the solar-bio-energy hybrid fruit dryer as lower temperatures are optimum for phenolic compound retention during thermal processing (Minatel *et al.*, 2017).

## **Conclusions**

The hybrid bio-solar dryer unit utilizes renewable energy and is suitable for use by small scale agro-processors and smallholder farmers. It is capable of contributing to the reduction of postharvest losses. It can also be valuable to address the problem of the short shelf life of fruits and resulting in spoilage. The residual organic material that remains in the bioreactor after heat energy generation can be used as a bio-fertilizer. This study highlights the potential for application value addition technology in the processing of indigenous fruits as a means of contributing to food security in rural areas. In addition, this initiative also contributes to the provision of food diversity and income generation. However, further research is needed to assess the optimum heat for higher phenolic content in fruit leather dried in the solar-bio-energy hybrid fruit dryer.

## REFERENCES

- Abeliotis, K., Lasaridi, K. and Chroni, C. (2016). Life cycle assessment of food waste home composting in Greece. *Toxicological and Environmental Chemistry*, 98(10), pp. 1200-1210.
- Adeyeye, S. (2017). The role of food processing and appropriate storage technologies in ensuring food security and food availability in Africa. *Nutrition and Food science*, 47(1), pp. 122-139.
- Affognon, H., Mutungi, C., Sanginga, P. and Borgemeister, C. (2015). Unpacking postharvest losses in Sub-Saharan Africa: a meta-analysis. *World development*, 66, pp. 49-68.
- Agrawal, A. and Sarviya, R. M. (2016). A review of research and development work on solar dryers with heat storage. *International Journal of Sustainable Energy*, 35(6), pp. 583-605.
- Ahmed, S., Byker Shanks, C., Garvin, T. and Shanks, J. (2018). Fruit and vegetable desirability is lower in more rural built food environments of Montana, USA using the Produce Desirability (ProDes) Tool. *Food Security*, 10(1), pp.169-182.
- Alemu, M. (2017). banana as a cash crop and its food security and socioeconomic contribution: the case of Southern Ethiopia, Arba Minch. *Journal of Environmental Protection*, 8,(3), pp. 319-329.
- Alkokaik, F., Abdel-Ghany, A., Rashwan, M., Fulleros, R. and Ibrahim, M. (2018). energy analysis of a rotary drum bioreactor for composting tomato plant residues. *Energies*, 11(2), pp. 449-462.
- Ameen, A., Ahmad, J. and Raza, S. (2016). Effect of pH and moisture content on composting of municipal solid waste. *International Journal of Scientific and Research Publications*, 6(5), pp. 35-37.
- Anastasi, A., Varese, G. and Marchisio, V. (2005). Isolation and identification of fungal communities in compost and vermicompost. *Mycologia*, 97(1), pp. 33-44.
- Anbudhasan, P., Surendraraj, A., Karkuzhali, S. and Satishkumaran, S. (2014). Natural antioxidants and its benefits. *International Journal of Food and Nutritional Sciences*, 3(6), pp. 226-232.
- AOAC. (2000). *Official Methods of Analysis*. 17th ed, USA: The Association of Official Analytical Chemists.
- Aremu, A. O., Ncama, K. and Omotayo, A. O. (2019). Ethnobotanical uses, biological activities and chemical properties of Kei-apple [*Dovyalis caffra* (Hook.f. and Harv.) Sim]: An indigenous fruit tree of southern Africa. *Journal of Ethnopharmacology*, 241, p. 111963.
- Aridi, A. S., Noriza, A., Mustafa, H. M. and Mya, S. M. Y. (2016). A study on reducing fat content of fried banana chips using a sweet pretreatment technique. *International Food Research Journal*, 23(1), pp. 68-71.
- Arrigoni, J. P., Paladino, G., Garibaldi, L. A. and Laos, F. (2018). Inside the small-scale composting of kitchen and garden wastes: Thermal performance and stratification effect in vertical compost bins. *Waste Management*, 76, pp. 284-293.
- Asadu, C., Aneke, N., Agulanna, A. and Eze, C. (2018). Degradation of sawdust by thermo tolerant microorganisms for bio fertilizer synthesis. *Asian Journal of Biotechnology and Bioresource Technology*, 2(3), pp. 1-7.
- Asogwa, I. S., Okoye, J. I. and Oni, K. (2019). Promotion of indigenous food preservation and processing knowledge and the challenge of food security in Africa. *Journal of Food Security*, 5(3), pp.75-87.
- ASTM. (1993). ASTM D 2974-87 Standard test for moisture, ash and organic matter for peat and other organic soils. *Annual Book for ASTM Standards*. Philadelphia: American Society for Testing and Materials.
- Athawale, V. M. and Chakraborty, S. (2012). Material selection using multi-criteria decision-making methods: a comparative study. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, 226(4), pp. 266-285.
- Aziz, S. Q., Ali O, I. and Mustafa, J. (2018). Design and study for composting process site. *International Journal of Engineering Inventions*, 7(9), pp. 9-18.

- Bailey, K. L. (2014). Chapter 13 - The bioherbicide approach to weed control using plant pathogens. In: ABROL, D. P. (ed.) *Integrated Pest Management*. San Diego: Academic Press.
- Bajko, J., Fišer, J. and Jícha, M. (2018). Temperature measurement and performance assessment of the experimental composting bioreactor. *EPJ Web of Conferences*, 180, p. 02003.
- Bakari, R., Minja, R. and Njau, K. (2014). Effect of glass thickness on performance of flat plate solar collectors for fruits drying. *Journal of Energy*, 2014, pp. 1-8.
- Belayneh, M., Seyoum Workneh, T. and Belew, D. (2013). Physicochemical and sensory evaluation of some cooking banana (*Musa* spp.) for boiling and frying process. *Journal of Food Science and Technology*, 51(12), pp. 3635-3646.
- Bernal, M. P., Sommer, S. G., Chadwick, D., Qing, C., Guoxue, L. and Michel Jr, F. C. (2017). Current approaches and future trends in compost quality criteria for agronomic, environmental, and human health benefits. In *Advances in Agronomy*. 144, pp. 143-233, Academic Press.
- Bhave, P. P. and Joshi, Y. S. (2017). Accelerated in-vessel composting for household waste. *Journal of the Institution of Engineers (India): Series A*, 98(4), pp. 367-376.
- Bhupathiraju, S. N., Wedick, N. M., Pan, A., Manson, J. E., Rexrode, K. M., Willett, W. C., Rimm, E. B. and Hu, F. B. (2013). Quantity and variety in fruit and vegetable intake and risk of coronary heart disease. *The American Journal of Clinical Nutrition*, 98(6), pp. 1514-1523.
- Bikam, P. (2015). Food preservation challenges in rural areas of developing countries. a case study of Ha-Makuya rural areas in Limpopo Province, South Africa. *International Journal Series in Multidisciplinary Research*, 1(3), pp. 31-45.
- Bobeck, M. (2011). *Organic household waste in developing countries, an overview of environmental and health consequences, and decentralised technologies and strategies for sustainable management*, Sweden: VDM Verlag Dr. Müller.
- Boeykens, S., Falco, C. A., Ruiz Vázquez, M. M. and Tortorelli, M. D. C. (2015). Evaluation of an organic waste composting device to household treatment. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 3(3), pp. 245-255.
- Bohac, J. (2017). Lignocellulose-degrading enzymes, free-radical transformations during composting of lignocellulosic waste and biothermal phases in small-scale reactors. *Science of The Total Environment*, 580, pp. 744-754.
- Boldrin, A., Andersen, J. K., Møller, J., Christensen, T. H. and Favoino, E. (2009). Composting and compost utilization: accounting of greenhouse gases and global warming contributions. *Waste Management and Research*, 27(8), pp. 800-812.
- Bong, C. P. C., Lim, L. Y., Ho, W. S., Lim, J. S., Klemeš, J. J., Towprayoon, S., Ho, C. S. and LEE, C. T. (2017). A review on the global warming potential of cleaner composting and mitigation strategies. *Journal of Cleaner Production*, 146, pp. 149-157.
- Bortolotti, A., Kampelmann, S. and De Muynck, S. (2018). Decentralised organic resource treatments – classification and comparison through extended material flow analysis. *Journal of Cleaner Production*, 183, pp. 515-526.
- Briški, F., Vuković, M., Papa, K., Gomzi, Z. and Domanovac, T. (2007). Modelling of composting of food waste in a column reactor. *Chemical Papers*, 61(1), pp. 24-29.
- Bullerman, L. B. (2003). MYCOTOXINS | Classifications. In: Caballero, B. (ed.) *Encyclopedia of Food Sciences and Nutrition (Second Edition)*. Oxford UK: Academic Press.
- Bundhoo, Z. M. A. (2018). Solid waste management in least developed countries: current status and challenges faced. *Journal of Material Cycles and Waste Management*, 20(3), pp. 1867-1877.
- Burile, M. C., Thele, B. and Lanjewar, P. S. (2017). In-vessel composter technique for municipal solid waste composting. *International Journal on Recent and Innovation Trends in Computing and Communication*, 5(3), pp. 32-40.
- Chaka, B. and Osano, A. M. (2019). Analysis of selected nutrient levels at different growth stages of *Dovyalis Caffra* (Kei-apple) fruits. *International Journal of Research and Innovation in Applied Science (IJRIAS)*, 4(5), pp. 2454-6194.

- Chang, S. K., Alasalvar, C. and Shahidi, F. (2016). Review of dried fruits: phytochemicals, antioxidant efficacies, and health benefits. *Journal of Functional Foods*, 21, pp. 113-132.
- Chauhan, Y. B. and Rathod, P. P. (2018). A comprehensive review of the solar dryer. *International Journal of Ambient Energy*, pp. 1-20.
- Chel, A. and Kaushik, G. (2011). Renewable energy for sustainable agriculture. *Agronomy for Sustainable Development*, 31(1), pp. 91-118.
- Coleman, J. P. and Smith, C. J. (2014). Microbial classification. *Reference Module in Biomedical Sciences*. Oxford: Elsevier.
- Comesaña, I. V., Alves, D., Mato, S., Romero, X. M. and Varela, B. (2017). Decentralized composting of organic waste in a European rural region: a case study in Allariz (Galicia, Spain). In: MIHAI, F.-C. (ed.) *Solid Waste Management in Rural Areas*, p. 53.
- Conklin, A. I., Forouhi, N. G., Suhrcke, M., Surtees, P., Wareham, N. J. and Monsivais, P. (2014). Variety more than quantity of fruit and vegetable intake varies by socioeconomic status and financial hardship. Findings from older adults in the EPIC cohort. *Appetite*, 83, pp. 248-255.
- DAFF. (2011). *A Profile of the South African Banana Value Market Chain*. Pretoria: Department of Agriculture, Forestry and Fisheries.
- DAFF (2015). *Food Trade*. In: FISHERIES, D.O.A.F.A. (ed.). South Africa: Department of Agriculture Forestry and Fisheries.
- DAFF (2017). *A Profile Of The South African Banana Market Value Chain*. Pretoria: Department of Agriculture Forestry and Fisheries.
- DAFF (2019). *Abstract of Agricultural Statistics 2019*. Pretoria, South Africa: Department of Agriculture Forestry and Fisheries.
- De Campos, S. X., Zittel, R., Da Cunha, K. M. and Colares, L. G. T. (2017). Home composting using facultative reactor. In: MIHAI, F.-C. (ed.) *Solid Waste Management in Rural Areas*.
- Déportes, I., Benoit-Guyod, J.-L. and Zmirou, D. (1995). Hazard to man and the environment posed by the use of urban waste compost: a review. *Science of The Total Environment*, 172(2), pp. 197-222.
- Desai, S. N. and Shah, M. A. (2018). Decentralized solid waste management in urban areas: a review. *International Journal of Current Engineering and Technology*, 8(1), pp. 21-23.
- Dhakar, K., Sharma, A. and Pandey, A. (2013). Cold, pH and salt tolerant *Penicillium* spp. inhabit the high altitude soils in Himalaya, India. *World Journal of Microbiology and Biotechnology*, 30(4), pp. 1315-1324.
- Diamante, L. M., Bai, X. and Busch, J. (2014). Fruit Leathers: method of preparation and effect of different conditions on qualities. *International Journal of Food Science*, 2014, pp. 1-12.
- Digiacomio, A., Wu, D. W. L., Lenkic, P., Fraser, B., Zhao, J. and Kingstone, A. (2018). Convenience improves composting and recycling rates in high-density residential buildings. *Journal of Environmental Planning and Management*, 61(2), pp. 309-331.
- Donald, A. M. (2001). Food Gels. In: Buschow, K. H. J., Cahn, R. W., Flemings, M. C., Ilshner, B., Kramer, E. J., Mahajan, S. and Veysseyre, P. (eds.) *Encyclopedia of Materials: Science and Technology*. Oxford: Elsevier.
- Donatti, C. I., Harvey, C. A., Martinez-Rodriguez, M. R., Vignola, R. and Rodriguez, C. M. (2019). Vulnerability of smallholder farmers to climate change in Central America and Mexico: current knowledge and research gaps. *Climate and Development*, 11(3), pp. 264-286.
- Dotto, J., Matemu, A. and Ndakidemi, P. (2018). potential of cooking bananas in addressing food security in East Africa, *International Journal of Biosciences*. 13(4), pp. 278-294.
- EPA. (2004). EPA SW 846 Test Method 9045D, *Test Methods for evaluating Solid Waste : Physical and Chemical Methods*, USA: Environmental Protection Agency.
- Ermolaev, E., Sundberg, C., Pell, M. and Jönsson, H. (2014). Greenhouse gas emissions from home composting in practice. *Bioresource Technology*, 151, pp. 174-182.
- Fanzo, J. (2017). From big to small: the significance of smallholder farms in the global food system. *The Lancet Planetary Health*, 1(1), e15-e16.

- FAO. (2014). *Food losses and waste in Europe and Central Asia*. Europe Regional Conference, 2-4 April 2014 Bucharest, Romania. FAO, 11.
- FAO. (2016). *The State Of Food And Agriculture Climate Change, Agriculture And Food Security*. Rome: Food and Agriculture Organization of the United Nations
- FAO. (2017a). *Food insecurity and poverty pose major challenge to goal of ending hunger by 2030 in sub-Saharan Africa*. Rome: Food and Agriculture Organisation of the United Nations.
- FAO. (2017b). *The future of food and agriculture: Trends and challenges*. Rome: Food and Agriculture Organisation of the United Nations.
- Faverial, J. and Sierra, J. (2014). Home composting of household biodegradable wastes under the tropical conditions of Guadeloupe (French Antilles). *Journal of Cleaner Production*, 83, pp. 238-244.
- Gargurevich, I. (2016). Aqueous urea decomposition reactor: reaction modeling and scale up. *Journal of Chemical Engineering and Process Technology*, 7, p. 289.
- Gawkowska, D., Cybulska, J. and Zdunek, A. (2018). structure-related gelling of pectins and linking with other natural compounds: a review. *Polymers*, 10, p. 762.
- Genobiagon Jr, C. and B. Alagao, F. (2019). Performance of low-cost dual circuit solar assisted cabinet dryer for green banana. *Journal of Mechanical Engineering Research and Developments*, 42(1), pp. 42-45.
- Gerba, C. P. and Pepper, I. L. (2019). Chapter 22 - Municipal wastewater treatment. In: Brusseau, M. L., Pepper, I. L. And Gerba, C. P. (eds.) *Environmental and Pollution Science (Third Edition)*. Oxford: Academic Press.
- Goddard, J., Panhorst Harris, K., Kelly, A., Cullen, A., Reynolds, T. and Anderson, L. (2015). *Root, Tuber, and Banana Textural Traits A Review of the Available Food Science and Consumer Preferences*. Literature, USA: University of Washington.
- Gollin, D. (2014). *Smallholder agriculture in Africa: An overview and implications for policy*, IIED Working Paper, London: IIED.
- Gonawala, S. and Jardosh, H. 2018. Organic waste in composting: a brief review. *International Journal of Current Engineering and Technology*, 8(1), pp. 36-38.
- Graves, R. E., Hattemer, G. M., Stettler, D., Krider, J. N., Chapman, D., Kitzner, B., Moffitt, C., Payne, V. W. E. and Geter, F. (2000). Composting. In: Mattinson, M. R. (ed.) *Part 637 National Engineering Handbook*. USA: USDA.
- Gupta, P. M., Pandav, R. G., Singh, R. V. and Khuje, S. K. (2017). Review of solar dryer for drying agricultural products. *International Journal for Scientific Research and Development*, 4(11), pp. 524-528.
- Gurtler, J., Doyle, M., Erickson, M., Jiang, X., Millner, P. and Sharma, M. (2018). Composting to inactivate foodborne pathogens for crop soil application: a review. *Journal of Food Protection*, 81(11), 1821-1837.
- Gyurova, D. K. and Enikova, R K. (2014). Dried fruits – brief characteristics of their nutritional values. Author's own data for dietary fibers content. *Journal of Food and Nutrition Sciences*, 2(4), pp. 105-109.
- Hammond, S., Brown, J., Burger, J., Flanagan, T., Fristoe, T., Mercado-Silva, N., C Nekola, J. and Okie, J. (2015). Food spoilage, storage, and transport: implications for a sustainable future. *BioScience*, 65(8), pp. 758-768.
- Harvey, C. A., Saborio-Rodríguez, M., Martinez-Rodríguez, M. R., Viguera, B., Chain-Guadarrama, A., Vignola, R. and Alpizar, F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture and Food Security*, 7(57), pp. 1-20.
- Hegde, V. N., Hosur, V. S., Rathod, S. K., Harsoor, P. A. and Narayana, K. B. (2015). Design, fabrication and performance evaluation of solar dryer for banana. *Energy, Sustainability and Society*, 5(23), pp. 1-12.
- Hii, C. L., Jangam, S. V., Ong, S. P. and Mujumdar, A. S. (2012). *Solar drying fundamentals, applications and innovations*, Singapore: TPR Group Publications.

- Huang, J., Yu, Z., Gao, H., Yan, X., Chang, J., Wang, C., Hu, J. and Zhang, L. (2017). Chemical structures and characteristics of animal manures and composts during composting and assessment of maturity indices. *PloS One*, 12(6), e0178110.
- Hubballi, M., Sevugapperumal, N., Thiruvengadam, R., Theerthagiri, A. and Ramasamy, S. (2010). Effect of environmental conditions on growth of *Alternaria alternata* causing Leaf Blight of Noni. 6(2), pp. 171-177.
- IRENA. (2015). *A background paper to “Renewable Energy in Manufacturing”*. Abu Dhabi: International Renewable Energy Agency.
- Irvine, G., Lamont, E. R. and Antizar-Ladislao, B. (2010). Energy from waste: reuse of compost heat as a source of renewable energy. *International Journal of Chemical Engineering*, 2010.
- Iwabuchi, K. 2009. Specific heat capacity of biological solid waste. *Journal of the Japanese Society of Agricultural Machinery*, 71(1), pp. 131-132.
- Jain, M. S., Jambhulkar, R. and Kalamdhad, A. S. (2018). Biochar amendment for batch composting of nitrogen rich organic waste: Effect on degradation kinetics, composting physics and nutritional properties. *Bioresource Technology*, 253(1), pp. 204-213.
- Jin, Q. and Kirk, M. (2018). pH as a primary control in environmental microbiology: 1. thermodynamic perspective. *Frontiers in Environmental Science*, 6, pp. 1-15.
- Kalamdhad, A. S. and Kazmi, A. A. (2009). Rotary drum composting of different organic waste mixtures. *Waste Management and Research*, 27(2), pp. 129-137.
- Kaluarachchi, U., Pilapitiya, S. and Weerasinghe, V. P. (2018). resource conservation by effective composting of municipal solid waste in Sri Lanka – optimum moisture range for the bio-oxidative phase. *International Journal of Waste Resources*, 7(4), pp. 1-5.
- Kar, T. and Keles, S. (2016). Environmental impacts of biomass combustion for heating and electricity generation. *Journal of Engineering Research and Applied Science*. 5(2), pp.458-465.
- Kaur, G., Grewal, J., Jyoti, K., Jain, U. K., Chandra, R. and Madan, J. (2018). Chapter 15 - Oral controlled and sustained drug delivery systems: Concepts, advances, preclinical, and clinical status. In: Grumezescu, A. M. (ed.) *Drug Targeting and Stimuli Sensitive Drug Delivery Systems*. New York: William Andrew Publishing.
- Kaur, M. (2017). Screening of *Alternaria* pathogens associated with *Parthenium hysterophorus* for the production of lignocellulolytic enzymes. *Bioengineering and Bioscience*, 5(1), pp. 14-23.
- Khandani, S. (2005). Engineering design process. *Education Transfer Plan*. California
- Khurmi, R. S. and Gupta, J. K. 2005. *A Textbook of Machine Design*, New Delhi India: Eurasia Publishing House (PVT.) LTD.
- Kirkham, M. B. (2014). Chapter 3 - Structure and properties of water. In: KIRKHAM, M. B. (ed.) *Principles of Soil and Plant Water Relations (Second Edition)*. Boston: Academic Press.
- Kitinoja, L. and Alhassan, H. Y. Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia - part 1. Postharvest losses and quality assessments. 2012. International Society for Horticultural Science (ISHS), Leuven, Belgium, 31-40.
- Kookal, S. and Thimmaiah, A. (2018). Nutritional composition of staple food bananas of three cultivars in India. *American Journal of Plant Sciences*, 9(12), pp. 2480-2493.
- Krogh, K. B. R., Mørkeberg, A., Jørgensen, H., Frisvad, J. C. and Olsson, L. *Screening Genus Penicillium for Producers of Cellulolytic and Xylanolytic Enzymes*. (2004) Totowa, New Jersey: Humana Press.
- Kucich, D. A. and Wicht, M. M. (2016). South African indigenous fruits – Underutilized resource for boosting daily antioxidant intake among local indigent populations? *South African Journal of Clinical Nutrition*, 29(4), pp. 150-156.
- Kumar, K. P. S., Bhowmik, D., S, D. and Umadevi, M. (2012). Traditional and medicinal uses of banana. *Journal of Pharmacognosy and Phytochemistry*, 1(3), pp. 51-63.

- Lanza, C. M. (2003). CITRUS FRUITS | Processed and derived products of oranges. In: Caballero, B. (ed.) *Encyclopedia of Food Sciences and Nutrition (Second Edition)*. Oxford: Academic Press.
- Le Roux, W. (2016). Optimum tilt and azimuth angles for fixed solar collectors in South Africa using measured data. *Renewable Energy*, 96, pp. 603-612.
- Livleen, S., Satish, D. L., Indra, M. M., Archana, S. and Annapurna, K. (2016). rural composting for improvement of soil health and sustainable agriculture. *Agricultural Research and Technology*, 1(5), pp. 105-112.
- Lohri, C. R., Diener, S., Zabaleta, I., Mertenat, A. and Zurbrügg, C. (2017). Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings. *Reviews in Environmental Science and Bio/Technology*, 16(1), pp. 81-130.
- Loots, D. T., Van Der Westhuizen, F. H. and Jerling, J. (2006). Polyphenol composition and antioxidant activity of Kei-Apple (*Dovyalis caffra*) Juice. *Journal of Agricultural and Food Chemistry*, 54(4), pp. 1271-1276.
- Madrau, M., Piscopo, A., Sanguinetti, A. M., Del Caro, A., Poiana, M., Romeo, F. and Piga, A. (2009). Effect of drying temperature on polyphenolic content and antioxidant activity of apricots. *European Food Research and Technology*, 228(3), pp. 441-448.
- Makan, A., Assobhei, O. and Mountadar, M. (2013). Effect of initial moisture content on the in-vessel composting under air pressure of organic fraction of municipal solid waste in Morocco. *Iranian Journal of Environmental Health Science and Engineering*, 10(3), pp. 1-9.
- Malakahmad, A., Idrus, N. B., Abualqumboz, M. S., Yavari, S. and Kutty, S. R. M. (2017). In-vessel co-composting of yard waste and food waste: an approach for sustainable waste management in Cameron Highlands, Malaysia. *International Journal of Recycling of Organic Waste in Agriculture*, 6(2), pp. 149-157.
- Manu, M. K., Kumar, R. and Garg, A. (2017). Performance assessment of improved composting system for food waste with varying aeration and use of microbial inoculum. *Bioresource Technology*, 234, pp. 167-177.
- Manu, M. K., Kumar, R. and Garg, A. (2019). Decentralized composting of household wet biodegradable waste in plastic drums: Effect of waste turning, microbial inoculum and bulking agent on product quality. *Journal of Cleaner Production*, 226, pp. 233-241.
- Manyapu, V., Shukla, S., Kumar, S. and Rajendra, K. (2017). In-vessel composting: a rapid technology for conversion of biowaste into compost. *Open Access International Journal of Science and Engineering*, 2(9), pp.58-62.
- Maponya, P. and Mpandeli, S. 2015. Indigenous Post-harvest systems: A Case of Mamone village in Sekhukhune district of Limpopo Province,. *Journal of Human Ecology*, 50(3), pp. 197-203.
- Maremera, G. (2014). *Assessment of vegetable Post-Harvest losses amongst Smallholder Farmers in Umbumbulu of KZN, South Africa*. Master of Agriculture (Food Security), South Africa: University of Kwazulu Natal.
- Mashau, M., Moyane, J. and Jideani, A. (2012). Assessment of post harvest losses of fruits at Tshakhuma fruit market in Limpopo Province, South Africa. 7(29), pp. 4145-4150.
- Mba, O. (2013). Effect of ripening stages on basic deep-fat frying qualities of plantain chips. *Journal of Agricultural Science and Technology*, 3(5A), pp. 341-348.
- Mehboob, N., Asad, M., Asgher, M., Gulfraz, M., Mukhtar, T. and Mahmood, R. T. (2014). Exploring thermophilic cellulolytic enzyme production potential of *Aspergillus fumigatus* by the solid-state fermentation of wheat straw. *Applied biochemistry and biotechnology*, 172(7), pp. 3646-3655.
- Miller, V., Yusuf, S., Chow, C. K., Dehghan, M., Corsi, D. J., Lock, K., Popkin, B., Rangarajan, S., Khatib, R., Lear, S. A., Mony, P., Kaur, M., Mohan, V., Vijayakumar, K., Gupta, R., Kruger, A., Tsolekile, L., Mohammadifard, N., Rahman, O., Rosengren, A., Avezum, A., Orlandini, A., Ismail, N., Lopez-Jaramillo, P., Yusufali, A., Karsidag, K., Iqbal, R., Chifamba, J., Oakley, S. M., Ariffin, F., Zatonska, K., Poirier, P., Wei, L., Jian, B., Hui, C.,

- Xu, L., Xiulin, B., Teo, K. and Mente, A. (2016). Availability, affordability, and consumption of fruits and vegetables in 18 countries across income levels: findings from the Prospective Urban Rural Epidemiology (PURE) study. *The Lancet Global Health*, 4(10), e695-e703.
- Minatel, I. O., Borges, C., Ferreira, M. I., Gomez, H., Chen, O., Pace, G. and Lima, G. (2017). *Phenolic Compounds - Biological Activity*, Phenolic compounds: functional properties, impact of processing and bioavailability, InTechOpen.
- Misra, R. V., Roy, R. N. and Hiraoka, H. (2003). On-farm composting methods. In: FAO (ed.) *Land and Water Discussion*. Rome: Food and Agriculture Organisation of the United Nations.
- Mo, J. P. T. (2016). Design of solar energy system in food manufacturing environment. *Cogent Engineering*, 3, pp 1-16.
- Mohamed S, N., Stentiford, E., Stewart, D. and Fletcher, L. A. (2014). *The process and pathogen behavior in composting: a review*, pp. 78-87.
- Mu, D., Horowitz, N., Casey, M. and Jones, K. (2017). Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the U.S. *Waste Management*, 59, pp. 476-486.
- Mudgil, D. (2017). Chapter 3 - The interaction between insoluble and soluble fiber. In: Samaan, R. A. (ed.) *Dietary Fiber for the Prevention of Cardiovascular Disease*. USA: Academic Press.
- Nakasaki, K., Hirai, H., Mimoto, H., Quyen, T., Koyama, M. and Takeda, K. (2019). Succession of microbial community during vigorous organic matter degradation in the primary fermentation stage of food waste composting. *Science of The Total Environment*, 671(18), pp. 1237-1244.
- Naraian, R. and Gautam, R. L. (2018). Chapter 6 - penicillium enzymes for the saccharification of lignocellulosic feedstocks. In: Gupta, V. K. and Rodriguez-Couto, S. (eds.) *New and Future Developments in Microbial Biotechnology and Bioengineering*. Amsterdam: Elsevier.
- Ndirangu, S. N., Kanali, C. L., Mutwiwa, U. N. and Kituu, G. M. (2016). A model for renewable energy based agroprocessing technology transfer. *Annual Conference on Sustainable Research and Innovation*. pp. 304-317.
- Ndukwu, C. (2011). Development of clay evaporative cooler for fruit and vegetables preservation. *Agricultural Engineering International : The CIGR e-journal*, 13(1), pp. 1-6.
- Nelson, V. L., Crowe, T. G., Shah, M. A. and Watson, L. G. (2006). Temperature and turning energy of composting feedlot manure at different moisture contents in southern Alberta. *Canadian Biosystems Engineering*, 48, pp. 6.32-6.37.
- Nemš, M., Nemš, A. and Pacyga, P. (2018). A granite bed storage for a small solar dryer. *Materials (Basel, Switzerland)*, 11(10), p. 1969.
- Neugebauer, M. (2018). Kitchen and garden waste as a source of heat for greenhouses. *Agricultural Engineering*, 22(1), pp.83-93.
- Neugebauer, M. and Sołowiej, P. (2017). The use of green waste to overcome the difficulty in small-scale composting of organic household waste. *Journal of Cleaner Production*, 156, pp. 865-875.
- Neugebauer, M., Sołowiej, P. and Piechocki, J. (2014). Fuzzy control for the process of heat removal during the composting of agricultural waste. *Journal of Material Cycles and Waste Management*, 16(2), pp. 291-297.
- NRC (2008). Kei Apple. In: Council, N. R. (ed.) *Lost Crops of Africa: Volume 111: Fruits*. Washington DC: The National Academics Press.
- Ntshagase, T. P., L.; Potelwa, Y., (2016). *South African Fruit trade flow*, Issue no 22., In: Centre, M. AE.R. (Ed.). South Africa: National Agricultural Marketing Council.
- Nwanze, K. and Clark, G. (2015). Optimising heat extraction from compost. *CSBE/SCGAB 2015 Annual Conference*. Delta Edmonton South Hotel, Edmonton, Alberta: The Canadian Society for Bioengineering.

- OECD (2018). Guidelines on objective tests to determine quality of fruit and vegetables, dry and dried produce. *OECD Fruit and Vegetable scheme*. France: OECD
- Oguntibeju, O., Truter, E. and Esterhuysen, A. J. (2013). The role of fruit and vegetable consumption in human health and disease prevention. *Intech chapter*, 7, pp. 117-131.
- Ogunwande, G. A., Osunade, J. A. and Ogunjimi, L. A. O. (2008). Effects of carbon to nitrogen ratio and turning frequency on composting chicken litter in turned windrow piles. *Agricultural Engineering International: The CIGR E-journal*, X, pp. 1-16.
- Omotayo, A., Ncama, K. and Aremu, A. (2018). *Potentials of the underutilized Kei-apple (Dovyalis caffra L.): beyond its nutritional and functional value*, pp. 1-17.
- Pandya, M. and Chandra, Y. K. 2014. Study on effect of pretreatments and microwave drying on banana chips. *IOSR Journal of Agriculture and Veterinary Science*, 7(7), pp. 4-10.
- Pasupathi, S. and Devendran, D. (2018). Studies on the screening of bacterial and fungal population from vermicompost and compost. *Journal of Terrestrial and Marine Research*, 2(1), pp. 1-14.
- Patel, J. (2016). Drying of fruits, vegetables, spices and medicinal plants with a mixed-mode solar drying system with internal reflectors, *The Asian Conference on Sustainability, Energy and the Environment*.
- Perla, V., Holm, D. G. & Jayanty, S. S. 2012. Effects of cooking methods on polyphenols, pigments and antioxidant activity in potato tubers. *LWT - Food Science and Technology*, 45, 161-171.
- Poongodi, S. and Damodharan, V. (2016). Comparative study of in-vessel composting of municipal solid waste using industrial organic wastes as inoculums. *International Journal of Engineering. Research and Industrial. Applications.*, 9(1), pp. 27-40.
- Prabodh, S. D. (2016). Experimental comparative analysis of clay pot refrigeration using two different designs of pots. *International Journal of Latest Research in Engineering and Technology (IJLR ET)*, 2(2), 30-35.
- Prendeville, S., O'connor, F., Rafferty, S. and Palmer, L. (2013). Material selection and design for sustainable material innovation. *10th European Academy of Design Conference - Crafting the Future*, pp. 1-13.
- Ramsay, S. A., Shriver, L. H. and Taylor, C. A. (2017). Variety of fruit and vegetables is related to preschoolers' overall diet quality. *Preventive Medicine Reports*, 5, pp. 112-117.
- Rawat, S. (2015). Food Spoilage: Microorganisms and their prevention. *Asian Journal of Plant Science and Research*, 5(4), pp. 47-56.
- Raza, S. and Ahmad, J. (2016). Composting process: a review. *International Journal of Biological Sciences*, 4(2), pp.102-104.
- Rich, N., Bharti, A. and Kumar, S. (2018). Effect of bulking agents and cow dung as inoculant on vegetable waste compost quality. *Bioresource Technology*, 252, pp. 83-90.
- Román, P., Martínez, M. M. and Pantoja, A. (2015). *Farmer's compost handbook Experiences in Latin America*. Rome: Food and Agriculture Organization of the United Nations (FAO).
- Sahu, T., Gupta, V. and Kumar Singh, A. (2016). A review on solar drying techniques and solar greenhouse dryer. *IOSR Journal of Mechanical and Civil Engineering*, 13(3), pp. 31-37.
- SAICA 2015. (2015). *SME INSIGHTS REPORT*. South Africa: The South Africa Institute of Chartered Accountants.
- Shakoor, A., Wahab, S. and Khan, A. (2015). Effect of different levels of sucrose-glucose mixture on overall quality of guava bar. *Journal of Food Processing and Technology*, 6(8), pp. 1-7.
- Sharma, D. and Yadav, K. D. (2018). Application of rotary in-vessel composting and analytical hierarchy process for the selection of a suitable combination of flower waste. *Geology, Ecology, and Landscapes*, 2(2), pp. 137-147.
- Sidhu, J. S. and Zafar, T. A. (2018). Bioactive compounds in banana fruits and their health benefits. *Food Quality and Safety*, 2(4), pp.183-188.
- Sims, R., Flammini, A., Puri, M. and Bracco, S. (2015). *Opportunities for agri-food chains to become energy-smart*. Rome: FAO and USAID.

- Singh, R., Kaushik, R. and Gosewade, S. (2018). Bananas as underutilized fruit having huge potential as raw materials for food and non-food processing industries: A brief review. *7(6)*, pp. 574-580.
- Sivakumar, D. (2018). Phytochemicals and nutritional composition in accessions of Kei-Apple (*Dovyalis caffra*): Southern African Indigenous fruit. *Food Chemistry*, *253*, pp. 37-45.
- Slavin, J. L. and Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in nutrition (Bethesda, Md.)*, *3(4)*, pp. 506-516.
- Smith, M. M. and Aber, J. D. (2018). Energy recovery from commercial-scale composting as a novel waste management strategy. *Applied Energy*, *211*, pp. 194-199.
- Smith, M. M., Aber, J. D. and Rynk, R. (2017). Heat Recovery from composting: a comprehensive review of system design, recovery rate, and utilization. *Compost Science and Utilization*, *25(1)*, pp. S11-S22.
- Sokolovs, A., Grigans, L., Dzelzkaleja, L., Majore, G. and Bikulciene, L. (2015). Heat recovery technologies from aerobic bio-degradation: from theoretical finding to modeling results. *Procedia Computer Science*, *77*, pp. 141-150.
- Sontakke, M. S. and Salve, S. P. (2015). Solar drying technologies: a review. *International Refereed Journal of Engineering and Science*, *4(4)*, pp. 29-35.
- Spivey, N. (2015). Analysis of micronutrients in fresh and dried fruits by flame atomic absorption using microwave digestion and fast flame sample automation. [https://www.perkinelmer.com/lab-solutions/resources/docs/APP\\_FAST-Flame-PinAAcle-900-Fruit-Micronutrients-012238\\_01.pdf](https://www.perkinelmer.com/lab-solutions/resources/docs/APP_FAST-Flame-PinAAcle-900-Fruit-Micronutrients-012238_01.pdf) [Accessed 07/07/2019].
- Srivastava, Y. (2019). Climate change: a challenge for postharvest management, food loss, food quality, and food security. In *Climate Change and Agricultural Ecosystems* (pp. 355-377). Woodhead Publishing.
- Storino, F., Arizmendiarieta, J. S., Irigoyen, I., Muro, J. and Aparicio-Tejo, P. M. (2016). Meat waste as feedstock for home composting: effects on the process and quality of compost. *Waste Management*, *56*, pp. 53-62.
- Storino, F., Menéndez, S., Muro, J., Aparicio-Tejo, P. M. and Irigoyen, I. (2017). Effect of feeding regime on composting in bins. *Compost Science and Utilization*, *25*, pp. 71-81.
- Tatàno, F., Pagliaro, G., Di Giovanni, P., Floriani, E. and Mangani, F. (2015). Biowaste home composting: experimental process monitoring and quality control. *Waste Management*, *38*, pp. 72-85.
- Teodoro, A. J. (2019). Bioactive compounds of food: their role in the prevention and treatment of diseases. *Oxidative Medicine and Cellular Longevity*, *2019*, 4.
- Tibebu, B. T., Yaw Obeng, G., Mensah, E. and Smith, A. (2016). Solar dryer with biomass backup heater for drying fruits: development and performance analysis. *Journal of Science and Technology (Ghana)*, *36(2)*, pp.10-25.
- Tischer, S., Börnhorst, M., Amsler, J., Schoch, G. and Deutschmann, O. (2019). Thermodynamics and reaction mechanism of urea decomposition. *Physical Chemistry Chemical Physics*, *21*, pp. 16785-16797.
- Tiwari, A. (2016). A Review on solar drying of agricultural produce. *Journal of Food Processing and Technology*, *7(9)*, p. 623.
- Torshizi, M. V. and Mighani, A. H. (2017). The application of solar energy in agricultural systems. *Journal of Renewable Energy and Sustainable Development (RESO)*, *3(2)*, pp. 234-240.
- Toshniwal, U. and Karale, S. R. (2013). A review paper on solar dryer. *International Journal of Engineering Research and Applications (IJERA)*, *3(2)*, pp. 1-7.
- Uçaroglu, S. and Alkan, U. (2016). Composting of wastewater treatment sludge with different bulking agents. *Journal of the Air and Waste Management Association*, *66(3)*, pp. 288-295.
- Van Lin, M., Van Den Bos, A. and N., S. (2018). The current state of fruit and vegetable agro-processing in south africa challenges and opportunities. Netherlands: Netherlands Enterprise Agency.

- Van Wyk, B. E. (2011). The potential of South African plants in the development of new food and beverage products. *South African Journal of Botany*, 77(4), pp. 857-868.
- Vázquez, M. A., Sen, R. and Soto, M. (2015). Physico-chemical and biological characteristics of compost from decentralised composting programmes. *Bioresource Technology*, 198, pp. 520-532.
- Veverka, K., Stolcova, J. and Ruzeck, P. (2007). Sensitivity of fungi to urea, ammonium nitrate and their equimolecular solution UAN. *Plant Protection Science*, 43, 8.
- Walther, E., Ferrier, R., Bennacer, R., Desa, C. and Thierry, E. (2016). *Heat recovery in compost pile for building applications*. [https://www.researchgate.net/publication/311247991\\_Heat\\_recovery\\_in\\_compost\\_piloe\\_for\\_building\\_applications](https://www.researchgate.net/publication/311247991_Heat_recovery_in_compost_piloe_for_building_applications). [Accessed 07/07/2019].
- Wei, H., Wang, L., Hassan, M. and Xie, B. (2018). Succession of the functional microbial communities and the metabolic functions in maize straw composting process. *Bioresource Technology*, 256, pp. 333-341.
- Wiebe, K., Robinson, S. and Cattaneo, A. (2019). Chapter 4 - Climate Change, agriculture and food security: impacts and the potential for adaptation and mitigation. In: Camphanola, C. And Pandey, S. (Eds.) *Sustainable Food And Agriculture*. USA: Academic Press.
- Xiao, H.-W., Pan, Z., Deng, L.-Z., El-Mashad, H. M., Yang, X.-H., Mujumdar, A. S., Gao, Z.-J. and Zhang, Q. (2017). Recent developments and trends in thermal blanching – A comprehensive review. *Information Processing in Agriculture*, 4(2), pp. 101-127.
- Yadav, A., Kumari, R., Yadav, A., Mishra, J. P., Srivastava, D. S. and Prabha, S. (2016). Antioxidants and its functions in human body - A Review. *Research in Environment and Life Science*, 9(11), pp. 1328-1331.
- Yim, S. D., Kim, S. J., Baik, J. H., Nam, I. S., Mok, Y. S., Lee, J.-H., Cho, B. K. and Oh, S. H. (2004). Decomposition of urea into NH<sub>3</sub> for the SCR process. *Industrial and Engineering Chemistry Research*, 43(16), pp. 4856-4863.
- Yuwono, A., Wirasembada, Y., Febrita, J., Sabarina, R. and Sefiani, A. (2016). Design and performance test of non odorous and low maintenance (NOL) composting bin prototype. *International Journal of Applied Environmental Sciences*, 11(5), pp. 1199-1212.
- Zhao, R., Gao, W. and Guo, H. (2017). Comprehensive review of models and methods used for heat recovery from composting process. *International Journal of Agricultural and Biological Engineering*, 10(4), pp.1-12.
- Zhu, L., Zhao, Y., Zhang, W., Zhou, H., Chen, X., Li, Y., Wei, D. and Wei, Z. (2019). Roles of bacterial community in the transformation of organic nitrogen toward enhanced bioavailability during composting with different wastes. *Bioresource Technology*, 285, p. 121326.

## APPENDIX I: ANOVA TABLES FOR CHAPTER 2.

Variate: pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F	pr.
Bio-energy reactors	4	8.28467		2.07117	41.26	<.001
Residual	30	1.50600		0.05020		
Total	34	9.79067				

Variate: Moisture Content

Source of variation	d.f.	s.s.	m.s.	v.r.	F	pr.
Bio-energy reactors	4	253.53		63.38	5.24	0.003
Residual	30	363.19		12.11		
Total	34	616.71				

Variate: CN Ratio

Source of variation	d.f.	s.s.	m.s.	v.r.	F	pr.
Bio-energy reactors	4	910.31		227.58	2.62	0.054
Residual	30	2601.67		86.72		
Total	34	3511.98				

**APPENDIX II: TABLES FOR PHYSICOCHEMICAL PARAMETERS IN ALL THE  
BIO-ENERGY REACTOR.**

**Table 1:** Correlation matrix of four physicochemical parameters in B1.

	Moisture Content	C/N Ratio	Temperature	pH
Moisture Content	1			
C/N Ratio	0,37	1		
Temperature	0,44	0,64	1	
pH	-0,25	0,08	-0,30	1

**Table 2:** Correlation matrix of four physicochemical parameters in B2.

	Moisture Content	C/N Ratio	Temperature	pH
Moisture Content	1			
C/N Ratio	0,40	1		
Temperature	0,49	0,59	1	
pH	-0,64	-0,42	-0,87	1

**Table 3:** Correlation matrix of four physicochemical parameters in B3.

	Moisture Content	C/N Ratio	Temperature	pH
Moisture Content	1			
C/N Ratio	0,70	1		
Temperature	0,71	0,78	1	
pH	-0,64	-0,58	-0,94	1

**Table 4:** Correlation matrix of four physicochemical parameters in B4.

	Moisture Content	C/N Ratio	Temperature	pH
Moisture Content	1			
C/N Ratio	0,33	1		
Temperature	-0,01	0,66	1	
pH	0,20	0,69	0,36	1

**Table 5:** Correlation matrix of four physicochemical parameters in B5.

	Moisture Content 5	C/N Ratio	Temperature	pH
Moisture Content 5	1			
C/N Ratio	0,28	1		
Temperature	-0,51	0,09	1	
pH	-0,29	-0,80	-0,09	1

**Table 6:** Summary of the fungi obtained during the experiment.

Bio-energy reactor ↓	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
B1	Alternaria spp. Aspergillus spp. Penicillium spp.	-	-	Aspergillus spp.	-	Penicillium spp.	Alternaria spp. Penicillium spp.
B2	-	-	-	-	-	Penicillium spp.	Penicillium spp.
B3	-	-	-	-	-	Penicillium spp.	Penicillium spp.
B4	-	-	-	Alternaria spp. Penicillium spp.	-	-	Penicillium spp.
B5	Alternaria spp.	-	-	-	-	-	-

Where: B1-cattle manure mix, B2-chicken manure mix, B3-plastic bio-energy reactor chicken mix, B4-grass mix, B5-Urea mix

**APPENDIX III. PICTURES FOR CHAPTER THREE.**



**Fig 1.1:** Drying cabinet interior.



**Fig 1.2:** Drying unit without bioreactor.



**Fig 1.3:** Bioreactor unit.



**Fig 1.4:** Growth media.



**Fig 1.5:** Open sun drying tray.



**Fig 1.6:** Grass used in growth media.



**Fig 1.7:** Resulting bio-fertiliser.



**Figure 1.8:** Solar-Bio-energy Hybrid Dryer

## APPENDIX IV: DESIGN OF SOLAR-BIO-ENERGY HYBRID COMPONENT.

**Table 1: Values for design parameters.**

Parameter	Value
Initial mass of product to be dried ( $W_w$ )	1 kg
Initial moisture content of product ( $M_i$ )	75.915%
Final moisture content of product ( $M_f$ )	10.54%
Amount of moisture to be removed ( $M_w$ )	0.73 kg
Final relative humidity (ERH)	54.89%
Initial humidity ratio ( $w_i$ ) (using psychrometric charts)	0.0056 kg <sub>water</sub> /kg <sub>dry air</sub>
Final humidity ratio ( $w_f$ )	0.0281 kg <sub>water</sub> /kg <sub>dry air</sub>
Initial enthalpy ( $h_i$ )	337.73 kJ/kg
Final enthalpy ( $h_f$ )	1630.47 kJ/kg
Drying time ( $\tau_d$ )	36000 s
Total global radiation during period (I)	191.5 JW/m <sup>2</sup>
Average ambient temperature (T)	23.23°C
Average relative humidity ambient	31.8%
Specific heat capacity of air ( $C_p$ )	1.007 kJ/kg°C
Moisture removed during drying ( $m_w$ )	0.73 kg
Moisture content dry basis	0.1178 kg <sub>w</sub> /kg <sub>s</sub>

**Table 2:** Design component equations.

Component/Design	Equation/Data	Abbreviation meaning	Value
Solar collector area	$m_a = \frac{d_r}{w_f - w_i}$	$m_a$ is mass of air required to carry out drying, $d_r$ is the drying rate and $w_f$ is the final humidity ratio and $w_i$ the initial humidity ratio [kg(water)/kg(dry air)]	0.0009012 kg
	$E = \frac{m_a(h_f - h_i)\tau_d}{3600}$	E is the total heat energy [kJ], $m_a$ is the mass flow rate of air [kg/s], $h_f$ is the final enthalpy, $h_i$ is the initial enthalpy [kJ/kg dry air] and $\tau_d$ is the drying time [s].	11.65 KJ
	$h = 1.007T + w(251.2131 + 1.5524\tau_d)$	Enthalpy (h) of moist air at temperature T (°C), $\tau_d$ is the drying time [s].	$h_i = 337.7$ kJ/kg $h_f = 1630$ kJ/kg
	$Q = Mw * Hfg$	Q is the amount of energy required for the drying process (kJ), $M_w$ is the quantity of moisture to be removed from fruit (kg), Hfg is the latent heat of vaporisation (kJ/kg water)	1.7353 MJ
	$Hfg = 4.186 * 10^3(597 - 0.56(T_{pr}))$	$T_{pr}$ is product temperature (°C)	2.3771 MJ
	$A_c = \frac{Q}{I\tau_d\eta}$	$A_c$ is the solar collector area [m <sup>2</sup> ], Q is the amount of heat required	0.699 m <sup>2</sup> However,

		for the drying process [kJ], I is the total global irradiation [kJ/s/m <sup>2</sup> ], $\tau_d$ is the drying time [s] and $\eta$ is the dryer efficiency ranging between 20-50% 36% was chosen	0.72 m <sup>2</sup> was selected due to collector aspect ratio
Drying cabinet	$R = \frac{A_s}{v}$	R is the ratio which must be equal to or greater than 3, A <sub>s</sub> is the surface area of the collector glazing [m <sup>2</sup> ] and v is the volume of the drying chamber [m <sup>3</sup> ].	A ratio of 4 was selected therefore v=0.18 m <sup>3</sup>
Fan design	$V = \frac{m_a}{\rho wh}$	V is velocity volume flow rate of air that is required to dry the fruit [m <sup>3</sup> /s], $\rho$ is the density of air [kg/m <sup>3</sup> ], w is the width of duct [m] and h is the height of duct [m].  $m_a$ is the mass flow rate of air [kg/s],	V=0.00112 m <sup>3</sup> /s  However, 1 m/s was chosen based on a study on drying banana (Hegde <i>et al.</i> , 2015)
	$m_a = \rho V A_c$	$m_a$ is the mass flow rate of air [kg/s], A <sub>c</sub> is the area of the solar collector [m <sup>2</sup> ]	

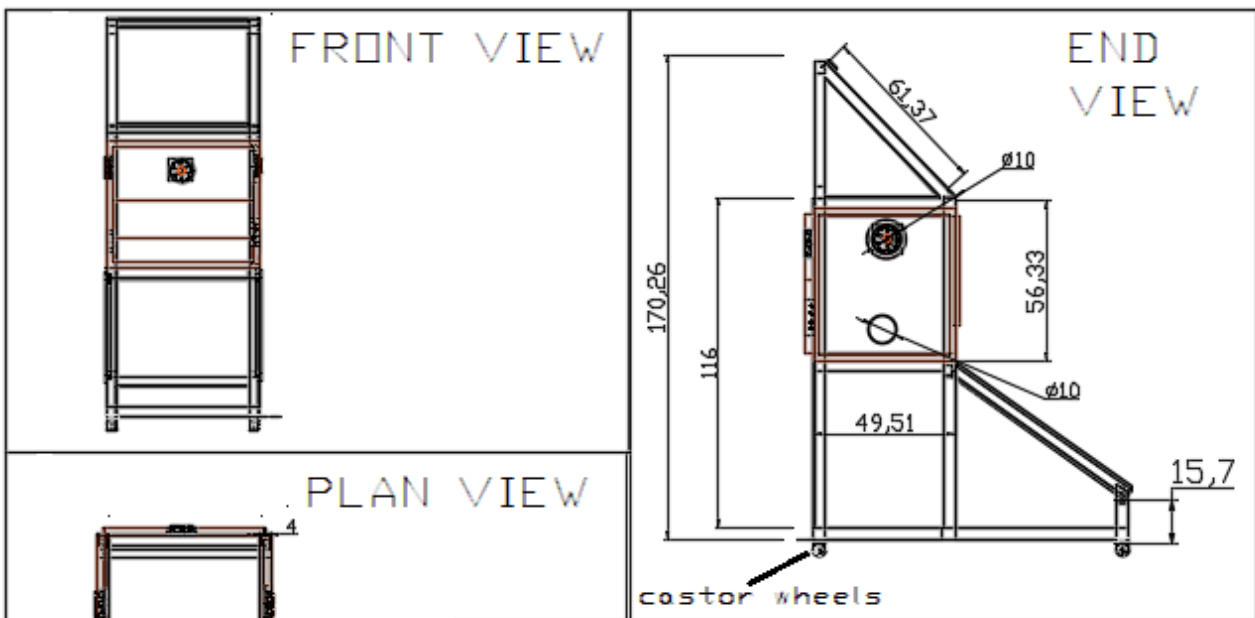
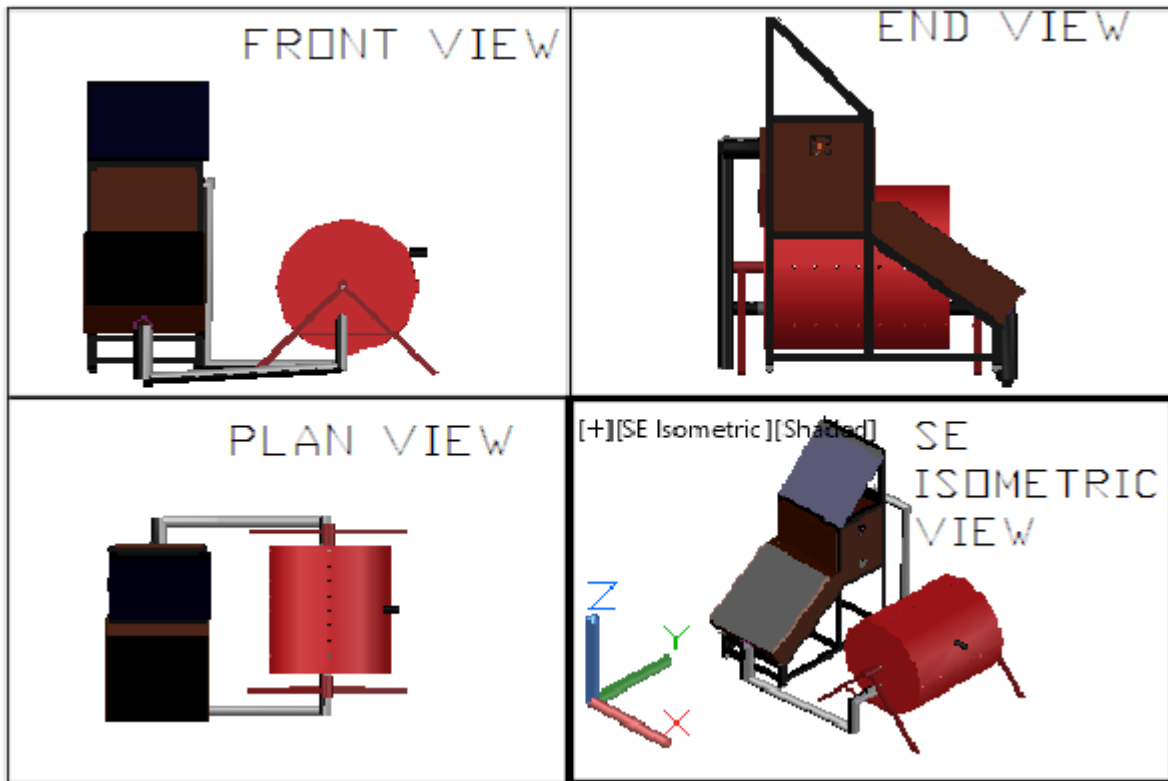
Heat energy from solar-bio-energy hybrid dryer	$P_w = m_a C_p \Delta T$	P <sub>w</sub> the energy input from the bioreactor [J], m <sub>a</sub> is the amount of air used to effect drying [kg/s], C <sub>p</sub> is the specific heat capacity of air and [kJ/kg°C] ΔT is the temperature change [°C].	0.0261 kJ/s
Solar panel system	$P = IV$	P is power, I is current [A], V is voltage [V]	2.88 W
	Total fan I is 0.24		
	Thermostat I is 0.035		
	$D_l = P_w T_h$	P <sub>w</sub> is total power [W], T <sub>h</sub> is hours of operation [h], D <sub>l</sub> is daily load [Wh]	33 Wh/day
T <sub>h</sub> is 10hours			
Considering temperature, battery, wiring losses,	$PV_1 = \frac{kWh/day}{daily\ insolation}$ $PV = \frac{PV_1}{0.74}$	Daily insolation was calculated at 0.73kW/m <sup>2</sup> PV <sub>1</sub> is photovoltaic panel module size without losses calculated PV is photovoltaic panel with losses calculated	PV <sub>1</sub> = 45.21 W PV = 61.09 W  80 W panel selected However, it was out of stock 100 W was used
$Bc = \frac{D_l}{B_e}$ <p>B<sub>e</sub> is 0.85</p> $Amp\ hours = \frac{Watt\ hours}{Volts}$	Considering depth of discharge (0.8) and number of no sunshine	D <sub>l</sub> is daily load [Wh], B <sub>e</sub> is battery efficiency, Bc is battery capacity	98.18 Watt hours  7.76 Ah

	days (3)		
	From Sizing charts for 12V (Appendix)		4 mm wires chosen
Frame analysis	<p>Drying cabinet:</p> $F = ma$ $m = mpw + mr + mal + mf + mt + mp$ $\rho = \frac{m}{v}$ <p>For free body diagram (Appendix)</p> $R_b = \frac{F * 0.25}{0.5}$ $R_a = F - R_b$ $m_a = 0.5 * bh$ <p>Of shear force diagram</p> <p>Bending moment and shear force diagram shown in Appendix</p>	<p>F is total load of drying cabinet [N], m is mass [kg], a is gravitational acceleration 9.81m/s<sup>2</sup>, v is volume [m<sup>3</sup>], ρ is density [kg/m<sup>3</sup>],</p> <p>Mpw is mass of wood [ρ=370 kg/m<sup>3</sup>], mr is mass of rockwool [ρ=80 kg/m<sup>3</sup>], mal is mass of aluminium foil [0.02kg],mf is mas of fans[0.324kg], mt is mass of trays [0.5kg] , mp is mass of product [1kg]</p> <p>R<sub>a</sub> is reaction force at A.</p> <p>R<sub>b</sub> is reaction force at B</p> <p>m<sub>a</sub> is maximum bending moment about point A, b is base, h is height [m]</p> <p>A<sub>y</sub> is reaction force at solar collector point A</p> <p>Fb is total load of solar</p>	<p>R<sub>a</sub> = R<sub>b</sub> =114.04 N m<sub>a</sub>=14.255 N/m</p> <hr/> <p>m<sub>a</sub> = 15.38 N/m A<sub>y</sub> = 165 N</p>
	<p>Solar collector:</p> <p>From free body diagram,</p> $m_a = Fb * 12 * 0.3 - (R_a * 0.6)$ $A_y = Fb * 1.2 - R_a$		

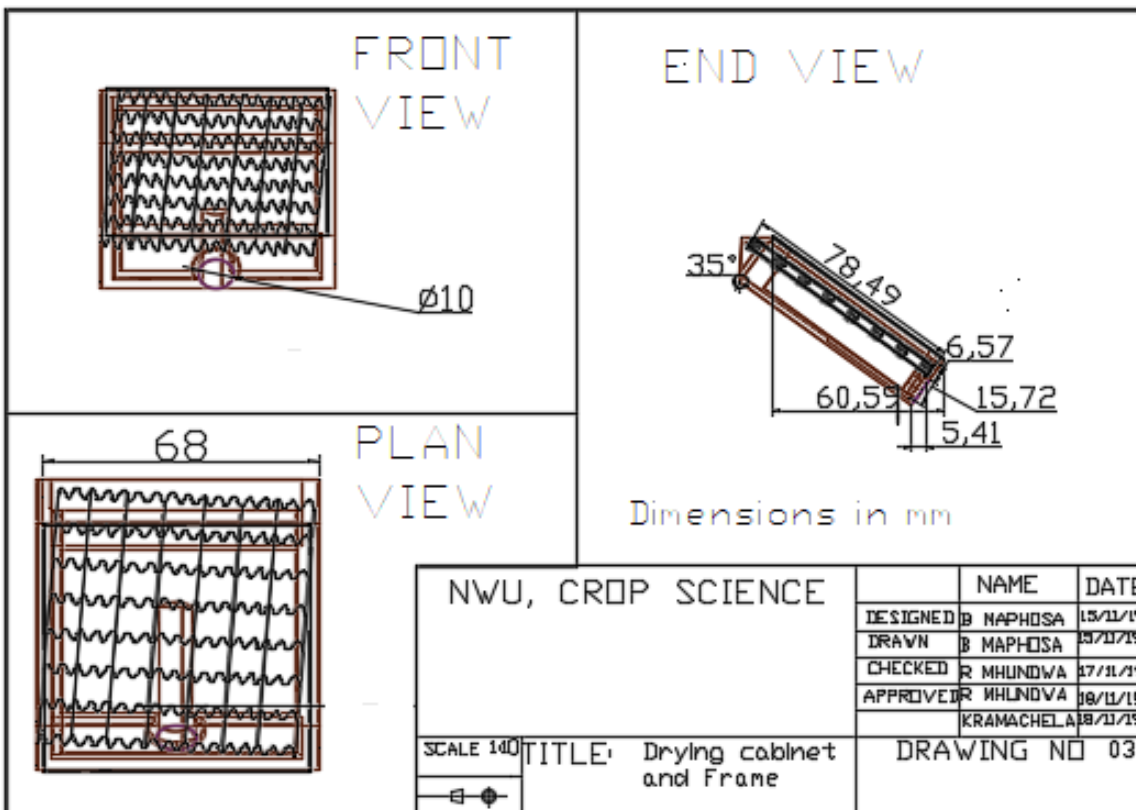
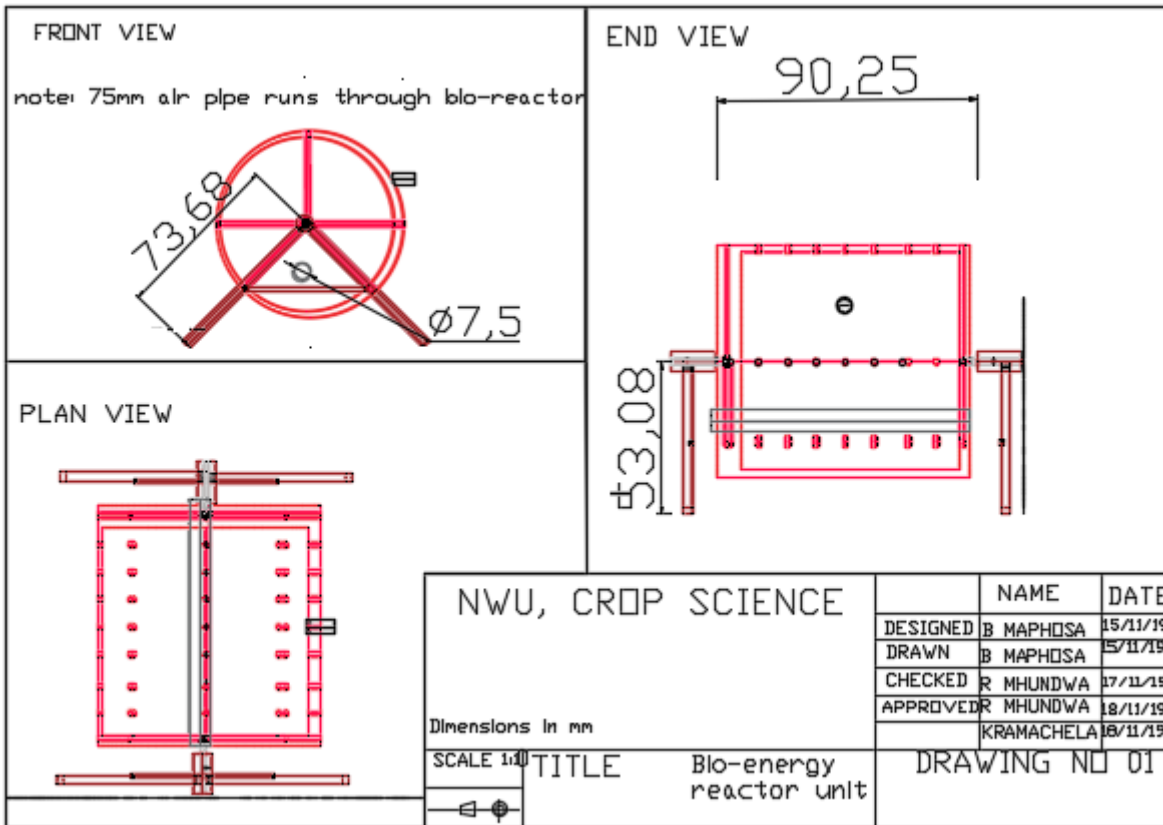
**Table 3:** Wire cross section area.

Voltage loss per 100 m of wire run (volts per 200m of wire)			
	Wire Cross Section (mm <sup>2</sup> )		
Flow (Amps)	1.5	2.5	4.0
0.1	0.21	0.14	0.08
0.2	0.43	0.27	0.17
0.3	0.64	0.41	0.25
0.4	0.86	0.54	0.34
0.5	1.07	0.68	0.42
0.6	1.29	0.81	0.51
0.7	1.50	0.95	0.59
0.8	1.72	1.08	0.68
0.9	1.93	1.22	0.76
1.0	2.15	1.35	0.85
2.0	4.29	2.70	1.69
3.0	6.44	4.05	2.4
4.0	8.58	5.41	3.38
5.0	10.73	6.76	4.23
6.0	12.87	8.11	5.08
7.0	15.02	9.46	5.92
8.0	17.16	10.81	6.77
9.0	19.31	12.16	7.62

APPENDIX V: DRAWINGS.



NWU, CROP SCIENCE		NAME	DATE
DESIGNED	B MAPHOSA		15/11/19
DRAWN	B MAPHOSA		15/11/19
CHECKED	R MHUNDWA		17/11/19
APPROVED	R MHUNDWA		18/11/19
		KRAMACHELA	18/11/19
Dimensions in mm		DRAWING NO 03	
SCALE 1:10	TITLE: Drying cabinet and Frame		



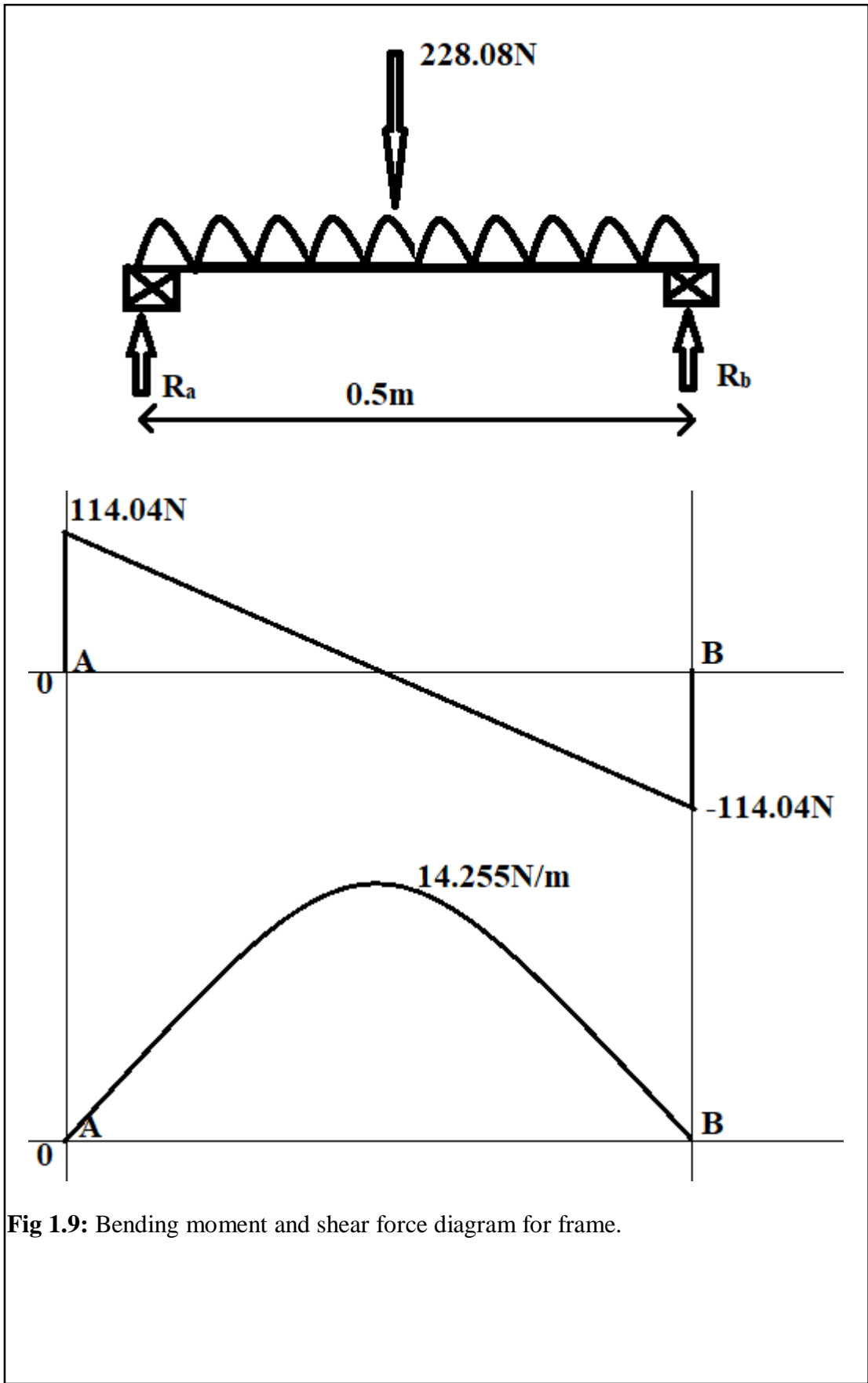
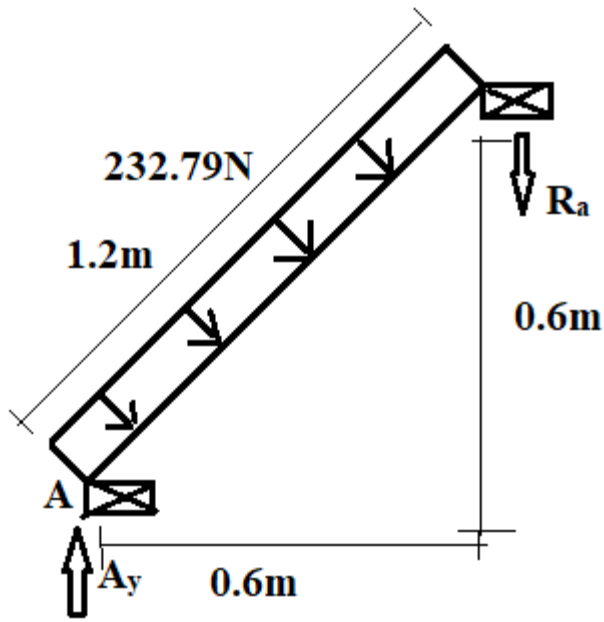


Fig 1.9: Bending moment and shear force diagram for frame.



**Fig 1.10: Free body diagram for inclined frame part.**  $R_a$  -force reaction at 0.6 m from the ground,  $A_y$  -force reaction at point A.

**APPENDIX VI: SENSORY EVALUTION FORMS.**

**Sensory evaluation Score card**

**Section A: Consumer Questionnaire: Strictly Confidential**

**Demographic Information**

Gender: Male  Female

Age: 17-24   
25-34   
35-44   
45-54   
Above 54

Occupation: Student   
Part time employment   
Full time employment   
Self employed   
Unemployed   
Home maker   
Retired

**Section B: Sensory Evaluation Record Card A**

You are presented with 3 fruit leather samples. Please evaluate the samples and indicate with the appropriate value which best describes how much you like or dislike it. You may cleanse your palate with water in between tasting.

Score value assigned:

I liked it a lot = 5, I liked it little = 4, I neither liked it or disliked it = 3, I disliked it a little = 2, I disliked it a lot = 1

**1. Acceptability**

Criteria	Sample LSC	Sample MBQ	Sample TRH
Appearance/Color			
Sweetness			
Texture			
Overall Acceptability			

**2. Preferences**

Please rank the samples in the order of your preference. Start with your most preferred sample

Order of Preference	Sample Code
1	
2	
3	

Please comment on the reasons for choices.....  
 .....

**3. Purchase Intent**

Please indicate with a tick✓ how likely you are to buy this product if it were available in the stores where you normally shop.

Purchase Intent	Sample LSC	Sample MBQ	Sample TRH
I would certainly buy it			
I might buy it			
I might or might not buy it			
I might not buy it			
I would certainly not buy it			

**Section C: Sensory Evaluation Record Card B**

You are presented with 4 dried fruit samples. Please evaluate the samples and indicate with the appropriate value which best describes how much you like or dislike it. You may cleanse your palate with water in between tasting.

Score value assigned:

I liked it a lot = 5, I liked it little = 4, I neither liked it or disliked it = 3, I disliked it a little = 2, I disliked it a lot = 1

**1. Acceptability**

Criteria	Sample GFR	Sample HTS	Sample KLM	Sample JPY
Appearance/Color				
Sweetness				
Texture				
Overall Acceptability				

**2. Preferences**

Please rank the samples in the order of your preference. Start with your most preferred sample

Order of Preference	Sample Code
1	
2	
3	
4	

Please comment on the reasons for choices.....

.....

**3. Purchase Intent**

Please indicate with a tick✓ how likely you are to buy this product if it were available in the stores where you normally shop.

Purchase Intent	Sample GFR	Sample HTS	Sample KLM	Sample JPY
I would certainly buy it				
I might buy it				
I might or might not buy it				
I might not buy it				
I would certainly not buy it				

Thank you for your cooperation.