GREENHOUSE SOLAR DRYING AND THIN LAYER DRYING OF FRESH KAPENTA

(*STOLOTHRISSA TANGANICAE*)

By

Aduke Ngira Rhoda

A dissertation submitted to the University of Zambia in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Agricultural Engineering

The University of Zambia

Lusaka

July, 2016

DECLARATION

I, **Aduke Ngira Rhoda** declare that this thesis is an original report of my research and has not been submitted for any previous degree award. The collaborative contributions have been indicated clearly and acknowledged. Due references have been provided on all supporting literatures and resources used in the dissertation.

Aduke N. Rhoda

Signed ……………………………………Date……………………………

CERTIFICATE OF APPROVAL

DISSERTATION TITLE: Greenhouse Solar Drying and Thin Layer Drying of Fresh Kapenta (*Stolothrissa tanganicae*)

This dissertation submitted by, **Aduke N. Rhoda** has been approved as fulfilling the requirements for the award of the degree of Master of Engineering in Agricultural Engineering at the University of Zambia.

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ABSTRACT

The aim of this study was to carry out an experimental investigation on drying fresh Kapenta (*Stolothrissa tanganicae*), in a Greenhouse Solar Dryer and to evaluate a suitable thin-layer drying model for fresh Kapenta. The nutritional constituents and quality of dried Kapenta produced from a Greenhouse Solar Dryer and that dried in the open sun were also analysed.

The Greenhouse Solar Dryer design; Kainji Solar Tent Dryer described by Olokor and Omojowo (2009) was adopted and constructed for this study. The length, width and height of the dryer were 1.5 metres by 1 metre by 1 metre, respectively. A rectangular wooden frame was fabricated and 20 mm diameter plastic pipes clamped on opposite ends to form the Greenhouse frame. Pieces of rock were spread within the base of the wooden frame and covered with black polythene. The Greenhouse plastic was fitted onto the entire Greenhouse framework. Kapenta was placed in a thin layer on a drying rack inside the Greenhouse Solar Dryer from 9.00 am and was dried until a constant weight of the samples was reached. Another set of two samples were placed on a drying rack in the open sun as control samples. The Kapenta in the Greenhouse Solar Dryer dried to a much lower moisture content compared to the Kapenta dried in the open sun.

In order to develop a thin-layer drying model, fresh Kapenta was dried by convection in a hot air dryer at different air temperatures. The influence of the drying temperature (35, 45 and 55°C) on the moisture ratio and drying rate has been studied in this research. The experimental drying data obtained for Kapenta under varying temperatures was fitted commonly used thin-layer drying models by using non-linear least squares regression analysis. All the models were compared according to three statistical parameters, i.e. coefficient of correlation (R^2), the reduced chi-square (x^2) and the root mean square error (*RMSE*). It was found that the coefficient of correlation values of Page were higher (0.9804-0.9970), and the corresponding reduced chi-square (0.0002-0.0012) and the root mean square error (0.0081-0.0328) values were lower as compared to the other models, indicating that the Page model is the best to describe drying curves of Kapenta among all the models.

Based on Student's t-test, the Kapenta dried in the Greenhouse Solar Dryer had higher nutritional values of protein fat and carbohydrates that differed significantly at 95% level of significance from the Kapenta dried in the open sun.

DEDICATION

I would like to dedicate this research to my father, Elisha Aduke and mother Benaddete Waganda for their prayers, love and unending support throughout my postgraduate studies at the University of Zambia.

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LIST OF ABBREVIATIONS

FAO Food and Agriculture Organization

KSTD Kainji Solar tent dryer

CTP Solar tent dryer with collector covered with transparent white polythene

NCTP Solar tent dryer without collector, covered with transparent white polythene

NCBP Solar tent dryer without collector covered with black polythene

IMC Initial moisture content

(w. b.) Wet basis

MR Moisture Ratio

RMSE Root Mean Square Error

NOMENCLATURE

R^2 Coefficient of Correlation

x^2 Reduced chi square

W_1 Initial weight of the sample

W_3 Weight at intervals of 20 minutes

M_3 Initial moisture content

M_2 Moisture content of the sample at time t

M_t Moisture content of the fresh Kapenta at time t

M_0 Initial moisture content of the fresh Kapenta and

M_e Equilibrium moisture content

$MR_{\exp}$ Experimental moisture ratio

MR_{pre} Predicted moisture ratio

N Number of observations and

Z Number of constants.

T Temperature in degrees Celsius (^{0}C)

n Page coefficient

$k(h^{-1})$ Page model drying Constant

A Volume of 0.2N HCL used in sample titration

B Volume of 0.2N HCL used in blank titration

N Normality of HCL

W Weight (g) of sample

14.007 Atomic weight of Nitrogen

6.25 Protein Nitrogen Conversion factor for fish and its' by products

CHAPTER ONE

1. INTRODUCTION

This chapter begins by describing the fisheries sector in Zambia and goes on to emphasize on the importance of Kapenta in the food and nutrition security of the country. It highlights the current preservation techniques used to process freshly harvested fish before narrowing down to drying as the preferred method of fish preservation. It also describes in detail the limitations of Open Sun Drying and justifies the need to investigate the Greenhouse Solar Dryer as an alternative approach to traditional Open Sun Drying.

1.1 BACKGROUND

1.1.1 Fisheries sector in Zambia

Zambia has an area of 145,194 km^2 covered by water in the form of rivers, lakes, swamps, flood plains and streams which provide the basis for extensive freshwater fisheries (Musumali *et al.*, 2009). There are 11 major fisheries: four within the Congo Basin (Bangweulu, Mweru-Luapula, Mweru-Wantipa and Tanganyika) and seven in the Zambezi Basin (Kafue, Kariba, Lukanga, Upper Zambezi, Lower Zambezi, Itezhi-Tezhi and Lusiwashi). Fish ponds and water impoundments also contribute to the fishery resource inventory of the country.

The Fisheries sector, because of its mostly rural setting, continues to contribute significantly to rural development in terms of employment, income generation and reduction of poverty in Zambia. According to FAO, (2006), it is estimated that the sector supports more than 300, 000 people deriving their livelihood directly as fishers and fish farmers, or indirectly as traders, fish processors and other service providers.

1.1.2 Fish consumption in Zambia

Most people in Zambia, irrespective of their socio-economic status, enjoy eating fish. A range of fish and fish products are being marketed domestically. The main species include several Tilapia species (breams) and a number of small pelagic species known as Kapenta. These species have wide market acceptance throughout the country since they are the most preferred type of fish protein by the populace.

Kapenta, a local name for small planktivorous, pelagic, freshwater clupeid *(Limnothrissa miodon and Stolothrissa tanganicae),* was introduced into Lake Kariba, a man-made reservoir on the Zambezi river shared between Zambia and Zimbabwe, in the late 1960s from Lake Tanganyika (Musumali *et al.*, 2009). Lake Kariba catches are about 98 percent Kapenta and two percent Tilapia (Food and Agriculture Organization, 2006).

The present consumption of Kapenta is 10 kg/head/year which is unevenly distributed between rural areas and urban areas. In the major towns of Zambia including Lusaka, consumption reaches 15 kg/head/year while in the rural areas, it is 7 kg/head/year (Food and Agriculture Organization, 2006). However, the domestic demand for Kapenta for consumption still outstrips production.

The continuous harvesting of fish from lakes and rivers and over exploitation of fisheries' resources to meet the increasing demand for fish and fish products by the rapidly growing population is a major concern to fisheries conservation organizations. In addition to the direct biological approach to tackle the problem; where particularly in Zambia from 1stDecember to 28thFebruary fishing is prohibited to allow for the fish to multiply in the rivers and lakes. There is also the need to minimize losses resulting from processing of the freshly harvested fish such as Kapenta *(Stolothrissa tanganicae*) and other fish species. Research has shown that 50% of fish are degraded to a bad condition for consumption barely twelve hours after harvesting. Some are then discarded completely and others are disposed of at very low prices because of this loss in quality (Ipinmoroti, 2012).

1.1.3 Malnutrition in Zambia

According to Musumali *et al.* (2009) it is estimated that more than 20 percent of animal protein intake for people in Zambia is from fish. Therefore fish and fish products play an important role in the food and nutrition security of the Zambian population.

In Zambia, malnutrition has continued to be a serious public health problem mostly affecting children and women of reproductive age. According to Zambia Demographic and Health Survey 2007, the latest figures on Protein Energy Malnutrition (PEM) indicate that 45% of Zambian children under the age of five years are stunted and 21% are severely stunted while 15% are underweight and 3% are severely underweight and 5% of children under five are wasted (Central Statistical Office, 2007). These rates are among the highest in the Sub-Saharan Africa.

Beside increasing food supply and limiting population growth, drastically reducing the food losses which occur throughout food production, harvest, post-harvest, and marketing chain is also a sustainable option to reducing malnutrition levels in the country. This research therefore focuses on significantly reducing the losses that occur during Open Sun Drying of Kapenta and therefore indirectly try to address the problem of malnutrition by increasing supply of fish protein to the populace.

1.1.4 Traditional Open Sun Drying of Fish

A number of preservation techniques are used to process freshly harvested fish. These include; smoking and salting which gives rise to health and environmental concerns. Of these, drying has been found to be an efficient method for fish preservation which allows obtaining the final products of high nutritive value and sensory quality.

Traditionally food products are dried by spreading them in the open sun in thin layers. This method is known as Open Sun Drying. According to Zooba and Bansal (2011) the solar radiation falling on the product surface is partly reflected and partly absorbed. The absorbed radiation and surrounding heated air heat up the product surface. Part of the heat is utilized to evaporate the moisture from the drying product surface to the surrounding air. Part of the heat is also lost through radiation (long wavelength) to the atmosphere and through conduction to the ground surface. The process of heat and mass transfer occurs simultaneously in Open Sun Drying. The rate of drying depends on a number of external factors such as solar radiation, ambient temperature, wind velocity, and relative humidity. The process also depends on internal factors such as initial moisture content, type of drying product, and mass of product per unit exposed area (Zooba and Bansal, 2011). The process of Open Sun Drying is illustrated in Figure 1.1

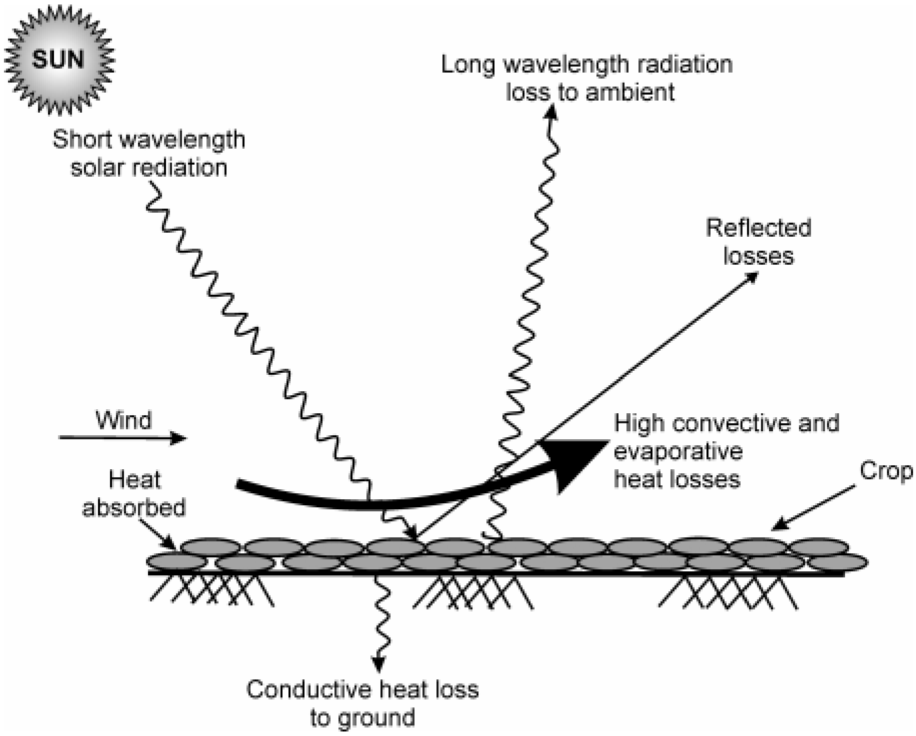

Figure 1.1: Process of Open Sun Drying, source: Zooba & Bansal (2011)

Open Sun Drying of fish is one of the oldest method of fish preservation using heat from the sun and atmospheric air. Although the method has been limited to certain climatic areas and seasons, it is the most common method of drying fish at the local fishermen level and is widely practiced in tropical and subtropical countries to preserve fish products where solar radiation is convenient, abundant and inexhaustible (Jain, 2007). The drying process involves the spreading of fish on the ground or on mats in the open where they are exposed to direct sunlight as shown in Figure 1.2. The benefits of Open Sun Drying are low capital investment and operating costs and the fact that little expertise is required. However Open Sun Drying has limitations; lack of control of the drying process and parameters, weather uncertainties, high labor costs, large drying area requirement, insect and microbial infestation and contamination with dust and other foreign materials. Another major drawback of Open Sun Drying is that it is limited to dry regions where periods of sunlight far exceed 10 hours/day and relative humidity is below 40% and the temperature is over 30°C (Ajisegiri, 2001).

Figure 1.2: Traditional Open Sun Drying of Kapenta along the shores of Lake Kariba

In Zambia, Open Sun Drying is commonly used for drying Kapenta near the lakes where air temperatures are remarkably high for prolonged periods (especially Kariba in Siavonga, Bangweulu in Samfya and Tanganyika in Mpulungu) and near the rivers (especially Zambezi, Luapula, Luangwa and Kafue) where most of the Kapenta and other fish species are harvested.

Due to the limitations of Open Sun Drying, alternative affordable, simple, hygienic and environmentally friendly methods must be developed and adopted for the drying of fish. The Greenhouse Solar Dryer provides a hygienic and environmental friendly fresh Kapenta dryer design capable of enclosing fish away from contaminants and is a reliable means for thin layer drying of Kapenta.

1.2 Statement of the problem

Open Sun Drying of fish and other food stuff has been in practice since time in memorial. This is the most common method of drying Kapenta at the local fishermen level especially along the shores of Lake Kariba. However, the method contaminates Kapenta by exposing it to dust, excreta from birds and subjects it to destruction by birds, blowflies' larvae and grazing animals. This leads to significant losses of Kapenta for artisanal fishermen along the shores of Lake Kariba. The process of Open Sun Drying is usually slow and in most cases, the Kapenta dries to unstable moisture content that are conducive for micro-organisms proliferation, and the Kapenta becomes a source of food poisoning. The process is also highly labor intensive, time consuming, and requires a large area.

Therefore this study focused on investigating the Greenhouse Solar Dryer as an alternative a solution to all the drawbacks of Open Sun Drying. The improvement of the drying process using the Greenhouse Solar Dryer will lead to reduced Kapenta losses as well improved hygiene and nutritional quality of the dried Kapenta.

1.3 Research questions

The research seeks to answer the following questions

i. Is the quality (in terms of nutritional Composition and hygiene) of Kapenta dried under a Greenhouse Solar Dryer better than that dried under Open Sun Drying?

ii. Are the drying rates of Kapenta dried under the Greenhouse Solar Dryer and Open Sun Drying comparable?

1.4 Justification of the study

Artisanal fish farmers, when trained will be able to easily construct the Greenhouse Solar Dryers using locally available materials. The Greenhouse Solar Dryer is easy to fabricate and simple in design. The enhancement of the drying process using the Greenhouse Solar Dryers instead of Open Sun Drying are likely to have the following impacts;

1) Increase the supply of fish protein (Kapenta) to the populace by significantly reducing the high post-harvest losses of Kapenta as is the case with Open Sun Drying. This is likely to increase food and nutrition security levels in the country.
2) Increase the artisanal fishers' income and subsequently improve their livelihoods and hence contributing to reducing poverty levels in the country.
3) Improve the quality in terms of hygiene and nutritional content of dried Kapenta.

1.5 Objectives of the study

1.5.1 General Objective

To explore the effectiveness of the Greenhouse Solar Dryer in the drying of Kapenta along the shores of lake Kariba, Siavonga.

1.5.2 Specific objectives

i. To carry out an experimental investigation on drying fresh Kapenta in a Greenhouse Solar Dryer in comparison to Open Sun Drying.
ii. To compare the quality in terms of nutritional content and hygiene of Kapenta dried in a Greenhouse Solar Dryer and that dried using traditional Open Sun Drying
iii. To evaluate a suitable thin-layer drying model for predicting the drying characteristics of Kapenta.

1.6 Scope of the study

This study endeavored to address the problem of high post-harvest losses of freshly harvested Kapenta due to spoilage and reduction in quality caused by Open Sun Drying that is currently practiced by most fishermen along the shores of Lake Kariba, Siavonga.

A laboratory sized Greenhouse Solar Dryer was constructed using locally available materials at the school of Agricultural Engineering Field Station. The Greenhouse Solar Dryer was used for thin layer drying of fresh Kapenta. Fresh Kapenta was also dried using traditional Open Sun Drying as a control experiment. The dried kapenta samples were taken to the food science and nutrition laboratory for comparison of the quality of Kapenta dried in the open sun and those dried in the Greenhouse Solar Dryer in terms of moisture content, nutritional content and micro-organisms present.

1.7 Closing remarks

This chapter discussed in detail the fisheries sector in Zambia and went on to emphasize on the role of Kapenta in the food and nutrition security of the country. The demerits of Open Sun Drying were also highlighted. The Problem of the research study as well as the objectives and scope of this study were also covered in chapter. The next chapter presents the relevant literature reviewed for this research study.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter begins with a description of the principles of food drying and goes on further to explain the types of solar dryers. It then narrows down to Greenhouse Solar Dryers and proceeds to cite the relevant literature on Greenhouse Solar Drying of different food products. Finally, thin layer drying and mathematical modelling of the thin layer drying equations is discussed in this chapter.

2.1 Principles of Food Drying

Drying is the process of reduction of the moisture in a product up to a safe limit of moisture content suitable for storage without decaying of the food product. It involves the migration of water from the interior of the product to its surface (thereby slowing down the activities of enzymes bacteria yeasts and moulds) and the removal of the water from the surface to the surrounding atmosphere (Zooba and Bansal, 2011). The rate of drying is dependent on the volume, temperature and moisture content of the air passing over the product (Zooba and Bansal, 2011).

Ekechukwua and Norton (1999) reported that under ambient conditions the drying process continues until the vapour pressure of the moisture in the product is equal to the atmospheric pressure. This implies that the rate of moisture removal from the product to the surrounding atmosphere and absorption of moisture from the atmosphere are in equilibrium. The moisture content of the product in this state is known as the equilibrium moisture content. However, under ambient conditions, the drying process is relatively slow, and in atmospheres of high relative humidity, the equilibrium moisture content reached can be too high for safe storage of the product (Ekechukwua and Norton, 1999). The product becomes susceptible to micro-organism proliferation due to the high moisture content.

2.2 Methods of Drying

In order to improve the quality and significantly reduce the equilibrium moisture content of the dried product to a level suitable for safe storage without deterioration in quality, researchers have developed different mechanisms of drying agricultural products.

These include; mechanical and electrical drying as well as solar drying. Solar energy has been a useful source of energy, which is utilized in the drying of food products.

This is majorly because the ever increasing fuel prices and its' continued depletion and the increasing concern about atmospheric pollution caused by conventional fossil fuels used for drying food products discourages many fishermen and farmers from using mechanical and electrical drying methods and thus they are turning to solar drying as the preferred method of drying and preserving most food products.

2.3 Types of Solar Drying Systems

The function of a dryer is to supply the food product with more heat than is available under ambient conditions, thereby increasing sufficiently the vapour pressure of the moisture held within the food product and decreasing significantly the relative humidity of the drying air. This significantly increases the moisture carrying capacity of the drying air and hence ensuring the product reaches allowed equilibrium moisture content suitable for storage of the food product (Ekechukwua and Norton, 1999).

There are mainly three types of solar drying systems: indirect, direct, and mixed-mode dryers. In direct solar dryers, collection of solar energy and drying of the product takes place in an enclosed insulated structure. In indirect dryers, air is heated in air heater and then flows over a product bed (Patil and Gawande, 2016). Indirect dryers are suitable for color sensitive food products, as the produce is not exposed directly to sunlight (Zooba and Bansal, 2011). In mixed mode dryers products are exposed directly to solar radiations and hot air from a solar collector. It is a combination of direct and indirect solar dryers (Patil and Gawande, 2016).

Solar dryers can also be classified according to the movement of air as natural and forced convection dryers. In natural convection (Passive) solar dryers, movement of air takes place due to a difference in air densities, while in forced convection (Active) solar dryers, a fan or blower is required to move the air through an air heater and over the product (Patil and Gawande, 2016).

2.3.1 Active Solar Dryers

A typical active solar dryer depends solely on solar-energy as the heat source but employs motorized fans for forced circulation of the drying air (Ekechukwua and Norton, 1999).

Thinly sliced foods are placed on drying racks made of a screen that allows drying air to flow to all sides of the food. Once inside the drying chamber, the warmed air flows up through the stacked food trays. The drying trays must fit tightly into the chamber so that the drying air is forced through the mesh and food. Active solar dryers are known to be suitable for drying higher moisture content foodstuffs such as papayas, kiwi fruits, and cabbages. Figure 2.1 shows an illustration of an active solar dryer. Active solar dryers are more efficient than passive dryers in terms of speed and quality of drying. However, they are not suitable in rural areas due to requirement of power for operating the fans. These limitations encourage researchers to develop new designs like solar tunnel and greenhouse type dryers.

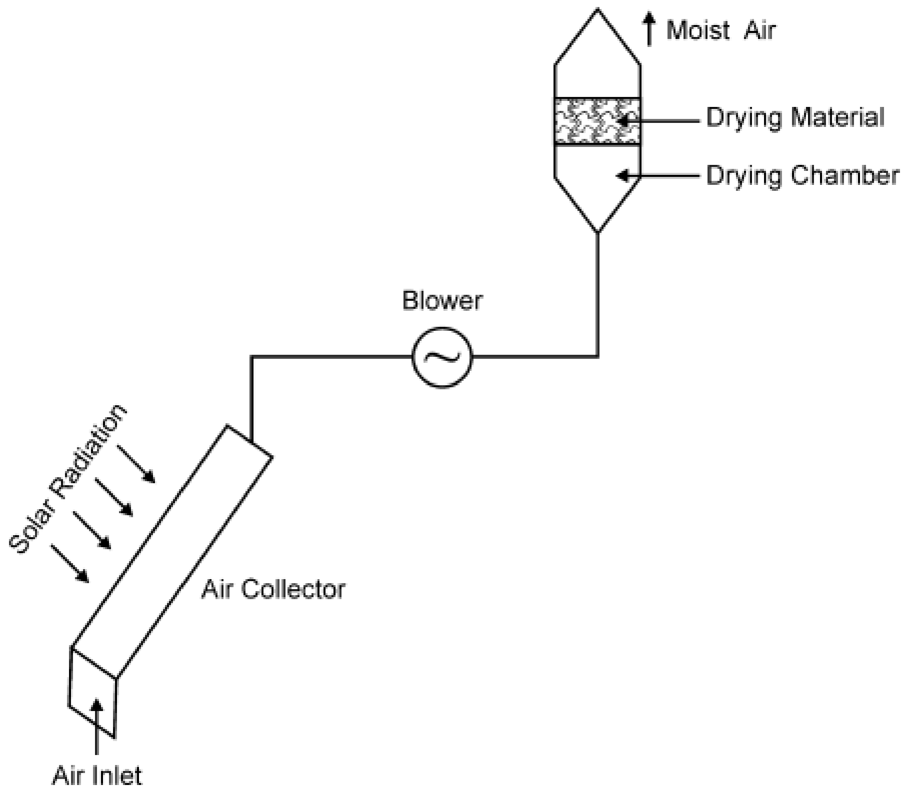

Figure 2.1: Schematic view of an Active solar dryer (Zooba and Bansal, 2011)

2.3.2 Passive Solar Dryers

Passive (Natural-convection) dryers depend solely on solar energy for their operation. In such systems, solar-heated air is circulated through the product by buoyancy forces or as a result of wind pressure (Ekechukwua and Norton, 1999). Natural circulation solar-energy dryers are the most suitable option for use in remote rural locations where there is no electricity available. They are superior operationally and compete economically compared to traditional Open Sun Drying (Ekechukwua and Norton, 1999).

These types of dryers are comprised of a drying chamber that is covered by a transparent cover made of glass or polythene. The drying chamber is usually a shallow, insulated box with air-vents in it to allow air to enter and exit the box. The food samples are placed on a perforated tray that allows the air to flow through it and the food product as shown in Figure 2.2 (Zooba and Bansal, 2011).

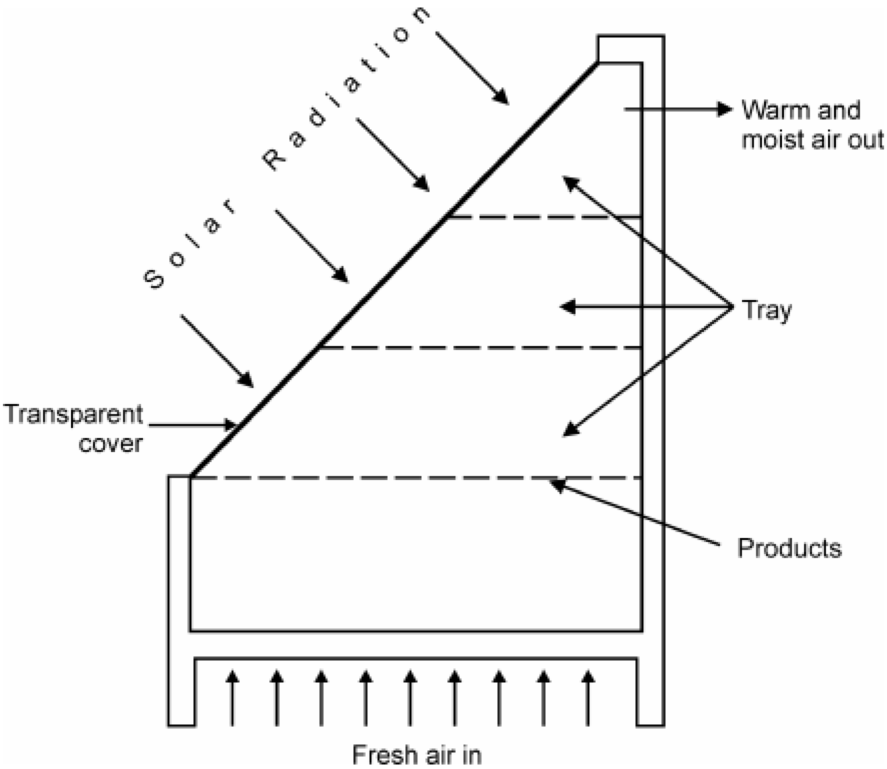

Figure 2.2: Schematic view of a direct type passive solar dryer (Zooba and Bansal, 2011)

2.3.3 Greenhouse Solar Dryers

Greenhouse Solar Dryers can be classified as passive solar dryers. Greenhouse Solar Dryers have the following advantages over Open Sun Drying which include;

(i) being rain-proof and hence can be kept in continuous operation even in bad weather,

(ii) able to dry in an enclosed environment which protects the products from dust, dirt, and attack by birds, rodents and insect infestation therefore producing a relatively high quality of dry agricultural products,

(iii) having shorter drying period compared with Open Sun Drying thus attaining higher rates of product throughput and

(iv) being commercially viable due to their relatively low capital costs because of the use of readily available indigenous materials for construction.

Greenhouse Solar Dryers are mainly classified into two types based on structure; the Dome shape and Roof even type (Kumar *et al.*, 2006).
The purpose of Dome type greenhouse dryer is to maximize the utilization of global solar radiation. The advantage of the Roof even type greenhouse dryer is the proper mixing of air inside the dryer.

The Solar Greenhouse Dryer based on natural convection was first reported by the Brace Research Institute, in Canada (Zooba and Bansal, 2011). The glass-roof solar dryer shown in Figure. 2.3 comprises of two parallel rows of drying platforms made of galvanized iron wire mesh surface laid over wooden beams placed along the sides of the dryer. A fixed slanted glass roof over the platform allows direct solar radiation to fall on the product. The dryer, has black coated internal walls for improved absorption of solar radiation. A ridge cap made of folded zinc sheet over the roof provides an air exit vent. Shutters at the outer sides of the platforms regulate the air inlet (Zooba and Bansal, 2011).

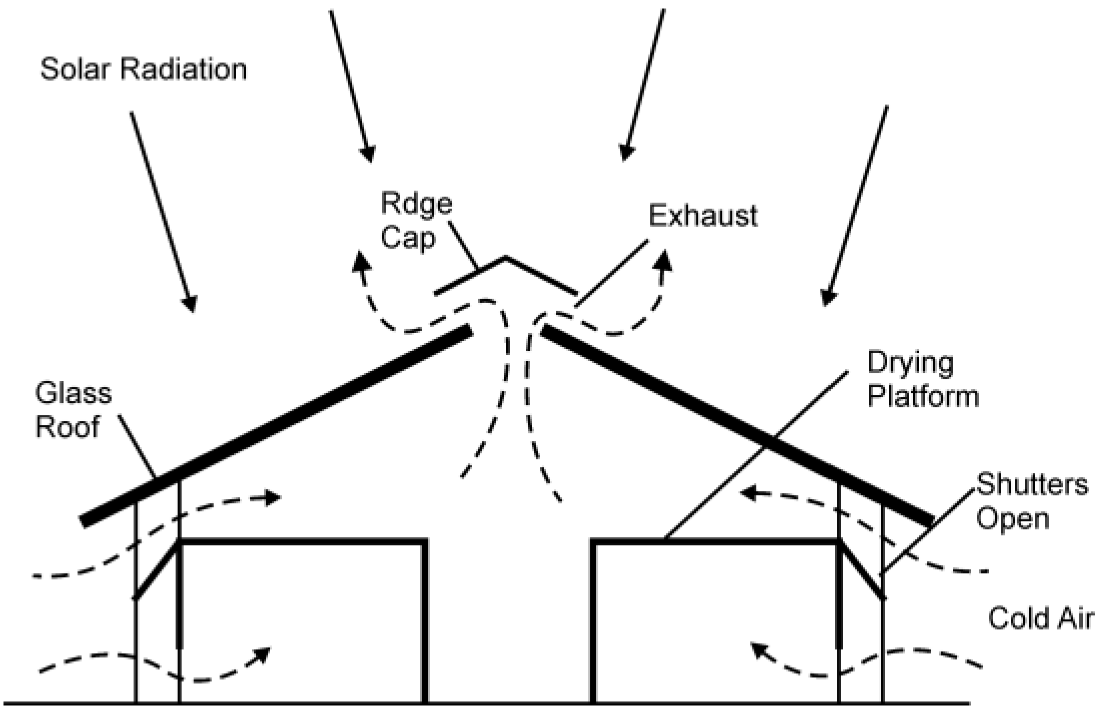

Figure 2.3: Natural-circulation glass-roof solar-energy dryer (Zooba and Bansal, 2011)

Subsequent designs of typical passive Greenhouse Solar Dryers included the widely reported Solar–tent dryer by Doe *et al.* (1977). The dryer illustrated in Figure.2.4 is comprised of a ridged bamboo framework clad with clear polyethylene sheet on the sun facing side and at the ends. The rear side is clad with black polyethylene sheet which is also spread on the floor to improve absorption of solar radiation. The clear plastic cladding at the bottom edge of the front side is rolled around a bamboo pole which could be adjusted to control air flow into the chamber, while the vents at the top of the ends serve as the exit for the moist exhaust air.

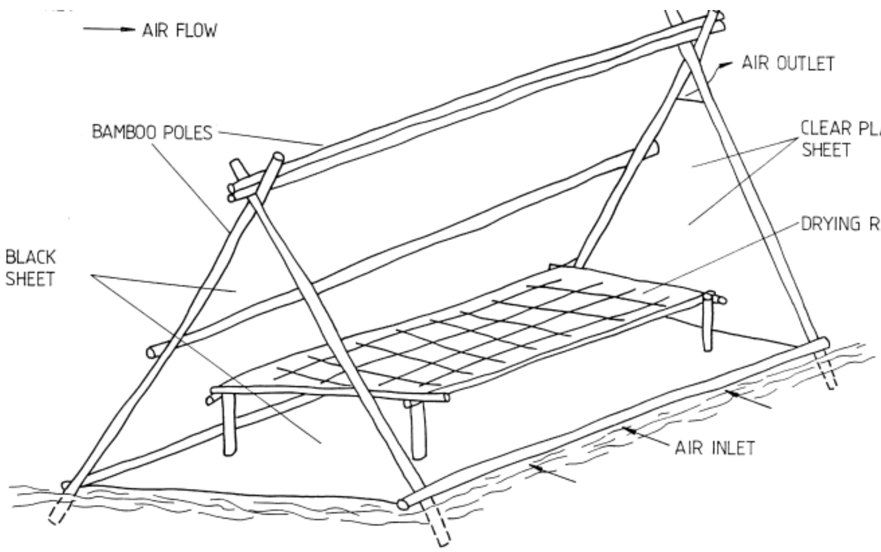

Figure 2.4: Schematic Diagram of Passive Greenhouse Solar tent dryer (Doe et al., 1977)

2.3.3.1 Performance of a Greenhouse Solar Dryer

Several studies explained below on natural convection Greenhouse Solar Dryers for drying of agricultural products have been documented in literature but there are no specific studies that have been found in literature on Greenhouse Solar Drying of Kapenta (*Stolothrissa tanganicae*).

Jain and Tiwari, (2004) studied the effect of Greenhouse on Crop drying under natural and forced convection. They developed mathematical models to predict the crop temperature, greenhouse room temperature and moisture evaporation for Open Sun Drying and Greenhouse drying under natural and forced convection. These models were validated with experimental observations for drying of cabbage and peas with each mode of drying. The predicted values were in good agreement with experimental observations with coefficient of correlation ranging between 0.77 and 0.97 for the crop and greenhouse room air temperatures and 0.98–0.99 for the crop mass during drying.

A thermal model for natural convection Greenhouse solar drying for jaggery was developed by Kumar and Tiwari (2006). The thermal model developed was validated with the experimental observations for the complete drying of jaggery under natural convection conditions. The predicted values and experimental observations were in good agreement with coefficient of correlation ranging between 0.90 and 0.98 for jaggery and Greenhouse air temperature and 0.96–1.00 for the jaggery mass during drying.

Elkhadraoui *et al.* (2015) performed an experimental analysis to investigate the performance of a mixed mode solar greenhouse dryer with forced convection which was used to dry red pepper and sultana grape. The drier consisted of a flat plate solar collector and a chapel-shaped Greenhouse. The moisture content of red pepper was reduced to 16% (wet basis) in 24 hours for Open Sun Drying, whereas the Greenhouse dryer took only 17 hours. The moisture content of Sultana grape was reduced to 18% (wet basis) in 76 hours for Open Sun Drying, whereas the Greenhouse dryer took 50 hours.

Bala and Mondol (2001) performed an experimental investigation on solar drying of fish using a solar tunnel dryer. The dryer comprised of a transparent plastic covered flat plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using four d.c. fans, operated by two 40 watt solar modules. Three sets of full scale experimental drying runs for drying silver jew *(Johnius argentatus)* fish were conducted in February-March, 1999. The temperature of the drying air at the collector outlet varied from 35.1 ° C to 52.2 ° C during drying. The salt treated fish was dried to a moisture content of 16.78% (w.b.) from 67% (w.b.) in 5 days of drying in solar tunnel dryer as compared to 5 days of drying under traditional Open Sun Drying for comparable samples to a final moisture content of 32.84%.

2.4 Thin Layer Drying and mathematical modelling

Thin layer drying is the drying of one layer of sample particles or slices (Akpinar, 2006). The most important aspect of thin layer drying is the mathematical modelling of the drying processes and equipment. The main objective of mathematical modelling is to enable design engineers to select the most suitable operating conditions and size the drying equipment and drying chamber accordingly to meet desired operating conditions.

The principle of mathematical modeling is based on having a set of mathematical equations that can adequately characterize the system. In particular, the solution of these equations must allow prediction of the process parameters as a function of time at any point in the dryer based only on initial conditions (Akhondi *et al.,* 2011).

The thin layer drying models that describe the drying characteristics of agricultural materials are sub-divided into three categories, namely theoretical, semi-theoretical and empirical (Midilli *et al.*, 2002).

The theoretical approach is concerned with either the diffusion equation or simultaneous heat and mass transfer equation and only takes into account the internal resistance to moisture transfer.

On the other hand the semi-theoretical approach deals with approximated theoretical equations and considers only the external resistance to moisture transfer between the product and air. Semi-theoretical models are developed by simplifying general series solution of Fick's second law and they offer a compromise between theory and ease of use. These models are only valid within the temperature, relative humidity and airflow velocity and moisture content range for which they were developed (Akpinar, 2006).

Empirical models derive a direct relationship between average moisture content and drying time but neglect fundamentals of the drying process and their parameters. Empirical models therefore do not give an accurate interpretation of the important processes occurring during drying. However they describe the drying curve for the conditions of the experiments (Akpinar, 2006).

Many studies have been documented on thin layer drying and mathematical modelling of different types of fish as described below. However, there is no specific literature on thin layer drying and mathematical modelling of Kapenta (*Stolothrissa tanganicae*) in a Greenhouse Solar Dryer.

Kituu *et al.* (2010) performed an investigation on the thin layer drying model for simulating the drying of Tilapia fish (*Oreochromis niloticus*) in a solar tunnel dryer, where he developed a model to predict plenum chamber temperatures and thin layer drying of tilapia fish in a solar tunnel dryer. There were strong linear correlations between the simulated and actual data for plenum chamber temperature with a coefficient of correlation, R^2 of 0.961. A strong linear correlation was also observed between the experimental and predicted moisture ratio with a coefficient of correlation, R^2 of 0.995. Therefore, the model can be used effectively to predict the drying of Tilapia fish in a solar tunnel dryer.

Guan *et al.* (2013) also studied the mathematical modelling on hot air drying of thin layer fresh tilapia (*Oreochromis niloticus*) fillets. The hot convective drying of fresh tilapia fillets was evaluated in a heat pump dryer. The influence of the drying temperature (35, 45 and 55°C), hot air velocity (1.50, 2.50 and 3.50 m/s) and thickness (3, 5 and 7 mm) of the tilapia fillets on the moisture ratio and drying rate was evaluated. The experimental drying data of fresh tilapia fillets under different conditions was fitted to nine thin-layer drying models by non-linear fitting methods and the Page model gave the highest values of coefficient of correlation, R^2 of 0.99254 and the corresponding reduced chi-square and the root mean square error values were lower 0.000632219 and 0.023854, respectively, indicating that the Page model was the best to describe drying curves of fresh tilapia fillets among them. The temperatures used by Guan *et al.* (2013) for the hot air drying of fresh tilapia fillets were used in this research for hot air drying of fresh Kapenta.

2.5 Water Activity

Water activity is expressed as the ratio of the vapour pressure in a food (P) to the vapour pressure of pure water (P_0) as indicated in Equation (2.1) (Labuza, 1980).

$$a_w = \frac{p}{p_o} \qquad (2.1)$$

Water activity (a_w) is a measurement of the availability of water for biological reactions in a food product (Rockland and Nishi, 1980). It determines the ability of micro-organisms to grow in a product. If water activity decreases, micro-organisms with the ability to grow will also decrease while if the water activity increases micro-organisms with growth ability will also increase (Labuza, 1980).

It predicts whether water is likely to move from the food product into the cells of micro-organisms that may be present. For example, a water activity of 0.90 means the vapour pressure is 90 per cent of that of pure water (Rockland and Nishi, 1980). According to Labuza *et al.* (1985) water activity increases with temperature due to changes in the properties of water such as the solubility of solutes like salt and sugar, or the state of the food.

The average water activity of the samples dried in the Greenhouse Solar Dryer and under Open Sun Drying was determined in order to determine and compare the ability of yeasts and moulds to grow in the dried Kapenta Samples. Tables 2.1 and 2.2 were used to determine whether the dried samples were susceptible to microbial infestation.

2.5.1 Typical Water Activity Limits for Organisms

By lowering the water activity, the shelf life of most food products can be increased significantly. Table.2.1 below shows water activity levels that can support the growth of particular groups of micro-organisms.

Table 2.1: Water Activity Limits for Micro-organisms

Group of Micro-Organisms	**Minimum a_w required for growth**
Most gram-negative bacteria	0.97
Staphylococcal toxin production (by Staphylococcus aureus)	0.93
Most gram-positive bacteria	0.90
Most yeasts	0.88
Staphylococcus aureus	0.86
Most moulds	0.80
Halophilic bacteria (grow best at high salt concentrations)	0.75
Xerophillic moulds (can grow on dry foods) and Osmophillic yeasts (can grow in the presence of high concentrations of organic compounds, ex: sugars)	0.62-0.60

Source; (Manitoba Agriculture Food and Rural Development, 2015)

Moulds have minimum water activities for growth and toxin production. Most moulds require a higher water activity than the minimum requirement for growth to produce mycotoxins (Manitoba Agriculture Food and Rural Development, 2015). The Table 2.2 below shows a few common mycotoxins and minimum water activities for mould growth and toxin production.

Table 2.2: Common mycotoxins and minimum water activities for mould growth and toxin production

Mycotoxin	**Mould**	**Minimum a_w Requirement**	
		Toxin Production	**Growth**
Aflatoxins	Asperagillus parasiticus	0.83-0.87	0.82
Ochratoxin	Aperagillus ochreceus	0.85	0.77
	Penicillium cyclopium	0.87-0.90	0.82-0.85
Patulin	Penicillium expansum	0.99	0.81
	Penicillium patulum	0.95	

2.6 Theory and Research literature specific to study topic

Several studies have been done to solve the problem of Open Sun Drying of fish using solar dryers.

2.6.1 Solar tent dryers for improved Sun drying of fish in Bangladesh (Doe *et al.*, 1977)

This solar tent dryer was developed to curb the problems associated with Open Sun Drying of fish. The dryer is made up of a polythene sheet spread over a wooden frame as illustrated in Figure 2.5. The solar tent dryer operates through evaporative drying using the greenhouse principle. When set up in the sun, solar energy passes through the transparent polythene and is trapped within the solar tent dryer thereby raising the internal temperature. Cool air flowing in through the inlet is heated up and removes moisture from fish laid on racks in the dryer. Doe *et al.* (1977) observed that the solar tent dryer speeded up the drying process of the fish considerably as compared to Open Sun Drying thus resulting in a high quality product with extended shelf life.

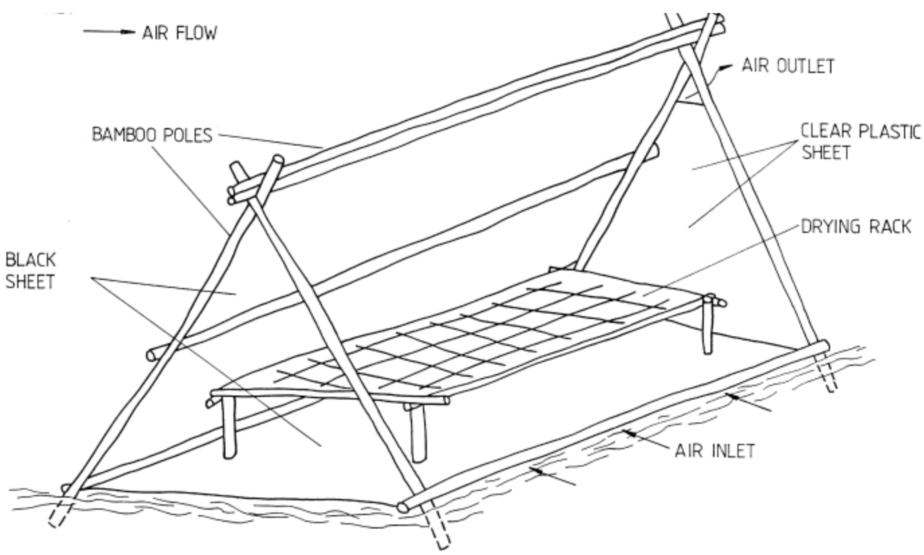

Figure 2.5: Schematic Diagram of the Framework of Doe's Tent (Doe et al., 1977)

2.6.2 Adaptation and Improvement of a Simple Solar Tent Dryer to Enhance Fish Drying in Nigeria (Olokor and Omojowo, 2009)

Kainji Solar Tent Dryer (KSTD) was constructed as an improvement of Doe's tent. Table.2 3 illustrates the constructional improvements made on the Doe's tent to come up with the Kainji Solar Tent Dryer (KSTD).

Table 2.3: Comparison of Doe (1977) and the Kainji (2009) Solar Tent design

Doe PE, Solar tent dryer	Olokor, Kainji solar tent dryer
Polythene tent not sewn but wrapped around the wooden frames	Polythene tent sewn to shape with roped hemmed around the tent to protect it against wind
Wooden frames are dug into the ground and not movable	Wooden frames are into the ground as with Doe's design.
Tent has no screened exit for air but cut out openings	Tent has screened exit for air sewn
Tent has no black rocks but PVC (black) polyethylene spread out on the base of the tent	Tent has black rocks to generate and store heat
A section of the tent has to be lifted up to gain access into the tent to check fish	Tent has zip attached to serve as access into the tent
Outlet of polythene tent not screened but wrapped up thus allows in flies and pests	Outlet screened against flies with mosquito net

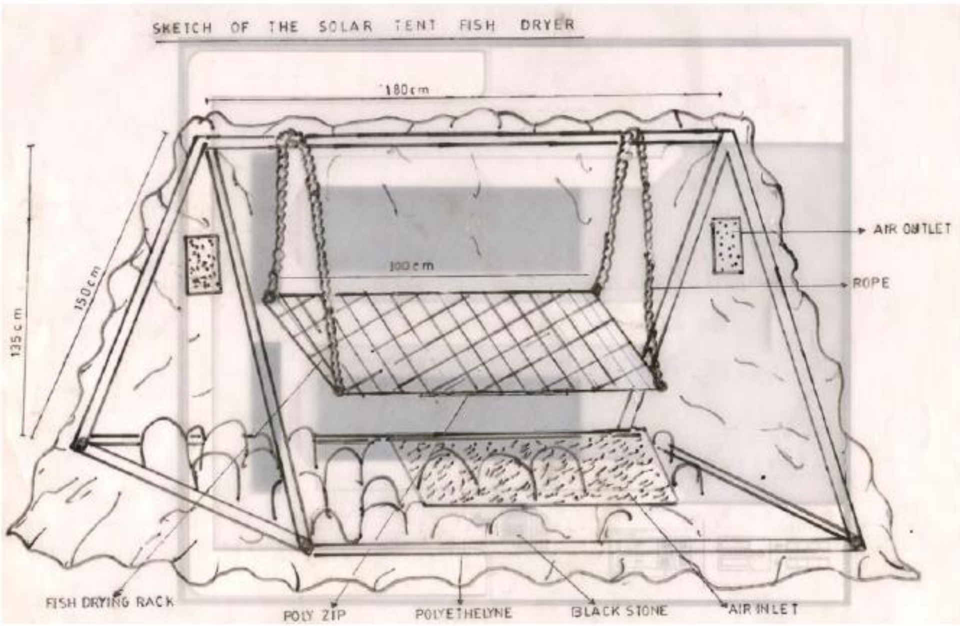

Figure 2.6: Schematic Diagram of the Framework of Kainji's Greenhouse Solar Tent Dryer (Olokor and Omojowo, 2009)

The following were the advantages of the improvements made on Doe's tent to develop the Kainji solar tent dryer.

1) There was a low incidence of flies in the KSTD due to the fact that both the inlet and outlets of the polythene were screened which prevented flies from entering the dryer, unlike the Doe's design, which had no screens and flies were observed to move in and out freely. The consequence of this was that flies would lay their eggs on the fish during the drying process thereby facilitating spoilage of the fish and subsequently reducing its shelf life.
2) The internal temperature in KSTD was consistently higher (49.8^{0}C in March 1999) than Doe's (43.9^{0}C in the same month and year). The inside conditions of the KSTD were more stable than Doe's tent because of the black igneous rocks, which absorbs and retain solar energy despite hourly fluctuation due to cloud cover prevalent at that time of the year while the Doe's design was more responsive to changes in ambient conditions.
3) There was a low relative humidity recorded in KSTD because of its consistent high temperature of 49.8°C and 38°C for March and August 1999.

The studies revealed that Kainji Solar Tent Dryer which was constructed as an improvement of Doe's is better in terms of structural make up, quality of the products and it dried fish faster than the Doe's tent dryer. On this basis it was adopted as the Greenhouse Solar Dryer design for this research study.

2.6.3 Qualities of Tilapia zillii products from solar tent dryers in a humid tropical environment (Ipinmoroti, 2012)

Ipinmoroti (2012) perfomed an experimental investigation to identify the best type of solar tent dryer for producing high quality (nutritional composition and shelf life) solar dried fish in a tropical humid environment.

The tent dryer designed by Doe *et al.* (1977) in Bangladesh and modified by Olokor, (2009) in Nigeria was adapted for Ipinmoroti's experimental investigation. The study was conducted in southwestern Nigeria where weather conditions were very humid.

Three dryers were constructed with wooden frames each with structural dimensions 4x3x3m and trays made with chicken wire placed over wooden frames. The three types of dryers were set up as follows: a solar tent dryer with collector covered with transparent white polythene (CTP); a solar tent dryer without collector but covered with transparent white polythene (NCTP) and a solar tent dryer without collector covered with black polythene (NCBP).

Fish samples of equal weight (350 ± 10.5g) and length (22±2.5cm) were prepared, treated with 30 % brine and exposed to gradual solar radiation from under the tents. The products were allowed to dry and were then analyzed for nutritional quality using the method described by the Association of Official Analytical Chemist.
The nutritional compositions of products from the dryers are presented on Table 4.

Table 2.4: Nutritional compositions of products from the dryers

Nutrient	Fresh fish	CTP	NCTP	NCBP
Moisture	60.13	23.64	23.07	25.59
Protein	28.71	51.99	53.88	52.99
Ether Extract	3.11	6.39	7.26	6.83
Fibre	0.55	1.66	1.92	1.62
Ash	7.45	16.78	13.55	12.79

The values were significantly different at ($P<0.05$)

The solar tent dryer without a collector and covered with transparent polythene (NCTP) gave the best final dried fish in terms of low moisture content, highest protein and higher fiber values.

The low moisture content has significant implication on shelf life of dried products and microbial activities. Deterioration processes progress faster with increasing moisture levels, thus affecting consumer acceptability of fish products. The better preservation method is therefore one that efficiently reduces the moisture content to a safe level that prevents microorganism proliferation, and preserves its nutritional properties to a level that is beneficial to consumers at the time of consumption.

The solar tent dryer without a collector and covered with transparent white polythene (NCTP) was recommended as the best option for drying of fish. On this basis the same design was adopted for this study.

2.7 Literature review summary

From the reviewed literature, it can be seen that Greenhouse Solar drying plays a key role in the preservation of fish and other food products. This is because it maintains the nutritional properties and quality of the food products. Passive Greenhouse Solar Dryers are the most commonly used type of solar dryers this is because of their simple design and the fact that they can be easily constructed using locally available materials. A number of Passive Greenhouse Solar Dryers that have been used for thin layer drying of various food products were described in this chapter. Thin layer drying and mathematical modelling were also described in detail in this chapter. The next chapter describes the methodology adopted for this study.

CHAPTER THREE

3. METHODOLOGY

This chapter describes how the entire research work was carried out in order to fulfill the objectives of the study. It gives a detailed account of all the procedures and the types of equipment that were used for the research.

3.1 Description of the Solar Greenhouse Dryer System

The solar Greenhouse natural convection drying system as shown in Figure 3.1 was located at the University of Zambia; Lusaka; School of Agricultural Sciences Field Station: Latitude; 15°23'39.50"S; Longitude; 28°20'7.96"E on a site that was well drained, nearly level, away from shading of trees and with full exposure to sunshine. The Greenhouse Solar Dryer had an east -west orientation to ensure the fish received maximum exposure to sun-light.

The Kainji Solar Tent Dryer described by Olokor and Omojowo (2009) was adopted for this study. The materials used in the construction of the Greenhouse Solar Dryer were; 200 µm thick greenhouse plastic, wooden frame, 20 mm diameter plastic pipes, black polythene sheet spread out on the base of the tent, pieces of rock, a drying rack, mosquito net and a zip.

Figure 3.1: Greenhouse Solar Dryer for Fresh Kapenta

The length, width and height of the Greenhouse Solar Dryer were 1.5 metres by 1metre by 1 metre, respectively as shown in Appendix 5. The Greenhouse Solar Dryer frame was constructed using straight wooden poles each measuring 1.5 m long.

A rectangular wooden frame measuring 1.5m by 1m was fabricated and 20 mm diameter plastic pipes clamped on opposite ends to form the Greenhouse frame as shown in Figure 3.2 (Appendix 4). Pieces of rock were spread within the base of the wooden frame and covered with black polythene as illustrated in Figure. 3.2.

Figure 3.2: Frame work of Greenhouse Solar Dryer

The Greenhouse plastic was fitted onto the entire Greenhouse framework as shown in Figure 3.1. On one of the longer sides of the polythene cover, a 1metre long zip was fitted to serve as an access opening into the tent for loading and unloading the Kapenta on the drying rack during the drying process. At the extreme narrow top part of the tent, an opening of 0.1 m x 0.5 m was made and covered with mosquito net to serve as outlet of moist air from the dryer. On the opposite end of the Greenhouse Solar Dryer at the bottom of the tent another opening measuring 0.1 m by 0.5 m was made to serve as the air inlet into the dryer (Appendix 3). The drying rack was a wire mesh framed with steel (0.9 m by 1m) and placed at a height of 0.20 m from the surface of the rocks (Appendix.3).

3.2 Methodology for achieving specific objectives

Drying experiments of the fresh Kapenta in the Greenhouse dryer were carried out in the months of November and December 2015. Freshly harvested Kapenta was obtained from a local supermarket in Lusaka. The samples were stored at -40^{0}C in a freezer before the experiments were conducted.

In order to determine the initial moisture content of the Kapenta, samples were dried in an oven (JeioTech, Model ON-02G, and accuracy ±0.5%) at 105^{0}C for 4 hours (AOAC, 2005). The initial moisture content (wet basis) was determined using Equation (3.1) (AOAC, 2005).

$$\%IMC\left(w.b\right)=\left(\frac{\left(\text{Original weight}-\text{Oven dry weight}\right)}{\text{original weight}}\right)\times 100 \qquad (3.1)$$

15 kilo grams of fresh Kapenta were dried in the Greenhouse Solar Dryer and in a hot air dryer to investigate the drying characteristics of Kapenta and establish a suitable thin layer drying model for solar drying of Kapenta. A total of eight experimental runs were conducted in the Greenhouse Solar Dryer and a total of twelve experiments in the hot air dryer during the period of November – December, 2015.

3.2.1 Experimental investigation on drying fresh Kapenta in a Greenhouse Solar Dryer in comparison to Open Sun Drying

The following procedure was followed in order to carry out an experimental investigation on drying of fresh Kapenta in the Greenhouse Solar Dryer and in Open Sun.

Kapenta was placed in a thin layer on a drying rack inside the Greenhouse Solar Dryer as shown in Figure.3.3. Another set of two samples weighing each 50 g each were placed on a drying rack in the open sun as control samples as shown in Figure 3.4. The experiments were started at 9.00 am and ran until a constant weight of the samples was reached. Product samples of 50 g from the Greenhouse Solar Dryer were weighed at 30 minutes intervals using a digital balance shown in Figure 3.5 (Metter, Model PE3000, accuracy, ±0.1 g) and the weight loss was recorded. The weights were then converted to moisture contents. The moisture contents of the products inside the dryer were compared with the control samples (open-air sun dried). The moisture content during drying was estimated from the weight of the product samples and the estimated dried solid mass of the samples.

Figure 3.3: Thin layer drying of Kapenta inside the Greenhouse Solar Dryer

Figure 3.4: Kapenta samples being dried in the Open Sun

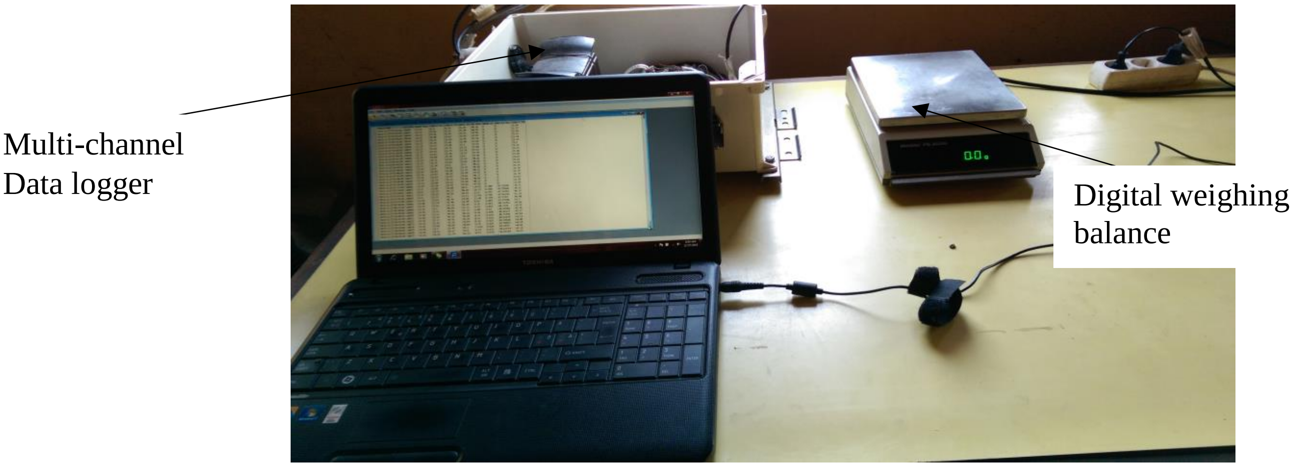

Figure 3.5: Multi channel data logger used to record the Temperature, Relative Humidity, and solar radiation and the digital weighing balance

Solar radiation was measured by a pyranometer (Kipp and Zonen, Model CM11, accuracy, ±0.5 %) placed on the roof of the Greenhouse Solar Dryer as shown in Figure 3.1. Three thermocouples (Campbell scientific, Model T108, accuracy ± 0.2 ^{0}C) were used to measure air temperatures at different positions of the Greenhouse Solar Dryer. Thermocouple positions for temperature measurement also shown in Figure.3.6. Voltage signals from the pyranometer, temperature and RH probe and thermocouples were recorded every minute by a multi-channel data logger (Campbell scientific, Model CR1000).

Figure 3.6: Positions of thermocouples and pyranometer on the Greenhouse Solar Dryer

3.2.2. To establish a suitable thin-layer drying model for predicting the drying Characteristics of Kapenta

Three samples of fresh Kapenta each weighing 20 g were dried at different temperatures of (35, 45 and 55 °C) Guan *et al.* (2013) using a hot air drier, (INNOTECH, Model Hohenheim). The weight of the samples were measured at 20 minute intervals using a digital balance (Metter, Model PE3000, accuracy, ±0.1 g). The drying procedure continued until a constant weight of the samples was achieved. The weight of the samples was converted into moisture content using Equation (3.2).

$$M_2 = \frac{100 - W_1(100 - M_1)}{W_3} \qquad (3.2)$$

The moisture ratio (MR) was determined using Equation (3.3);

$$\text{MR} = \frac{(M_t - \text{M}_\text{e})}{(M_0 - \text{M}_\text{e})} \qquad (3.3)$$

M_e Was determined by plotting a graph of moisture content against time and the equilibrium moisture content determined as illustrated in Figure.3.6. The point at which the moisture content curve reaches a constant value of 0.203 is the equilibrium moisture content of the Kapenta. At this point the Kapenta is neither gaining nor losing moisture to the surrounding atmosphere.

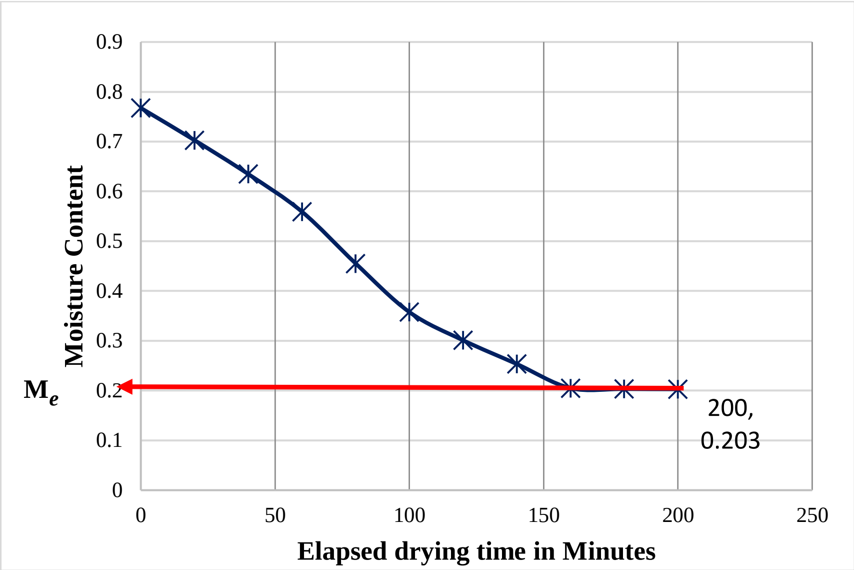

Figure 3.7: Equilibrium Moisture Content Curve

3.2.3 Comparison of the quality in terms of nutritional content and hygiene of Kapenta dried in a Greenhouse Solar Dryer and that dried using traditional Open Sun Drying

Samples of Kapenta that were dried inside the Greenhouse Solar Dryer and those that dried in the open sun were taken to the Food Science and Nutrition Laboratory at the University of Zambia for nutrition and microbial analysis.

The Samples were analyzed using the method described by the Association of Official Analytical Chemists (AOAC, 2005). The proximate composition of the samples in the Greenhouse Solar Dryer and the samples in the open sun were analyzed and compared in terms of the following nutritional content; Moisture content, Protein content, Fibre and Ash Content.

The hygiene indicators such as presence of yeasts and moulds, and E.coli *(Escherichia coli*) in both samples were analyzed.

3.2.3.1 Determination of protein content (AOAC, 2005)

The following chemicals were used for this test.

1) Kjedahl catalyst: Mix 9 parts of potassium Sulphate K_2SO_4 with one part of copper Sulphate ($CuSO_4$).
2) Sulphuric acid (H_2SO_4)
3) 40% Sodium Hydroxide Solution (NaOH)
4) 0.2 N HCL Solution
5) 4% Boric acid (H_3BO_3)
6) Indicator solution

Procedure

The dried Kapenta samples (0.5 g) were placed in a digestion flask. Five grams of Kjedahl catalyst and 200 ml of concentrated sulphuric acid were added into the digestion flask. A separate flask was prepared using the same procedure as above except without the dried kapenta sample as a control experiment. The flasks were placed gently in an inclined position and heated gently using a Bunsen burner. The samples in the flasks boiled until the frothing ceased and the solution cleared. The flasks were cooled immediately and 60 ml of distilled water added. The flask was immediately connected to the digestion bulb on condenser and the tip of condenser immersed in standard acid (0.2 N HCL Solution) and 5-7 drops of mix indicator in the receiver. The flask was rotated to mix the content thoroughly and then heated until all the ammonia (NH_3) was distilled. The receiver was removed and the tip of the condenser washed and excess standard acid was titrated with standard sodium hydroxide solution (NaOH). The percentage protein content was calculated using Equation (3.4).

Calculation

$$protein(\%) = \frac{(A-B)\times N \times 14.007 \times 6.25}{W} \qquad (3.4)$$

3.2.3.2 Determination of Ash Content (AOAC, 2005)

Two crucibles were placed in the furnace at 550 ^{0}C overnight to ensure that the impurities on the surface of the crucibles were burnt off. The crucibles were then cooled in the desiccator and weighed after 30 minutes and the weights recorded. Five grams of both kapenta samples were placed into the crucibles and heated over a low Bunsen burner flame until fumes were no longer being produced. The crucibles were then placed in the furnace and heated at a temperature of 550^{0}C overnight until the samples turned grey. Thereafter crucibles were removed from the furnace and cooled for 30 minutes in a desiccator. The crucibles were weighed with the ash and the weights recorded. The percentage ash content was determined using Equation (3.5).

Calculation

$$Ash(\%) = \frac{weight of\ ash}{weight of\ sample} \times 100 \qquad (3.5)$$

3.2.3.3 Determination of fat content (AOAC, 2005)

Procedure

Four bottles and their lids were placed in to the incubator at a temperature of 105^{0}C overnight to ensure that the weight of the bottle was stable. Five grams of each sample was weighed and placed in two separate filter papers, wrapped and the samples taken to the extraction thimble then transferred into Soxhlets. The bottles were filled with petroleum ether and taken to the heating mantle. The Soxhlet apparatus was connected, the water turned on to cool the bottles and the heating mantle switched on. The sample was heated for 14 hours and -the solvent evaporated using the vacuum condenser. The bottle was incubated at 80-90^{0}C until it was completely dry. The bottle with the dried content was reweighed and the weights recorded. The percentage of fat available in the dried Kapenta was calculated using Equation (3.6).

$$Fat(\%) = \frac{weight of\ fat}{weight of\ sample} \times 100 \qquad (3.6)$$

3.2.3.4 Determination of Water Activity

Two Samples each weighing five grams of the dried Kapenta from the Greenhouse Solar Dryer were crushed using a grinder and placed in two separate petri dishes. Each petri dish was then inserted in to the water activity meter one at a time (Aqua Lab, Model Series 3/3TE, accuracy, ±0.003 a_w) and left for three minutes and the water activity values recorded. The same procedure was repeated for the Kapenta that was dried under Open Sun Drying.

3.2.3.5 Procedure for analysis of yeasts and moulds present in Kapenta

Reagents used;

1) Potato Dextrose Agar (PDA)
2) Ringers Solution
3) Plate Count Agar (PCA)
4) Buffered Peptone Water (BPW)

Procedure

An amount of 25g of the Kapenta samples was weighed into 225 ml of Sterile Buffered Water (BPW) in a stomacher bag. The suspension was thoroughly mixed in the Stomacher for 2 minutes then allowed to stand for 1 hour. This constituted a dilution of 10^{-1}. Decimal dilutions with sterile Ringers solution were prepared in test tubes (each containing 9 ml) from 10^{-2} to 10^{-6}. Sterile pipettes were used to transfer 1.0 ml portions of sample dilution into pre-labelled petri plates (in duplicate) and 20 – 25 ml tempered PDA agar was added immediately. The contents were mixed by gently swirling plates clockwise, then counterclockwise. The plates were then incubated in the dark at 25 °C. The plates were counted after 5 days of incubation. The results were reported in colony forming units CFU/g or CFU/ml based on average count of duplicate plates.

3.2.3.6 Procedure for analysis of presence of E.coli (Escherichia coli) in Kapenta

Reagents used;

1) Ringers Solution
2) Plate Count Agar (PCA)
3) Buffered Peptone Water (BPW)
4) Lauryl Tryptose Broth (LTB)
5) EC Broth
6) Levine’s eosin-methylene blue (L-EMB)

Procedure

An amount of 25g of the Kapenta samples was weighed into 225 ml of Sterile Buffered Water (BPW) in a stomacher bag. The suspension was thoroughly mixed in the Stomacher for 2 minutes then allowed to stand for 1 hour. This constituted a dilution of 10^{-1}. Decimal dilutions with sterile Ringers solution were prepared in test tubes (each containing 9 ml) from 10^{-2} to 10^{-6}. Using dilutions 10^{-1}, 10^{-2} and 10^{-3}, 3 X 1 ml aliquots of each of dilution was transferred to the corresponding 3 LTB tubes giving a total of 9 LTB tubes for each sample. Therefore, this was a 3 tube MPN analysis. The LTB tubes were incubated at 35°C for 24–48 hours. After 24 hours the tubes were examined and the reactions for gas (i.e. displacement of medium in fermentation vial or effervescence when tubes are gently agitated) was recorded. Each gassing EC tube was gently agitated and a loop of broth and streak was removed for isolation on a L-EMB agar plate and incubated for 24 h at 35 °C. The plates were examined for suspicious *E.coli* colonies that is dark centered and flat, with or without metallic sheen.

3.3 Closing remarks.

This chapter described in detail the construction of the Greenhouse Solar Dryer and the procedures followed during drying of Kapenta in the Greenhouse Solar Dryer and under Open Sun Drying. It also described in detail the materials used and procedures followed for proximate and microbial analysis of the dried Kapenta Samples. The next chapter presents the results and analysis of data.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

This chapter presents in detail how the data collected was analyzed and interpreted.

4.1 Variation of Solar Radiation with Air Temperature inside the Greenhouse

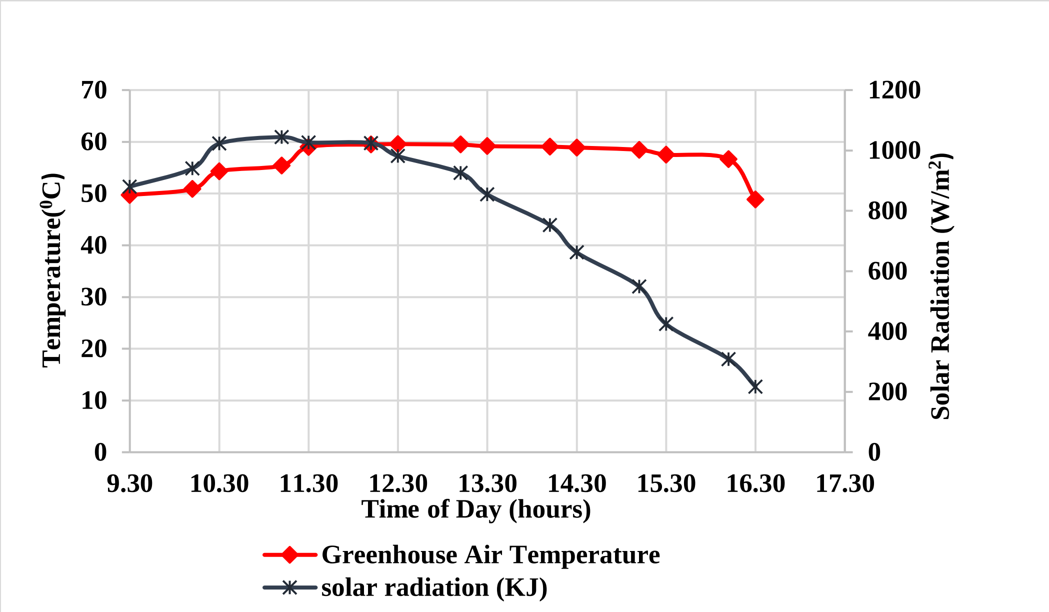

Figure 4.1: Mean solar radiation and temperatures at various times during the day (November 2015)

In the morning hours as the solar radiation gradually increased from 880 W/m^2 at 9.00 hours to 1024 W/m^2 at 12.30 hours, the air temperature in the dryer also increased simultaneously from 50^{0}C to 60 ^{0}C at midday. In the afternoon the air temperature inside the dryer remained relatively constant at approximately 57 ^{0}C as seen in Figure.4.1. As the solar intensity reduced in the afternoon due to the cloud cover the air temperature inside the Greenhouse Solar Dryer remained consistently high from 13.30 hours to 16.00 hours as seen in Figure 4.1 due to the effect of the pieces of rock covered with black polythene at the base of the Greenhouse Solar Dryer which acted as a capacitor by absorbing, retaining and releasing radiant energy needed for the Kapenta drying.

Olokor and Omojowo (2009) found similar behavior in the drying of fish (*Bagrus bayad*) in an improved solar tent dryer (KSTD). The temperatures recorded inside the dryer (KSTD) were consistently higher than the ambient conditions because of the black igneous rocks, which absorbed and retained the heat despite hourly fluctuation due to cloud cover.

This result therefore confirms that it is advantageous to use rocks as solar absorbers in a Greenhouse Solar dryer in order to maintain consistently high temperatures within the dryer during the day irrespective of cloud cover. The pieces of rock covered with black polythene intensify the greenhouse effect within the dryer through their capability to store and release solar energy in the form of heat (Charney, 1975).

4.2 Variation of Temperature and Relative humidity at different locations of the Greenhouse Solar Dryer

Figures.4.2 and 4.3 show the comparison of air temperature at three different locations on the Greenhouse Solar Dryer and the ambient air temperature for the experimental runs of solar drying of Kapenta in November and December 2015. The air entered the dryer at an average temperature of 34^0C and was heated up in the dryer to higher temperatures ranging from 45^0C -59^0C. The average air temperature in the dryer during the day was 55 ^{0}C but the temperatures inside the dryer could go as high as 60 ^{0}C at certain times of the day as shown in Appendices 6 and 7. The high temperatures attained in the Greenhouse were due to the effect of the pieces of stone covered with black polyethylene which absorbed and stored heat. The stored heat was used to heat the incoming air flowing into the Greenhouse Solar Dryer thereby raising the air temperature inside the dryer. The air inlet vent was positioned just below the tray as shown in Appendix 3. This was to allow the cool inflowing air to be heated up before it rises to the drying rack. As the hot air rises it was replaced with cool incoming air. At the exit the air temperature was lower than the air temperature inside the dryer. This was due to evaporative cooling of the hot air by the moisture absorbed from the Kapenta being dried inside the dryer.

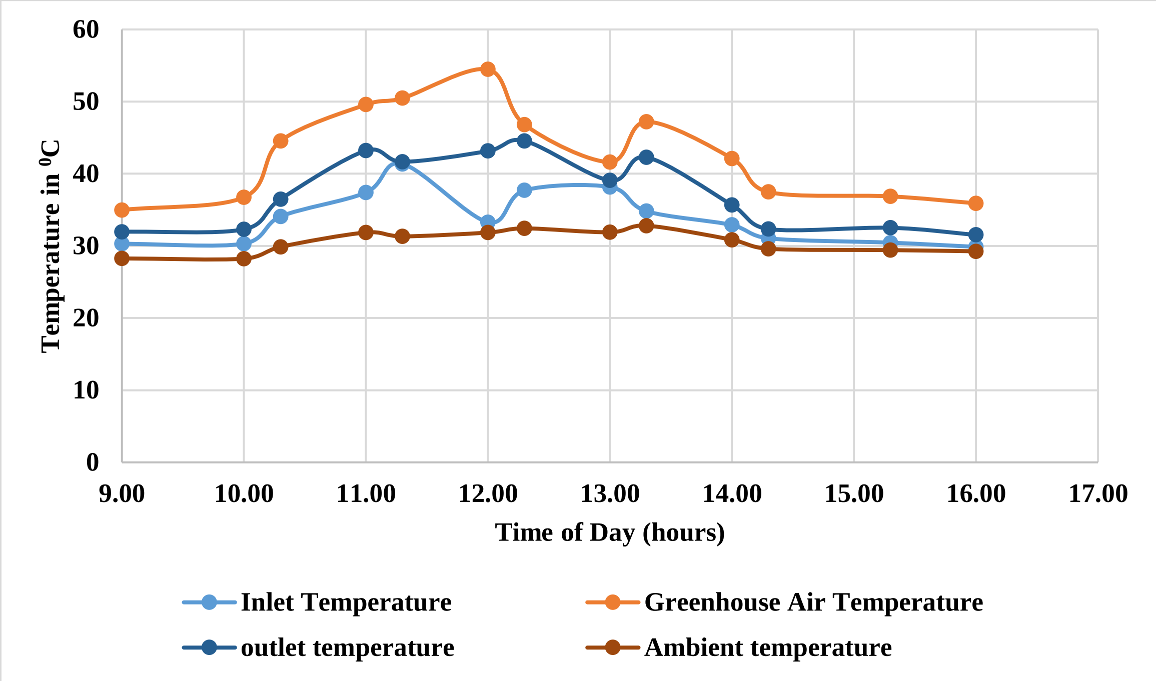

Figure 4.2: Mean temperatures at different locations of the Greenhouse Solar Dryer compared to the ambient temperatures (December 2015)

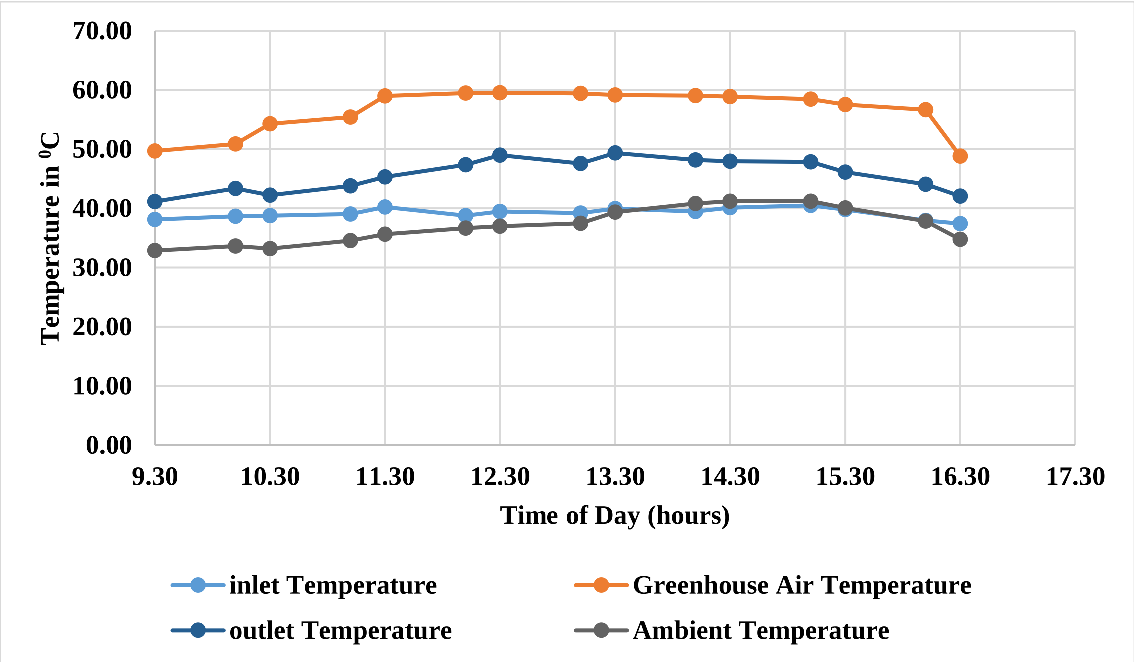

Figure 4.3: Mean temperatures at different locations of the Greenhouse Solar Dryer compared to the ambient temperatures (November 2015).

Figure.4.4 illustrates relative humidity at two different locations; inside the dryer and ambient air relative humidity during solar drying of Kapenta. The average relative humidity inside the dryer was 9.93% while the average ambient relative humidity was 29.82%. There was a significant difference of 19.89 % in relative humidity inside the dryer compared to the ambient relative humidity. The relative humidity of the air inside the dryer was lower than that of the ambient air due to the high air temperatures inside the Greenhouse Solar Dryer.

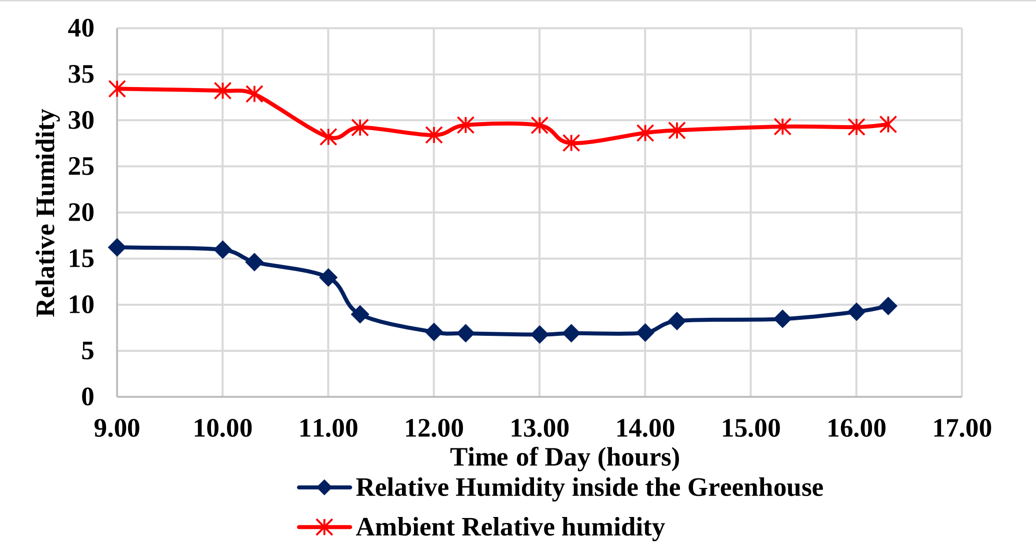

Figure 4.4: Air Relative humidity inside the Greenhouse Solar Dryer compared to the ambient relative humidity (December 2015)

4.3 Calculation of initial moisture content

Table 4.1. Shows the values of initial moisture content that were obtained from three samples. The initial moisture content (IMC) was calculated using Equation (4.1) and the average initial moisture content (wet basis) obtained as 76.74 %. This value is consistent with the initial moisture content observations by Oduor-Odote *et al.* (2010) found an initial moisture content value of 73.0% (w.b) for fresh sardine fish (*Rastrineobola argentea*) and Kilic (2009) who obtained an initial moisture content for fresh Anchovy fish as 70.68% ± 0.07 (w.b.).

$$\%\text{IMC}\,(\text{w.b}) = \left(\frac{(\text{Original weight} - \text{Oven dry weight})}{\text{original weight}}\right) \times 100 \qquad (4.1)$$

$$\%\text{IMC}\,(\text{w.b}) = \left(\frac{(18.72 - 10.766)}{10.36}\right) \times 100 = 76.805$$

Table 4.1: Calculation of Initial Moisture Content

DISH ID	Weight of dish (g)	original sample weight (g)	Weight of sample+ dish (g)	Oven dry weight (g)	Initial Moisture content (wet basis)
1	8.36	10.36	18.72	10.766	76.776
2	7.90	10.63	18.53	10.385	76.623
3	6.08	10.60	16.68	8.539	76.802

The high initial moisture content of Kapenta was indicative of high water activity. Consequently the shelf life of Fresh Kapenta is reduced, even under refrigeration as a result of high water activity which encourages the growth of organisms that cause spoilage. It is therefore important that immediately after harvesting the Fresh Kapenta it is dried to significantly reduce the moisture content to a safe storage level where the water activity is very low thus inhibiting micro-organism proliferation.

4.4 Variations of moisture content of the Kapenta under different drying conditions

The initial moisture content of the fresh Kapenta was obtained as 76.74% wet basis using the oven drying method. The variations in moisture content of the fresh Kapenta that was inside the dryer compared to the control sample dried by natural Open Sun Drying are showed in Figure.4.5. The moisture content of Kapenta in the Greenhouse Solar Dryer was reduced from an initial value of 76.74 % (w.b.) to a final value of 2.14% (w.b.) within 4.5 hours whereas the moisture content of the natural sun-dried samples was reduced to 14.34% (w.b.) in the same period. In addition, the Kapenta dried in this dryer was completely protected from insects, dust, animals and rain. Therefore the Greenhouse Solar Dryer is effective compared to Open Sun Drying since within the same amount of time the Greenhouse Solar Dryer dries the Kapenta to a significantly lower moisture content. This is a major advantage of the Greenhouse Solar Dryer since the Kapenta is completely dried to a stable moisture content which inhibits micro-organism proliferation thus increasing the shelf life of the dried Kapenta.

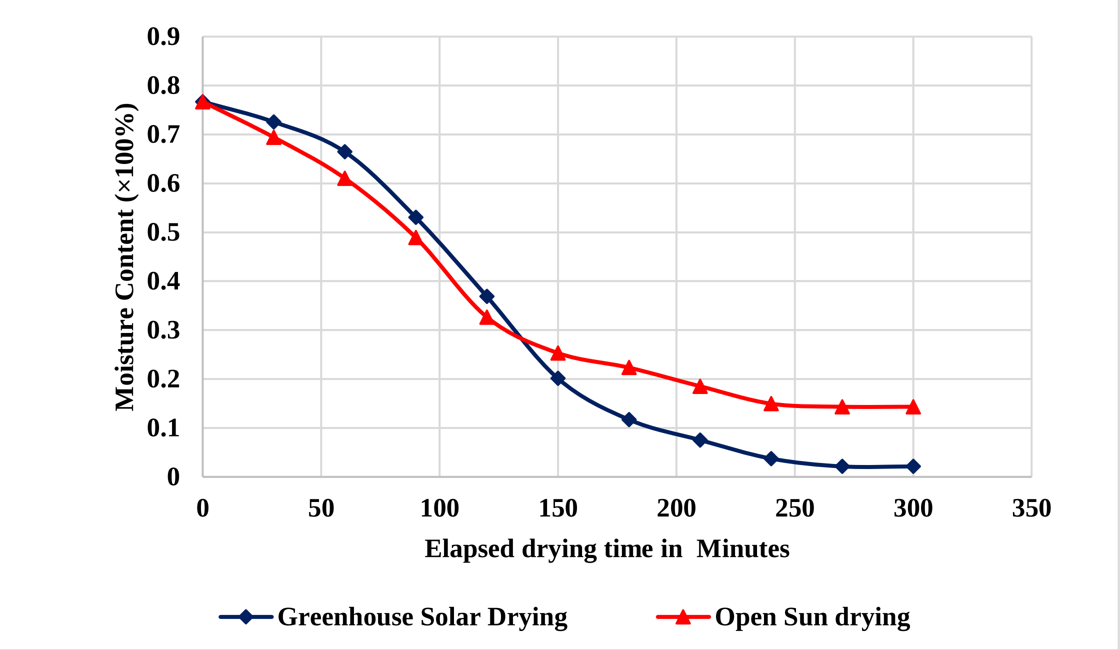

Figure 4.5: Variations of moisture content with time during drying of Kapenta both in the Greenhouse Solar Dryer and Open Sun Drying

From Figure.4.5, the moisture content after 180 minutes of drying is 11.7% and 22.3% for Greenhouse Solar Drying and Open Sun Drying respectively. Similarly, the moisture content after 240 minutes of drying is 3.7% and 15.0% for Greenhouse Solar Drying and Open Sun Drying respectively. This indicates a higher drying rate of Kapenta in the Greenhouse Solar Dryer in comparison with Open Sun Drying. This is because as the drying air temperature increased, the transfer rate of moisture from the internal of the drying Kapenta to its surface and the evaporation of moisture at surface increased, resulting in the higher drying rate experienced in the Greenhouse Solar Dryer.

4.5 Thin Layer Mathematical modeling

The moisture content data observed in the drying experiments under different temperatures in the hot air dryer were fitted to the seven commonly used thin-layer drying models listed in Table 4.2.

Table 4.2: Thin Layer Drying Curve Models

Model Name	Model
Henderson and Pabis	$MR = a \times \exp(-kt)$
Newton	$MR = \exp(-kt)$
Page	$MR = \exp(-kt^n)$
Logarithmic	$MR = a \times \exp(-kt) + b$
Middilli	$MR = a \times \exp(-kt^n) + bt$
Two term exponential	$MR = a \times \exp(-kt) + ((1-a) \times \exp(-kbt))$
Verma et al	$MR = a \times \exp(-kt) + ((1-a) \times \exp(-bt))$

Source; (Akpinar, 2006)

The suitability of each model against the experimental data was checked by using non-linear least squares regression analysis in Excel, Solver method (Darvishi *et al.*, 2013). The best model describing the drying characteristics of samples was chosen as the one with the highest coefficient of correlation (R^2), and the least reduced chi square (x^2) (Equation (4.3)) and root mean square error (RMSE) (Equation (4.2)) (Sarimeseli, 2011). These statistical parameters were calculated as follows (Darvishi *et al.*, 2013);

$$RMSE = \left[\left[\frac{1}{N}\right]\left[\sum_{i=1}^{N}\left(MR_{\exp i} - MR_{prei}\right)^2\right]\right]^{\frac{1}{2}} \qquad (4.2)$$

$$\chi^2 = \frac{\left[\sum_{i=1}^{N}\left(MR_{\exp i} - MR_{prei}\right)^2\right]^{1/2}}{N - Z} \qquad (4.3)$$

The statistical results of different models such as coefficient of correlation (R^2), the reduced chi-square (x^2) and the root mean square error (RMSE) values are summarized in Table 4.3. In all cases, the value of (R^2) was greater than 0.90 indicating a good fit (Madamba *et al.* (1996) except the Middilli model which gave (R^2) values of 0.7. But the Page model gave comparatively higher (R^2) values in all the drying treatments (0.9804-0.9970), and also the x^2 (0.0002-0.0012), and RMSE(0.0081-0.0328) values were lower as illustrated in Table 4.3 and figures 4.6 and 4.7 below. Hence, the Page model was selected as the best model describing the thin-layer drying behavior of fresh Kapenta in a hot air dryer.

Guan *et al.* (2013) also reported a similar result for Mathematical Modeling on Hot Air Drying of Thin Layer Fresh Tilapia Fillets. He established that the coefficient of correlation (R^2) values of the Page Model were higher than 0.99254, and the corresponding reduced chi-square (x^2) and the root mean square error values were lower 0.000632219 and 0.023854, respectively, indicating that the Page model was the best to describe drying curves of fresh tilapia fillets among the thin layer drying models evaluated.

Table 4.3: Obtained values of model constants and statistical parameters

T (^{0}C)	a	b	n	K	SSE	ADJUSTED R^2	RMSE	R^2	x^2
Henderson and Pabis $MR = a \times \exp(-kt)$									
35	1.0970			0.0136	0.0715	0.9409	0.0891	0.9468	0.0079
35	1.1150			0.0133	0.0867	0.9316	0.0981	0.9384	0.0096
45	1.0970			0.0104	0.0572	0.9605	0.0690	0.9635	0.0048
45	1.1060			0.0109	0.0570	0.9617	0.0689	0.9646	0.0047
55	1.0940			0.0147	0.0370	0.9682	0.0641	0.9714	0.0041
55	1.0940			0.0158	0.0383	0.9676	0.0652	0.9709	0.0043
Newton $MR = \exp(-kt)$									
35				0.0125	0.0867	0.9355	0.0931	0.9355	0.0087
35				0.0120	0.1083	0.9231	0.1041	0.9231	0.0108
45				0.0096	0.0748	0.9523	0.0758	0.9523	0.0058
45				0.0099	0.0795	0.9516	0.0774	0.9516	0.0061
55				0.0136	0.0504	0.9610	0.0710	0.9610	0.0050
55				0.0146	0.0515	0.9608	0.0718	0.9608	0.0051
Page $MR = \exp(-kt^n)$									
35			**1.8344**	**0.0003**	**0.0097**	**0.9920**	**0.0328**	**0.9928**	**0.0011**
35			**1.8344**	**0.0003**	**0.0061**	**0.9952**	**0.0261**	**0.9957**	**0.0007**
45			**1.5450**	**0.0007**	**0.0047**	**0.9968**	**0.0198**	**0.9970**	**0.0004**
45			**1.5643**	**0.0007**	**0.0028**	**0.9981**	**0.0152**	**0.9933**	**0.0002**
55			**1.5130**	**0.0014**	**0.0015**	**0.9988**	**0.0129**	**0.9804**	**0.0002**
55			**1.5438**	**0.0014**	**0.0006**	**0.9995**	**0.0081**	**0.9884**	**0.0001**

Logarithmic $MR = a \times \exp(-kt) + b$									
35	1.4259	-0.3787		0.0074	0.0266	0.9753	0.0492	0.9802	0.0033
35	1.5740	-0.5172		0.0063	0.0262	0.9767	0.0488	0.9813	0.0033
45	1.3968	-0.3565		0.0058	0.0108	0.9919	0.0277	0.9485	0.0010
45	1.3591	-0.3056		0.0064	0.0131	0.9904	0.0305	0.9409	0.0012
55	1.2631	-0.2074		0.0099	0.0128	0.9877	0.0341	0.9901	0.0016
55	1.2230	-0.1608		0.0114	0.0174	0.9834	0.0398	0.9868	0.0022
Middilli $MR = a \times \exp(-kt^n) + bt$									
35	1.0064	-0.0049	0.0898	0.1109	0.0748	0.7345	0.0825	0.7342	0.0107
35	1.0064	-0.0052	0.0844	0.0761	0.0670	0.7403	0.0780	0.7403	0.0096
45	1.0000	-0.0002	1.4200	0.0012	0.0017	0.9752	0.0129	0.9752	0.0002
45	1.0071	-0.0002	1.3716	0.0015	0.0017	0.9879	0.0109	0.9879	0.0002
55	1.0080	-0.0001	1.4611	0.0017	0.0006	0.9994	0.0097	0.9993	0.0001
55	1.0073	-0.00002	1.5152	0.0015	0.0006	0.9994	0.0097	0.9993	0.0001
Two term exponential $MR = a \times \exp(-kt) + ((1-a) \times \exp(-kbt))$									
35	0.2396	1.0000		0.0125	0.0867	0.9193	0.1041	0.9355	0.0108
35	0.3995	0.9736		0.0122	0.1083	0.9039	0.1164	0.9231	0.0135
45	0.3286	1.0000		0.0096	0.0748	0.9436	0.0825	0.9523	0.0068
45	0.2021	0.9995		0.0096	0.0748	0.9436	0.0825	0.9523	0.0068
55	0.2169	1.0000		0.0136	0.0504	0.9513	0.0794	0.9610	0.0063
55	0.2358	1.0000		0.0136	0.0504	0.9513	0.0794	0.9610	0.0063
Verma et al $MR = a \times \exp(-kt) + ((1-a) \times \exp(-bt))$									
35	1.2900	1.5000		0.0158	0.0443	0.9588	0.0744	0.9670	0.0055
35	1.3300	1.2460		0.0156	0.0499	0.9557	0.0790	0.9646	0.0062
45	1.2230	1.2220		0.0116	0.0360	0.9729	0.0572	0.9770	0.0033
45	1.2540	1.5000		0.0122	0.0305	0.9776	0.0526	0.9811	0.0028
55	1.3160	1.5000		0.0175	0.0087	0.9916	0.0330	0.9933	0.0011
55	1.3160	1.5000		0.0175	0.0087	0.9916	0.0330	0.9933	0.0011

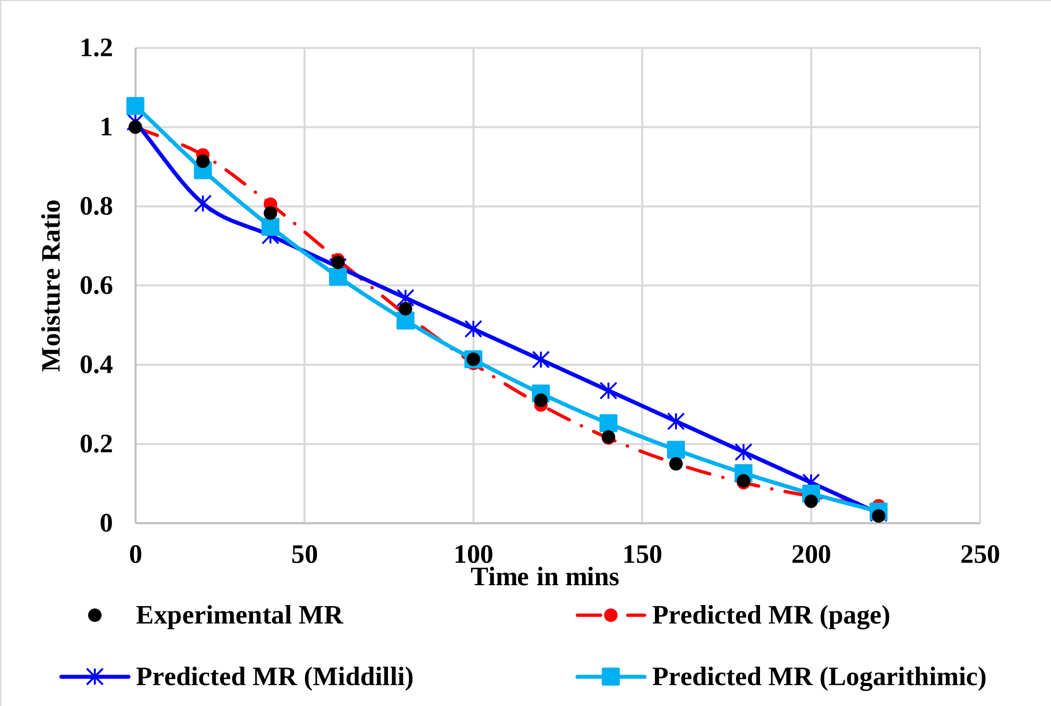

Figure 4.6: Variation of the experimental and predicted moisture ratio by the page, Middilli and Logarithmic models with drying time at 45^{0}C of drying air for fresh Kapenta

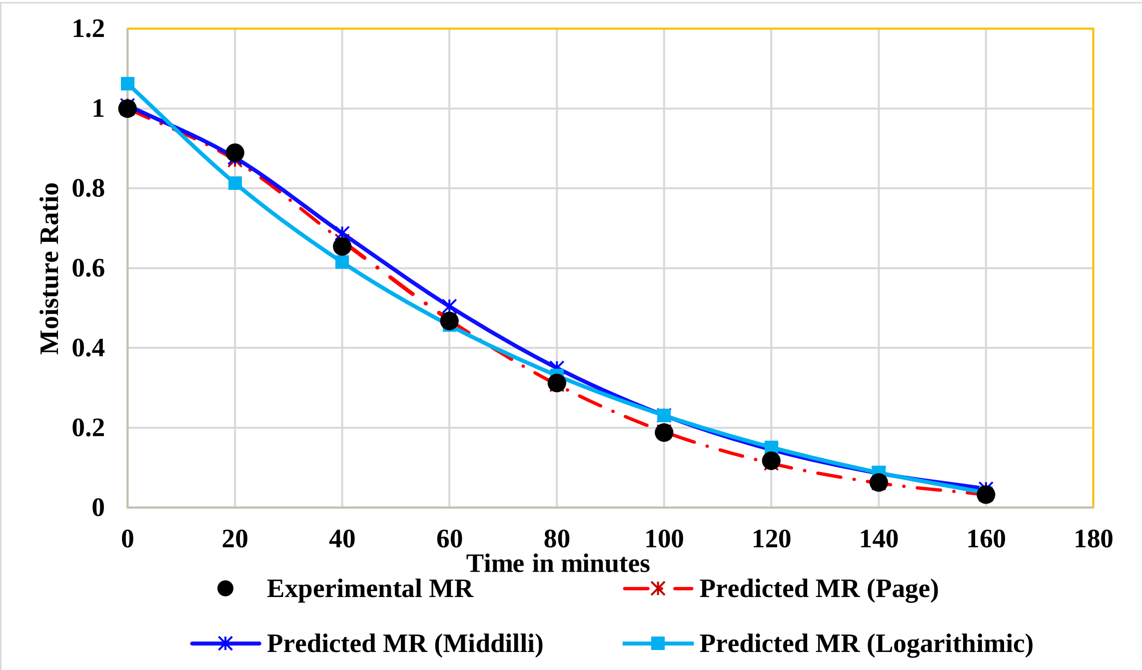

Figure 4.7: Variation of the experimental and predicted moisture ratio by the page, Middilli and Logarithmic models with drying time at 55^{0}C of drying air for fresh Kapenta

From Figures 4.6 and 4.7 it can be seen that the Page model shows a high correlation between the experimental and predicted moistures ratios as compared to the Logarithmic and Middilli models. Figure 4.8 also illustrates a good conformity between the experimental and predicted moisture ratios by the Page model, with the predicted data mostly banded on the straight line or very close to the straight line. This ascertains the suitability of the Page model in describing the solar drying behavior of Kapenta.

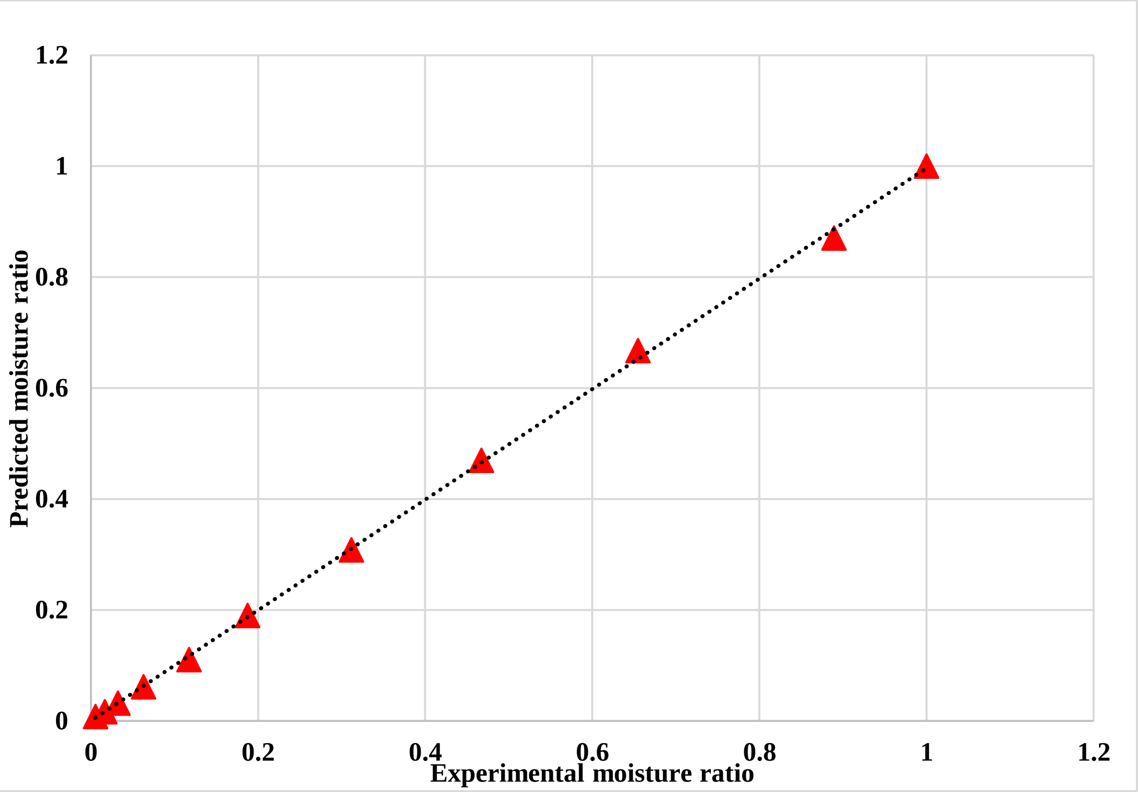

Figure 4.8: Comparison of experimental and predicted moisture ratios by Page model for hot air drying

To take into account the effect of the drying variables on the approximation of the Page model drying rate constant of $k(h^{-1})$ and coefficient n. The values of these parameters were regressed against those of the drying temperature (T) in ^{0}C in the hot air dryer using multiple regression analysis in Excel. The multiple combinations of different temperatures that gave the highest R^2 were finally included in the approximation of the Page model as presented in Appendix 8. This is illustrated in Figures 4.9 and 4.10.

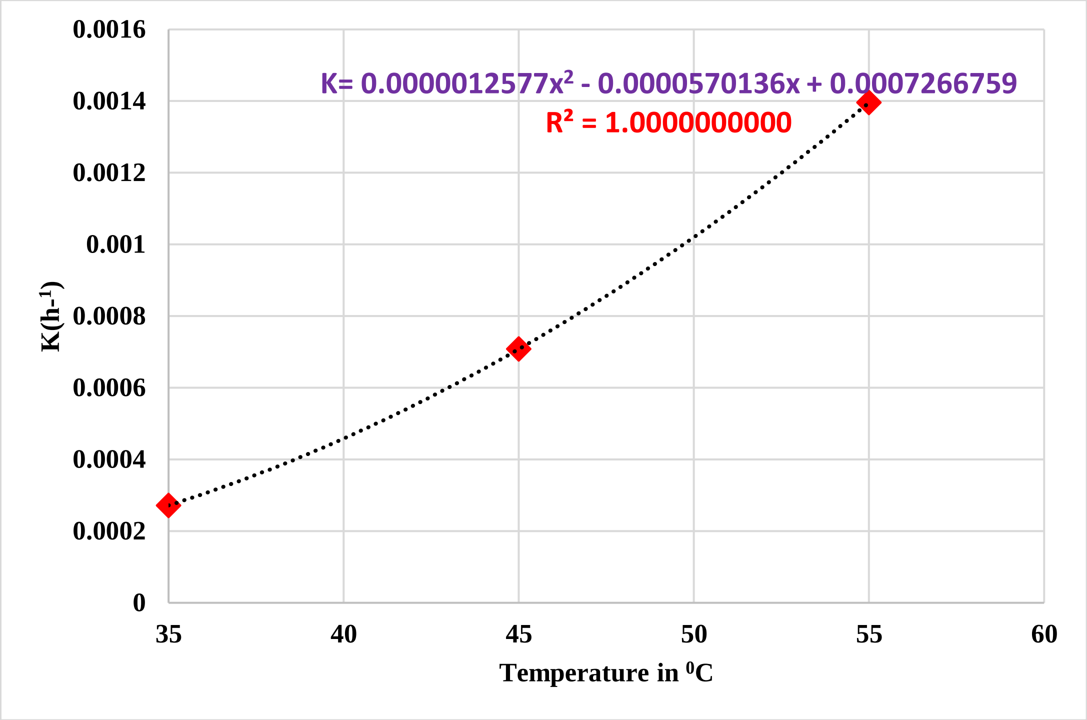

Figure 4.9: Determination of Page constant $k(h^{-1})$ using multiple regression analysis in Excel.

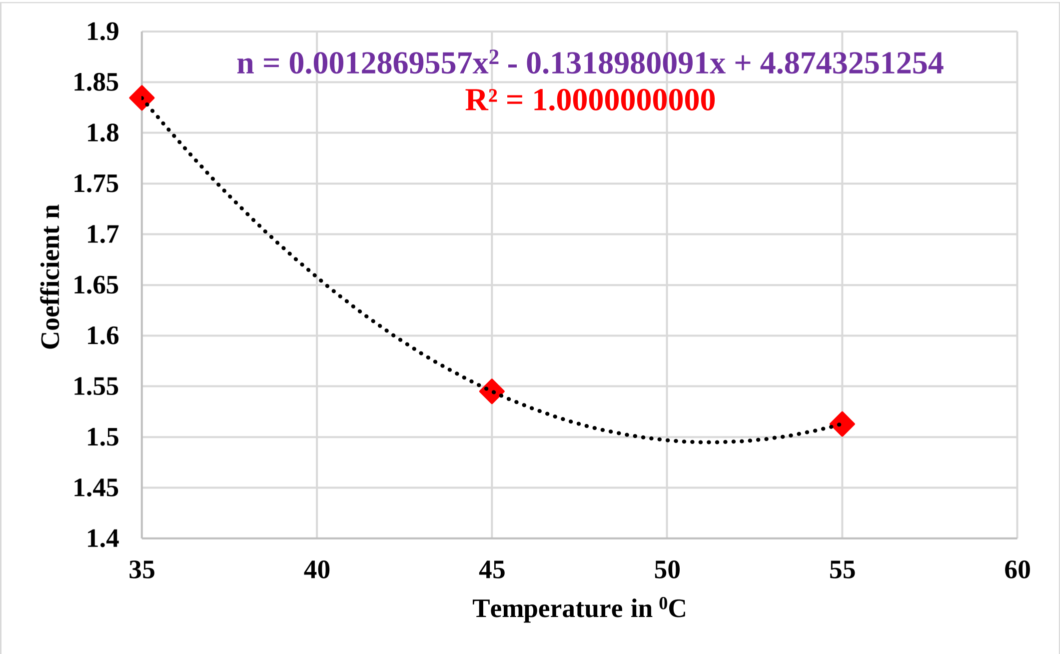

Figure 4.10: Determination of Page coefficient n using multiple regression analysis in Excel

The coefficients of the accepted Page model for the thin layer drying of fresh Kapenta were determined as;

$$K = 0.000001258T^2 - 0.00005701T + 0.0007267 \quad (4.4)$$

$$n = 0.001286955T^2 - 0.13189801T + 4.8743251 \quad (4.5)$$

The moisture ratio and consequently the moisture content of Kapenta at any time during the drying process could be estimated using these Equations (4.4) and (4.5) accurately. Equations (4.4) and (4.5) predicted the moisture ratio (MR) fairly accurately at the three drying temperatures 35, 45, and 55 ^{0}C for the Kapenta. These results can be proved from Figure.4.11 which shows plots of the Page Model predicted moisture ratios versus drying time at 35, 45, and 55 ^{0}C.

Accordingly, it can be concluded that the Page thin layer drying model adequately described the drying behavior of fresh Kapenta in the hot air drying process at a temperature range 35–55^{0}C.

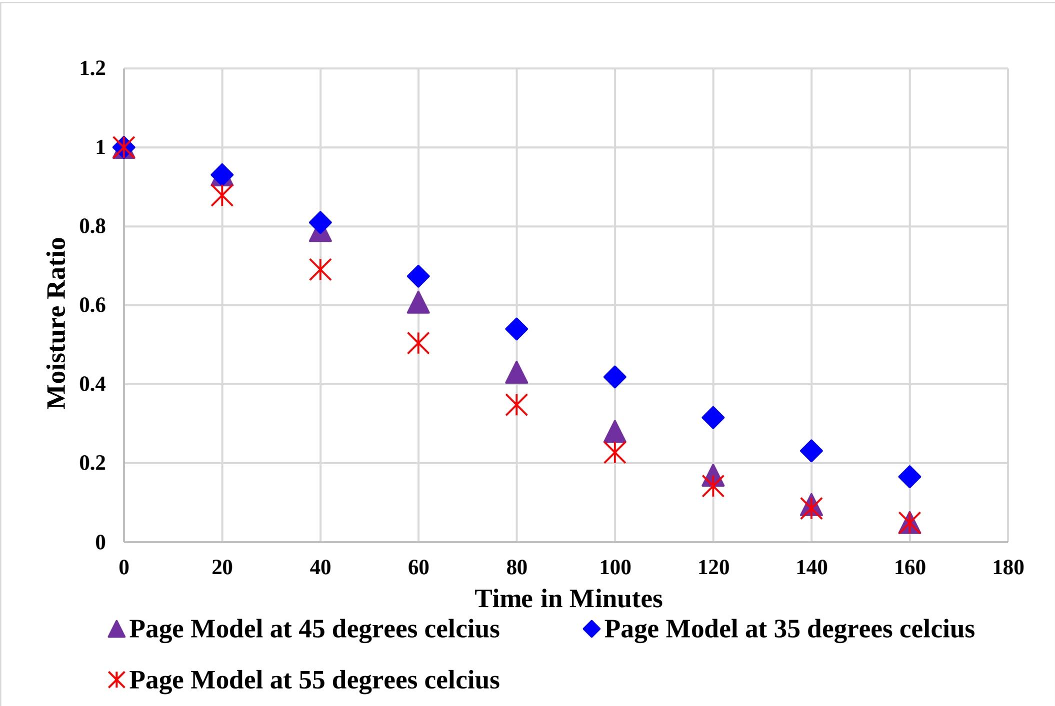

Figure 4.11: Influence of drying air temperature on moisture ratios predicted by Page model.

4.6 Nutritional Contents

The proximate composition of the products from the Green-house Solar Dryer and the open sun dried Kapenta is represented in Table 4.4.

Table 4.4: Nutritional properties of Kapenta under different drying conditions

Nutrients	Open sun dried (%)	Greenhouse Solar dried (%)	Student T- test
Moisture content	9.18	6.25	($P < 0.05$)
Crude Fibre	1.96	2.69	($P < 0.05$)
Ash content	12.66	13.08	($P < 0.05$)
Crude Protein	58.10	59.98	($P < 0.05$)
Crude fat	10.25	11.22	($P < 0.05$)

The Kapenta dried in the Greenhouse solar drier had a lower moisture content, (6.25%) ($P < 0.05$) as compared to the moisture content (9.18%) of the Kapenta dried in the open sun. Based on the student $t-$test; nutritional contents of the products significantly differed from one another at 95 % level of significance; products from the Greenhouse solar drier were richer in protein (59.98%), Crude fat (11.22%), crude Fibre (2.69%) and Ash content (13.08%) due to the lower moisture content obtained from Greenhouse solar drying. The removal of moisture brought about a significant increase in concentrations of nutrients in the products and thus higher percentages of protein, ash, Fibre and lipids (Ipinmoroti, 2012).

These results agree with findings reported by Ipinmoroti (2012) on qualities of *Tilapia zillii* products from solar tent dryers in a humid tropical environment who reported values of 53.88% for protein, 7.26% for crude fat 1.92% for crude Fibre and 13.55% Ash content from fish (*Tilapia zillii*) dried in a solar tent dryer without a collector but covered with transparent polythene.

This result therefore confirms that drying of Kapenta in a Greenhouse Solar dryer significantly increases the amount of moisture removed from the Kapenta, therefore significantly increasing the nutritional composition of Kapenta.

4.7 Hygiene Indicators

Table. 4.5 below shows the results obtained from the microbiological analysis done on the dried Kapenta samples, while Table. 4.6 shows East African Standards for Dry Fish.

Table 4.5: Microbiological analysis of Kapenta samples

Dried Kapenta sample	Yeast &moulds		*E.coli*	
	Results (cfu/g)	Observation	Results (MPN/g)	Observation
Open sun dried	300	Satisfactory	<3	Satisfactory
Greenhouse solar dried	20	Satisfactory	<3	Satisfactory

Table 4.6: East African Standards for Dry fish

No.	Type of micro-organism	Maximum limits	Method of test
1	E.coli	Absent	ISO 7251
2	Yeasts and Moulds	10^2	ISO 21527-1

Source; (East African Community, 2014)

The counts obtained in the Dry Kapenta for E.coli was zero for both samples which was within acceptable limits as shown in Appendix 9 for E.coli. However it can be seen that the Yeast and Moulds count was lower in the Greenhouse dried Kapenta (20 cfu/g) and was within acceptable limits compared to the Open Sun Dried Kapenta (300 cfu/g). This could be due to exposure of the Kapenta to moulds spores carried by dust in the air. These results go to show that exposure of Kapenta to open sun during drying as a method of preservation leads to deterioration in quality of the Kapenta due to the high amount of yeasts and moulds.

4.8 Water Activity

Table. 4.7. Shows the water activity results obtained from the dried Kapenta samples. From the results it can be seen that the drying of Kapenta reduces the water activity to a safe storage level which significantly reduces the growth ability of microorganisms. Table. 4.8 shows the water activity levels that can support the growth of particular groups of micro-organisms. From Table. 4.8 it can be seen that the Kapenta dried in the Greenhouse Solar Dryer has an increased shelf life because it's average water activity a_w=0.585 is below all the water activity levels show in Table 4.8 that can support the growth of particular groups of micro-organisms. Further the Kapenta dried in the open sun has a reduced shelf life and is prone to deterioration due to growth of yeasts and moulds because of the higher water activity a_w=0.61 which is within the water activity level required for growth of yeasts and moulds as seen in Table 4.8.

Table 4.7: Water activity results

Drying Mode	Water Activity a_w	Average Water Activity a_w
Green house Solar Drying	0.589 0.581	0.585
Open Sun Drying	0.619 0.601	0.61

Table 4.8: Water activity levels that can support the growth of particular groups of micro-organisms.

Group of Micro-Organisms	Minimum a_w required for growth
Most gram-negative bacteria	0.97
Staphylococcal toxin production (by Staphylococcus aureus)	0.93
Most gram-positive bacteria	0.90
Most yeasts	0.88
Staphylococcus aureus	0.86
Most moulds	0.80
Halophilic bacteria (grow best at high salt concentrations)	0.75
Xerophillic moulds (can grow on dry foods) and Osmophillic yeasts (can grow in the presence of high concentrations of organic compounds, ex: sugars)	0.62-0.60

Source;(Manitoba Agriculture Food and Rural Development, 2015)

4.9 Closing remarks

This chapter described in detail the variations between the mean solar radiation and the air temperatures within the Greenhouse Solar Dryer. A comparison was also made between the moisture contents observed under Greenhouse Solar Drying and Open Sun Drying. Variations of air temperature at the inlet, outlet and inside the Greenhouse Solar Dryer were also discussed. The proximate and microbial analysis results were also analyzed and discussed in this chapter. The next chapter presents the conclusions and recommendations.

CHAPTER FIVE

5. CONCLUSIONS AND RECCOMENDATIONS

5.0 Conclusions

The following conclusions can be drawn from this research;

1) The moisture content of Kapenta in the Greenhouse Solar Dryer was reduced from an initial value of 76.74 % (w.b.) to a final value of 2.14% (w.b.) within 4.5 hours whereas the moisture content of the natural sun-dried samples was reduced to 14.34% (w.b.) in the same period. Therefore the Greenhouse Solar Dryer resulted in considerable reductions in drying time and moisture content as compared with the Open Sun Drying.
2) The Page Model showed the best fit with high values for the coefficient of Correlation (R^2), (0.9804-0.9970) and lower values of reduced chi-square (x^2), (0.0002-0.0012), and the root mean square error (RMSE), (0.0081-0.0328) between temperatures of 35^{0}C -55 ^{0}C. Thus the Page Model best describes the drying characteristics of fresh Kapenta in a hot air dryer.
3) The Greenhouse Solar Dryer gave the best final products in terms of low moisture content (6.25%), highest protein (59.98%), Fibre (2.69%), Fat (11.22%) and Ash content (13.08%) values as compared to Open Sun Drying which gave lower values of protein (58.10%), Fibre (1.96%), Fat (10.25%) and Ash content (12.66%). Hence of the two drying methods tested in this study, the better preservation method was the Greenhouse Solar Dryer due to the fact that it produced a final product that maintains its nutritional properties to a level that is valuable to consumers at the time of consumption.

5.1 Recommendations

The following recommendations were made;

1) The Greenhouse Solar Dryer should be adopted as the primary Kapenta drying method especially by fish traders in Lake Kariba Siavonga. The dryer will provide an efficient, solution to the chronic problem of Open Sun Drying which is characterized by loss in quality and nutritive value. It will also prolong the shelf life of dried Kapenta as well as improve the nutritive value.
2) Further research can be carried out on the use of the Greenhouse Solar Dryer in drying of other fish species as a means of preservation of fish.
3) The Greenhouse Solar Dryer can be scaled up for industrial use in drying of Kapenta since it has a higher drying rate compared to Open Sun Drying. It has a simple design and can easily be constructed using locally available material.

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APPENDICES

Appendix. 1. Certificate of Proximate Analysis

UNIVERSITY OF ZAMBIA

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Mobile: 260-969 692845 E-mail: vnyau@unza.zm

CERTIFICATE OF ANALYSIS

DATE: 25/02/2016

RESULT SHEET: FC 004-2016
REF INVOICE No: FST 007-2016

In pursuance of instructions received from Rhoda **Aduke, Department of Agricultural Engineering** of Lusaka, Zambia, the Department of Food Science & Nutrition, UNZA certify having analyzed Two (2) Kapenta *(stolothrissatanganicae)* samples hereunder described.

FOOD CHEMISTRY LABORATORY

SAMPLE CODE	PARAMETERS					
	MOISTURE (%)	ASH (%)	CRUDE PROTEIN (%)	CRUDE FAT (%)	CRUDE FIBRE (%)	WATER ACTIVITY
OPEN SUNDRYING	9.18	12.66	58.10	10.25	1.96	0.604@ 27.6^{0}C
GREEN HOUSE DRYING	6.25	13.08	59.98	11.22	2.69	0.587@ 28.1^{0}C

DR V. NYAU

HEAD- FOOD SCIENCE AND NUTRITION

UNIVERSITY OF ZAMBIA
26 FEB 2016

Appendix. 2. Certificate of Microbiological Analysis

THE UNIVERSITY OF ZAMBIA
SCHOOL OF AGRICULTURAL SCIENCES
DEPARTMENT OF FOOD SCIENCE AND NUTRITION

P.O. Box 32379, Lusaka, Zambia.Tel: 260-095 5 753612/295141. Fax: +260-1-293937/295141
E-mail:vyau@unza.zm

CERTIFICATE OF ANALYSIS

DATE: 10/02/2016
RESULT SHEET: FM 003-16
REF INVOICE No: FST 006-16

In pursuance of instructions received from **RHODA ADUKE, AGRICULTURAL ENGINEERING STUDENT, UNZA, LUSAKA**, the Department of Food Science & Nutrition, UNZA certify having analyzed TW**O (2)KAPENT A SAMPLES** hereunder described.

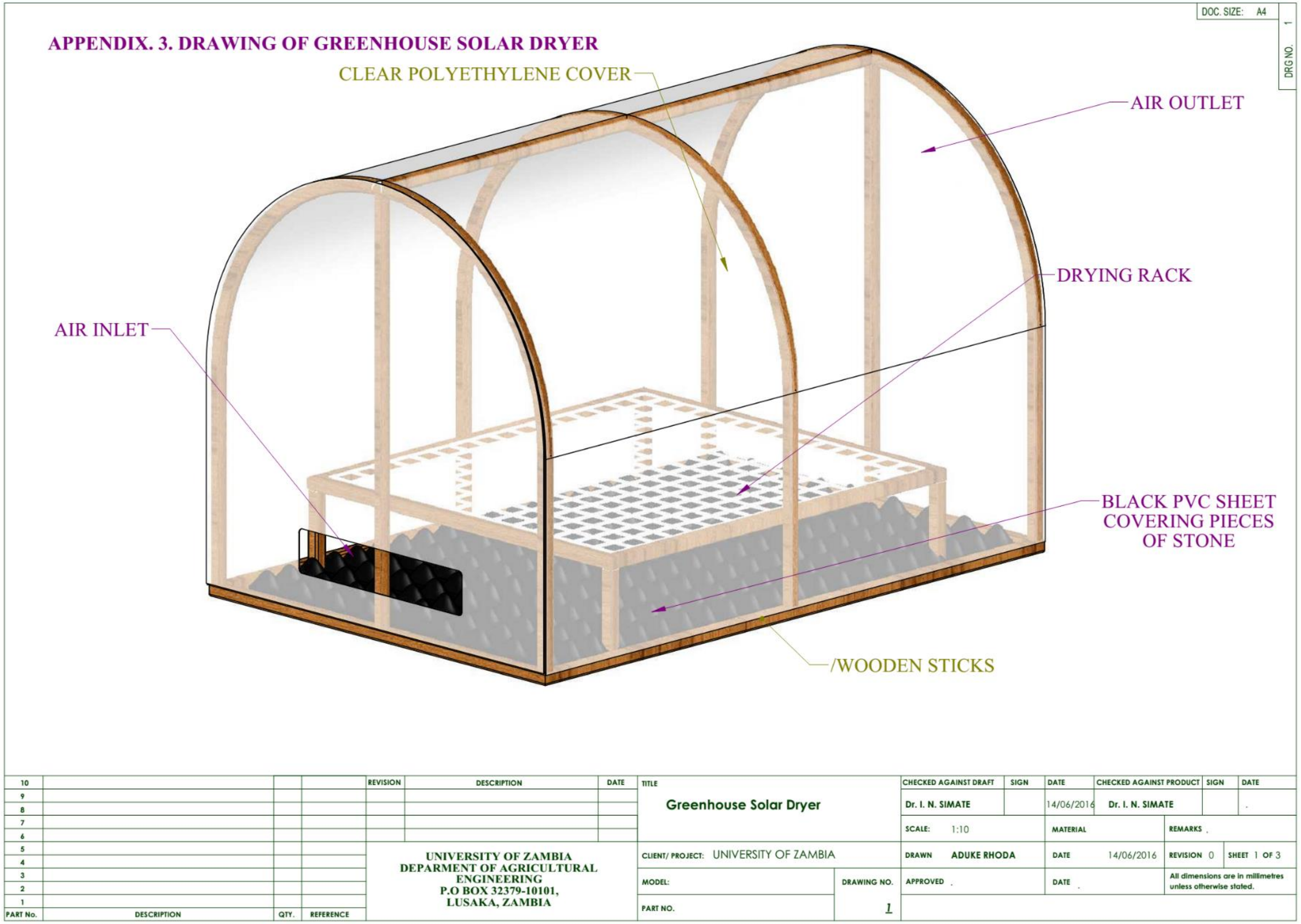
FOOD MICROBIOLOGY LABORATORY:

Sample No.	Yeasts &Moulds		E.coli (MPN)	
	Results (Cfu/g)	Observation	Results (MPN/g)	Observation
Kapenta - Sun Dried	3.0×10^2	Satisfactory	< 3	Satisfactory
Kapenta – Green House	2.0 x 10	Satisfactory	< 3	Satisfactory

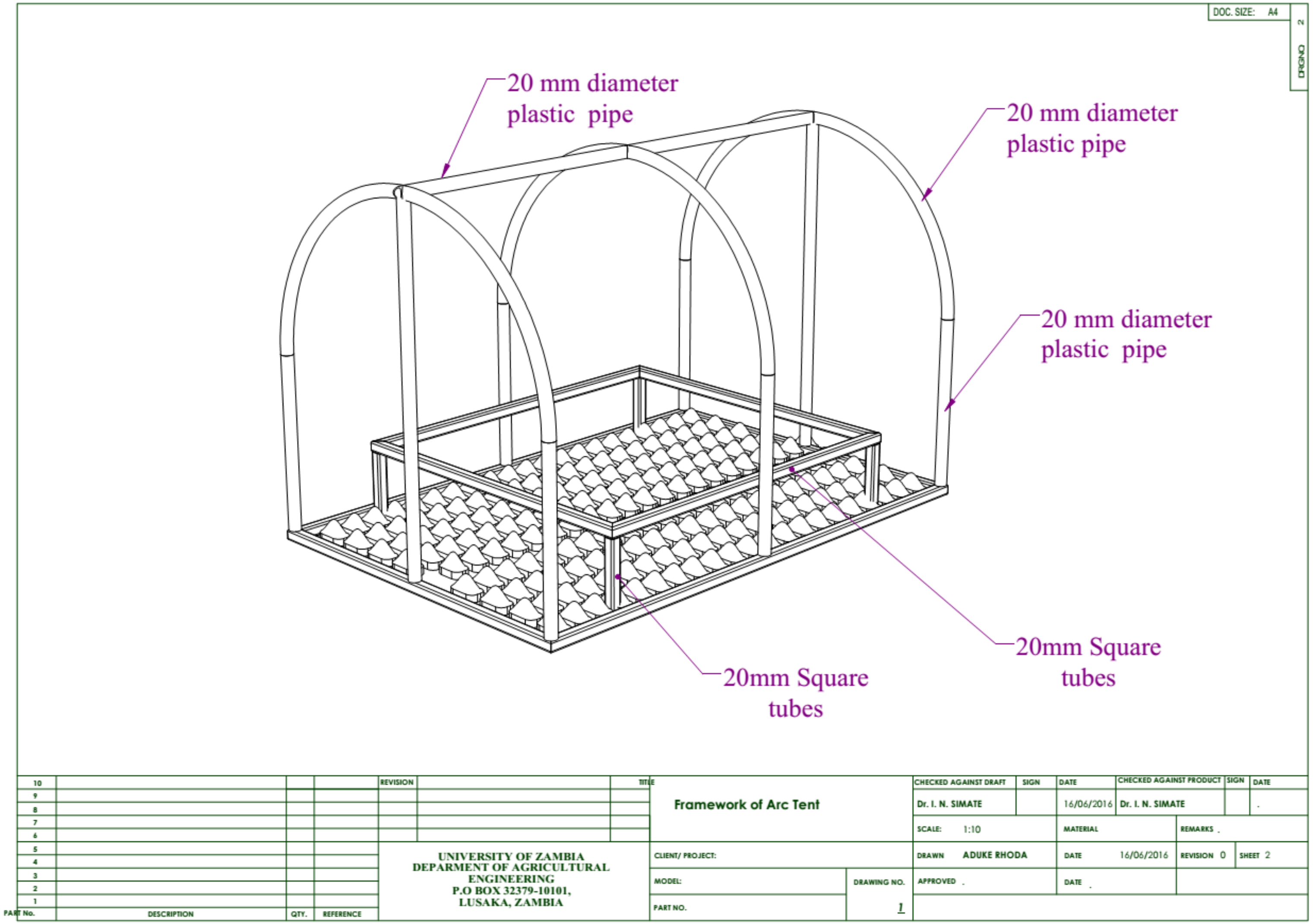
DRV.NYAU
HEAD-FOOD SCIENCE AND NUTRITION DEPARTMENT

UNIVERSITY OF ZAMBIA
11 FEB 2016

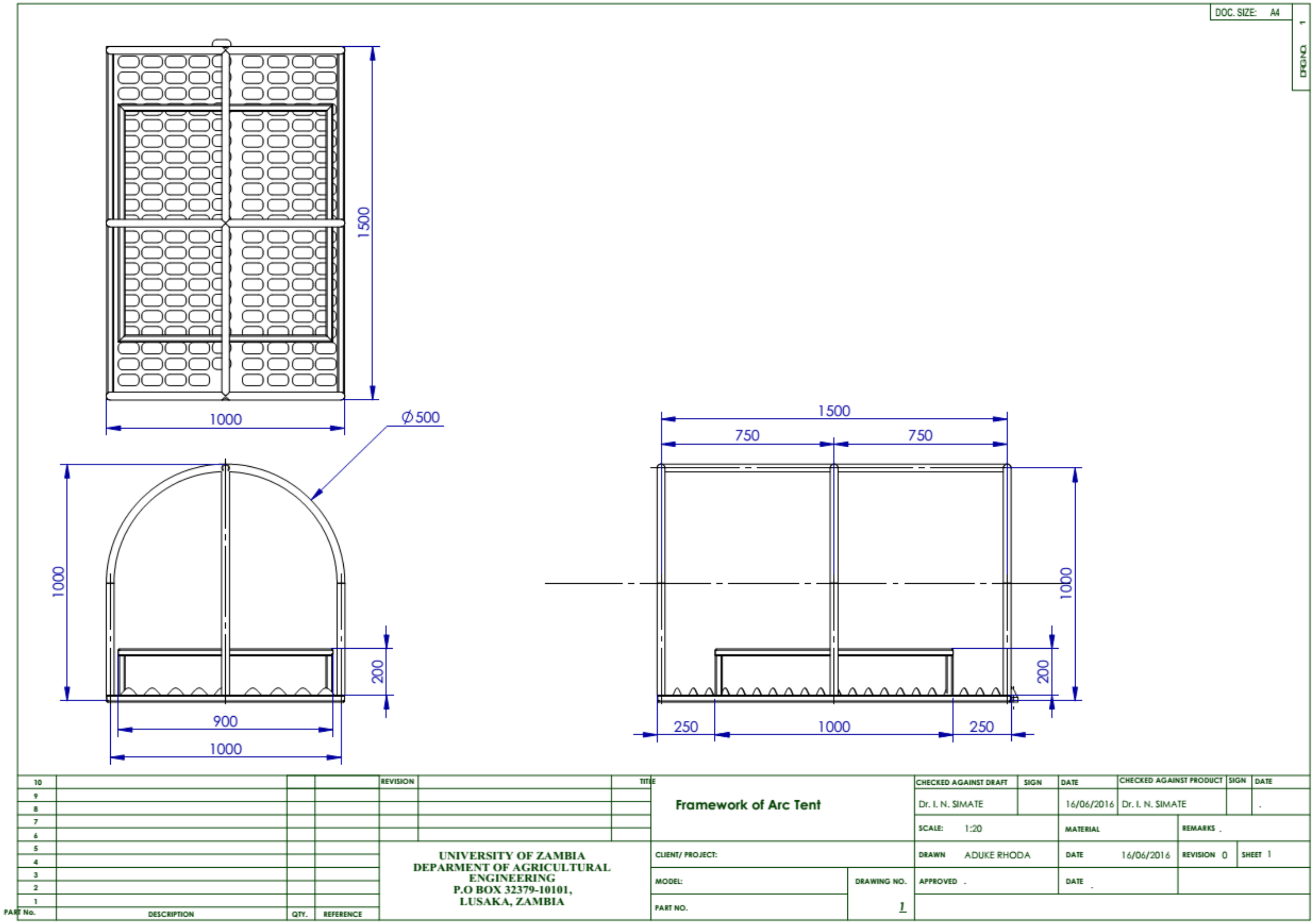
Appendix. 3. Schematic Drawing of Greenhouse Solar Dryer



Appendix. 4. Greenhouse Solar Dryer Frame work



Appendix. 5. Third Angle Orthogonal projection of framework



Appendix. 6. Mean temperatures, relative humidity and solar radiation at different locations of the Greenhouse Solar Dryer compared to the ambient temperatures and relative humidity (November 2015).

TIME	T_i (^0C)	T_t (^0C)	R_t	SLR (W/m^2)	SLR (KJ)	T_o (^0C)	T_a (^0C)	R_a (^0C)
9.30-10.00	38.14	50	10.34	880	52.80	41.16	32.86	28.53
10.00-10.30	38.65	51	8.94	940	56.40	43.38	33.66	29.96
10.30-11.00	38.80	54	7.02	1022	61.35	42.22	33.19	29.75
11.00-11.30	39.03	55	6.76	1044	62.63	43.82	34.55	29.82
11.30-12.00	40.25	59	5.68	1026	61.59	45.29	35.62	27.54
12.00-12.30	38.78	59	5.01	1024	61.44	47.38	36.66	25.82
12.30-13.00	39.46	60	4.98	981	58.92	49.01	36.98	25.79
13.00-13.30	39.22	59	5.53	926	55.59	47.56	37.45	24.67
13.30-14.00	39.96	59	4.60	854	51.25	49.36	39.39	23.87
14.00-14.30	39.47	59	4.64	752	45.22	48.18	40.81	24.75
143.30-15.00	40.11	59	4.27	662	39.79	47.98	41.21	23.35
15.00-15.30	40.50	58	4.15	548	33.00	47.87	41.23	23.85
15.30-16.00	39.79	58	4.86	425	25.56	46.13	40.08	23.80
16.00-16.30	37.96	57	6.15	308	18.59	44.07	37.84	25.34
16.00-16.45	37.42	49	6.89	217	13.74	42.05	34.77	29.75

Where;

T_i is the temperature at the inlet vent of the Greenhouse Solar Dryer in (^0C), `
T_t is the air temperature inside the Greenhouse Solar Dryer in (^0C),
R_t is the relative humidity of air inside the Greenhouse Solar Dryer in (^0C),
T_o is the temperature at the outlet vent of the Greenhouse Solar Dryer in (^0C),
SLR is the Solar Radiation in (W/m^2),
T_a and R_a are the ambient air temperature in (^0C) and relative humidity respectively.

Appendix. 7. Mean temperatures, relative humidity and solar radiation at different locations of the Greenhouse Solar Dryer compared to the ambient temperatures and relative humidity (December 2015).

TIME	T_i (^{0}C)	T_t (^{0}C)	R_t	SLR (W/m^2)	SLR KJ	T_o (^{0}C)	T_a (^{0}C)	R_a
9.00	30	35	16.23	490.00	29.40	32	28	33.43
10.00	30	37	15.96	500.00	30.00	32	28	33.21
10.30	34	45	14.63	478.83	29.58	36	30	32.85
11.00	37	50	12.95	1203.13	71.89	43	32	28.20
11.30	41	50	8.96	1081.37	65.09	42	31	29.23
12.00	33	54	7.03	847.30	50.72	43	32	28.40
12.30	38	47	6.89	823.63	50.66	45	32	29.48
13.00	38	42	6.76	377.07	22.00	39	32	29.46
13.30	35	47	6.90	565.67	34.79	42	33	27.54
14.00	33	42	6.96	367.40	21.64	36	31	28.64
14.30	31	37	8.23	200.58	12.06	32	30	28.92
15.30	30	37	8.45	183.21	11.00	33	29	29.32
16.00	30	36	9.23	122.33	7.40	32	29	29.27
16.30	30	21	9.85	94.30	5.61	31	29	29.56

Where;

T_i is the temperature at the inlet vent of the Greenhouse Solar Dryer in (^{0}C), `
T_t is the air temperature inside the Greenhouse Solar Dryer in (^{0}C),
R_t is the relative humidity of air inside the Greenhouse Solar Dryer in (^{0}C),
T_o is the temperature at the outlet vent of the Greenhouse Solar Dryer in (^{0}C),
SLR is the Solar Radiation in (W/m^2),
T_a **and** R_a are the ambient air temperature in (^{0}C) and relative humidity respectively.

Appendix. 8. Approximation of the page constant K (h^{-1}) and coefficient n.

Temp	Experimental		predicted K_1	predicted K_2	predicted n_1	predicted n_2
Sample 1	**K**	**n**				
35	0.00027	1.83442	0.0002721	0.0002724	1.834416	1.83441556
45	0.00071	1.54500	0.0006762	0.0007087	1.545000	1.56426644
55	0.00140	1.51298	0.0013583	0.0013966	1.512976	1.54383102
sample 2						
35	0.00027	1.83442	0.0002721	0.0002724	1.834416	1.83441556
45	0.00068	1.56427	0.0006762	0.0007087	1.545000	1.56426644
55	0.00136	1.54383	0.0013583	0.0013966	1.512976	1.54383102

Where;

$\mathbf{K_1} = 0.0000012577\mathbf{T}^2 - 0.0000570136\mathbf{T} + 0.0007266759$

$\mathbf{K_2} = 0.0000013898\mathbf{T}^2 - 0.0000707902\mathbf{T} + 0.0010470314$

$\mathbf{N_1} = 0.0012869557\mathbf{T}^2 - 0.1318980091\mathbf{T} + 4.8743251254$

$\mathbf{n_2} = 0.0012485685\mathbf{T}^2 - 0.1269003923\mathbf{T} + 4.7464328825$

T-Temperature in degrees Celsius (^{0}C)

Appendix. 9. Three Tube MPN Tables

For 3 tubes each at 0.1, 0.01, and 0.001 g inocula, the MPNs per gram and 95 percent confidence intervals.												
Pos. Tubes			**MPN/g**	**Conf. lim.**		**Pos. tubes**			**MPN/g**	**Conf. lim.**	
0.10	**0.01**	**0.001**		**Low**	**High**	**0.10**	**0.01**	**0.001**		**Low**	**High**
0	0	0	<3.0	–	9.5	2	2	0	21	4.5	42
0	0	1	3.0	0.15	9.6	2	2	1	28	8.7	94
0	1	0	3.0	0.15	11	2	2	2	35	8.7	94
0	1	1	6.1	1.2	18	2	3	0	29	8.7	94
0	2	0	6.2	1.2	18	2	3	1	36	8.7	94
0	3	0	9.4	3.6	38	3	0	0	23	4.6	94
1	0	0	3.6	0.17	18	3	0	1	38	8.7	110
1	0	1	7.2	1.3	18	3	0	2	64	17	180
1	0	2	11	3.6	38	3	1	0	43	9	180
1	1	0	7.4	1.3	20	3	1	1	75	17	200
1	1	1	11	3.6	38	3	1	2	120	37	420
1	2	0	11	3.6	42	3	1	3	160	40	420
1	2	1	15	4.5	42	3	2	0	93	18	420
1	3	0	16	4.5	42	3	2	1	150	37	420
2	0	0	9.2	1.4	38	3	2	2	210	40	430
2	0	1	14	3.6	42	3	2	3	290	90	1,000
2	0	2	20	4.5	42	3	3	0	240	42	1,000
2	1	0	15	3.7	42	3	3	1	460	90	2,000
2	1	1	20	4.5	42	3	3	2	1100	180	4,100
2	1	2	27	8.7	94	3	3	3	>1100	420	–