PREDICTION OF THIN LAYER DRYING CHARACTERISTICS OF GINGER RHIZOMES SLICES IN CONVECTIVE ENVIRONMENT

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AWKA

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TITLE PAGE

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(DESIGN OPTION)

MARCH, 2021

CERTIFICATION

This research work on "Prediction of Thin Layer Drying Characteristics of Ginger Rhizomes Slices in Convective Environment" was originally carried out by me, except in acknowledgement and references. Neither the dissertation nor the original work contained therein has been submitted to this university or any other institution for the award of a degree.

________________________ ___________________________
Gbasouzor Austin Ikechukwu Date
(2005247001F)

APPROVAL PAGE

This dissertation titled "**Prediction of Thin Layer Drying Characteristics of Ginger Rhizomes Slices in Convective Environment**" by **Gbasouzor, Austin Ikechukwu** with registration number **2005247001F** has been read and approved as having satisfied the requirements for the award of doctorate degree in Mechanical Engineering; it is approved for its contribution to knowledge and literary presentation by:

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DEDICATION

This work is dedicated to God Almighty and to my wife and children.

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ABSTRACT

This research presents the results of convective drying of ginger rhizomes under blanched, unblanched, peeled and unpeeled conditions using the ARS-0680 environmental chambers for the drying process and TD1002A - linear heat conduction experimental equipment to measure the thermal conductivities of the ginger at six temperature levels ranging from 10 - 60°C and drying times of 2 and 24 hours. The drying curves were drawn using the moisture and conductivity data. The drying rate at higher drying times (24 hours) was 0.889/^{o}C and 0.4437/^{o}C for 2 hours drying, giving 50% in moisture reduction rate. Whereas the initial moisture content was 95.12%, it reduced to 59.33% for the 24 hour-drying time. The result of this study shows that the lowest moisture content (5.98%) was obtained for unpeeled ginger while the highest was the blanched (9.04%) all for 24 hour-drying and at 60 ^{o}C. The average moisture content for 2 hours drying at 60°C was 70.6% while for 24 hours drying; it was an average of 7.55%. which is close to the target of 4 – 7% desired for this research. Though our results made our target, they are in line with the literature results that recommend moisture content of 7 – 12%. These show the superiority of higher temperature drying and the use of the convective drying method. The thermal conductivity for 24 hour-dried ginger at 60°C approximates to the thermal conductivity of dried ginger and it is 0.050 W/mK on the average. The unpeeled ginger gave the lowest value of 0.046 W/mK while the unblanched ginger gave the highest value of 0.055 W/mK. For 2 hours of drying, the average value was 0.079 W/mK while the unblancehd ginger gave the lowest (0.076 W/mK) while the blanched the highest (0.084 W/mK).

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: MATERIALS AND METHODS

CHAPTER FOUR: RESULTS AND DISCUSSIONS

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

M_0 or M_i	Initial moisture content (g water/g dry solid)
M_{wb}	Moisture content, wet basis (%)
M or M_t	Moisture content at any time
M_{db}	Moisture content, dry basis (%)
M_e	Equilibrium moisture content
k	Thermal conductivity $(\frac{W}{mK})$
Q	Amount of heat transfered through the material $\left(\frac{J}{s}\right)$ or $(Watts)$
ΔT	Change in temperature (°C or K)
L	Distance between $T_i - T_j$ (m)
A	Cross $-$ sectional area (m^2)
M_{cr}	Moisture content of a material at the end of the constant rate period of drying
D_{eff}	Effective moisture diffusivity(m^2/s);
t	Time (s),
MR	Moisture ratio;
J_0	Root of Bessel function
N	Number of observations,
$MR_{pre,i}$ ith	Predicted moisture ratio values,
$MR_{exp,i}$ ith	Experimental moisture ratio values,
d_f	Number of degree of freedom of regression model.
K	Slope
kg	Kilogram

mm	Milimeter
A	Shape factor
R^2	Coefficient of determination
h	hour
In	Natural Logarithm
α	Coefficient of volumetric expansion
β	Coefficient of volumetric expansion
Ea	Activation Energy
T	Temperature
ΔT	Temperature change
R	Universal gas constant

ABBREVIATIONS

MR	Moisture ratio;
RMSE	Root mean square error
SEE	Standard error of estimate
SSE	Sum square error
RH	Relative Humidity
EMERG	Electronic Manufacturing Engineering Group
LHCEU	Linear Heat Conduction Experiment Unit

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Thin layer drying can be employed to remove volatile liquid from porous materials such as food stuffs, ceramic products, wood and so on. Porous materials have microscopic capillaries and pores which cause a mixture of transfer mechanisms to occur simultaneously when subjected to heating or cooling. The drying of moist porous solids involves simultaneous heat and mass transfer. Heat penetrates into the product and moisture is removed by evaporating into an unsaturated gas phase. Owing to the complexity of the process, no generalized theory currently exists to explain the mechanisms of internal moisture movement (Hoque *et al.*, 2013).

Since the actual process of drying involves sumiltanous transfer of both heat and mass; the heat is transferred into the bulk material and mass transferred from the centre of porous solid to outer layer and consequently into the environment. During drying, the behavior of the material is influenced by temperature, relative humidity, permeability, and sorption-desorption characteristics, and thermo-physical properties of the material being dried. Transfer of non-condensable gases, vapours, and liquids occurs in porous bodies. Inert gases, and vapour transfer can take place by the molecular mass in the form of diffusion. And molar means as a filtration motion of the steam-gas mixture under the pressure gradient. Transfer of liquids can occur by means of diffusion, capillary absorption, and filtration motion in the porous material arising from the hydrostatic pressure gradient. The possible mechanisms of transfer of liquid within the porous material proposed by Gavrila et al., (2008) include:

(i) Liquid diffusion caused by concentration gradient.
(ii) Liquid transport due to gravity.
(iii) Liquid transport due to capillary forces.
(iv) Liquid transport due to suitable temperature gradient.
(v) Liquid transport due to the difference in total pressure caused by external pressure and temperature.
(vi) Evaporation and condensation effects caused by differences in temperature.

(vii) Vapour diffusion due to shrinkage and partial vapour-pressure gradients.

(viii) Surface diffusion in liquid layers at solid interface due to surface concentration gradient.

Drying is essentially important for preservation of agricultural crops for future use. It preserves crops by removing a good quantity of moisture from them to avoid decay and spoilage. For example, the principle of the drying process of ginger rhizomes involves decreasing the water content of the product to a lower level so that micro-organisms cannot decompose and multiply in the product. The drying process unfortunately can cause the enzymes present in ginger rhizomes to be killed, and such dry products can be preserved for a long time.

The porous material that will be used for this study is ginger. The physicothermal properties of ginger will be obtained and used in the resulting mathematical equations.

Ginger is an herbaceous perennial plant known as *Zingiberofficinale*, which belongs to the order *scitamineae* and the family *zingriberaceae*.

Ginger rhizomes are popular in most countries throughout the world (Omeni, 2015). Ginger rhizomes are edible and are cultivated in warm, very hot and humid (tropic and subtropical) regions. The harvesting season differs from a country to another or continent. In the southern hemisphere locales such as Kano State, Nigeria harvesting season is in July while in the northern hemisphere locales such as Hawaii, USA harvesting season is in December. Ginger rhizomes grow from 60-125cm high under viable environments and it is cultivated annually (Nishina et al., 2013; Salathe et al., 2014).

It is grown for its pungently aromatic underground stem or rhizome which is an important export crop valued for its powder, oil and oleoresin, all of which have both food and medicinal value (NEPC, 1999).

A thin-layer is a layer of material fully exposed to an airstream during processing. The thickness of the layer should be uniform and should not exceed 3 layers of particles (Onwude et al., 2016). Thin layer drying entails drying one layer to three layers of sample particles or slices (Akpinar, 2006). It is assumed that the temperature distribution of a thin-layer material is uniform because of its structure. Due to the thin-layer characteristics, lumped parameter models is very suitable for the analysis. It is imperative to note that the this concept can be applied to (1) a single material freely exposed to the drying air or one layer of the material and (2) a multilayer of different slice thicknesses, provided the drying temperature and the relative humidity of the drying air are in the same thermodynamic condition at any time of the drying process, which thus can be applied to the mathematical estimations of the drying kinetics (Onwude et al., 2016). Kucuk et al., (2014) reported that the thickness of a thin layer can be increased provided there is an increase in the drying air velocity and also if the simultaneous heat and mass transfers of the material are in equilibrium with the thermodynamic state of the drying air. Therefore, for a sample to be considered as a thin layer the airsteam should get to all segments simultaneously and the temperature distribution should be relatively uniform.

1.2 Statement of the Problem

Nigeria is presently the fifth top producer of ginger in the world and one of the principal exporters of ginger (FAO, 2008). The most important form in which ginger enters international trade is as a dried product; next in importance are a preserved ginger and the trade in fresh ginger of least significance (Edwards, 1975).

The quality of fresh ginger produced in Nigeria is the best in the world. However, it has been observed that the quality of her dried ginger has been declining due to low level of mechanization in ginger production and processing (Onu and Okafor, 2003) with the attendant mold growth and loss of some important ginger qualities which run down Nigerian ginger as the cheapest in the world market (Ekundayo et al., 1988).

Therefore, there is dire need for systematic study of the drying process of ginger rhizome. In this work, attention will be directed towards the use of thin layer drying process to determine the drying characteristics of ginger rhizome slices in a convective environment.

1.3 Aim and Objectives of the Study

The aim of this work is to study the thin layer drying characteristics of ginger rhizome slices. The following are the objectives of the study:

(i) Preliminary scientific examinations to ascertain the proximate and phytochemical composition of the test sample.

(ii) To apply different treatments on the ginger rhizomes, and cut them into required slices using scooper.

(iii) To conduct experiments on the drying of variously treated ginger rhizomes slices using ASAE Standard S352.2.

(iv) To estimate the moisture content at optimum temperature and drying time.

(v) To determine the thermal conductivity of variously treated ginger rhizomes experimentally at different moisture contents, drying time and temperature using the linear heat conduction equipment.

(vi) To compare the thermal conductivities of the variously treated ginger rhizomes samples as a function of moisture contents.

(vii) To generate a computer programme to analyze the thin layer drying characteristics of ginger rhizomes.

(viii) To benchmark and recommend a guideline for thin layer drying for ginger rhizomes which will in turn improve the quality of the products from Nigeria.

(ix) To establish the best drying model for the various drying characteristics of ginger rhizome slices.

1.4 Relevenace of the Study

The drying of the porous material will be conducted experimentally under free and forced convection environmental conditions. Ginger rhizomes will be peeled, split and unpeeled and cut into slices before drying at elevated temperatures in environmental chamber. The heat and mass transfers will be studied using available correlations of boundary layer equations.

The economy of Nigeria had since mid-1960s of oil boom deviated from agriculture to petroleum. This has placed an undue pressure on the oil reserves in volatile Niger Delta region, while agriculture and its produce were neglected. Therefore, any adverse influence on oil both locally and internationally affects the economy of Nigeria drastically. The present administration of President Muhammad Buhari has promised Nigerians better days, change in all sectors and improved agricultural outputs. Nigeria needs to process its agriculture produce in order to derive the desired benefits expected in the international markets. This research seeks to find solutions to the prevailing low quality of dried ginger in Nigeria.

1.5 Scope and Limitation

This study on the thin layer drying characteristics of ginger rhizomes produced in Nigeria will be experimental and analytical. It will not delve into production methods, harvesting techniques and marketing strategies. For the purpose of this study; the gingers are classified as Blanched, Unblanched, Peeled and Unpeeled.

The ginger rhizomes obtained for the study required a minimum duration of six to eight months of planting and will be dried to 7 – 15% moisture content. The Ginger rhizomes used in this study were obtained from one region. It is assumed that most ginger produced in Nigeria have similar quality and characteristics.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Ginger is the rhizome of the plant *Zingiber officinale*. It is one of the most important and most widely used spices worldwide, consumed whole as a delicacy and medicine. It lends its name to its genus and family zingiberaceae. Other notable members of this plant family are turmeric, cardamom, and galangal. Ginger is distributed in tropical and subtropical Asia, Far East Asia and Africa.

Figure 2.1 Fresh Ginger Rhizomes

2.1.1 Etymology of Ginger

Ginger, botanically known as *Zingiber officinaleRoscoe* belongs to the family zingiberaceae and in the natural order seitamineae. The Latin term zingiber was derived from ancient Tamil root, ingiver, meaning ginger rhizome. The term ingiver spread to ancient Greece and Rome through the Arab traders and from there to Western Europe. The present-day names for ginger in most of the Western language were derived from this. The English name ginger came from French gingifere, Medieval Latin gingener, Greek, Zingiberis.

2.1.2 Production Trends of Ginger

Ginger is not known to occur in the truly wild state. It is believed to have originated from Southeast Asia, but was under cultivation from ancient times in India as well as in China. There is no definite information on the primary center of domestication. Because of the easiness with which ginger rhizomes can be transported long distances, it has spread throughout the tropical and subtropical regions in both hemispheres. Ginger is indeed, the most wildly cultivated spice (Lawrence, 1984). India with over 30% of the global share, now leads in the global production of ginger.

Table 2.1 Top ten ginger producing nations

Country	Production (tones)
India	420,000
China	285,000
Indonesia	177,000
Nepal	158,000
Nigeria	138,000
Bangladesh	57,000
Japan	42,000
Thailand	34,000
Philippines	28,000
Sri Lanka	8,270
World	1,387,445

Source: Food and Agricultural Organization of United Nations Economic and Social Department: Statistical Division (FAO, 2008).

2.1.3 Ginger Rhizomes in Nigeria

In Nigeria, large- scale cultivation of ginger began in 1927 in southern Zaria, especially within Jemima's federated districts as well as in the adjoining parts of the plateau. Nigeria has tried to widen the genetics base of the crop through introduction of ginger cultivars, mainly from India. Currently, Nigeria is one of the largest producers and exporters of split-dried ginger (Ravindran and Babu, 2005). Ginger is readily available in the local Nigerian markets and inexpensive. They are obtained in numerous forms in the market: fresh, dry and powdered ginger rhizomes (Omeni, 2015).

Kaduna State is adjudged to be the largest producer of ginger whereas other states like Nassarawa, Gombe, Benue, Sokoto, Zamfara, Akwa Ibom, Oyo, Abia, Lagos, and Bauchi are among the main producers of the farm product. Although southern Kaduna still remains the largest producers of fresh ginger in Nigeria in Kachia, Jabba, Jama'a and Kagarko Local Government Areas (KADP, Production of ginger: an extension guide, 2000; KADP, Annual Report, 2004; Bernard, 2008).

2.1.3.1 Cultivation and Processing of Ginger in Nigeria

The lists below are requirements for ginger to grow and flourish:

- Mulched fertilized loamy soil.
- Average regular temperature of about 30°C
- Practicable ginger rhizomes with sprout
- Appropriate drainage system to stop flooding, erosion and water clogging
- Ridges must be prepared and aimed at planting of the ginger rhizomes
- Minimum yearly rainfall of around 1500mm (Omeni, 2015).

The cultivation of vegetative ginger is from its rhizomes. The following are the stages involved in the generation of vegetative gingers:

1. *Preparation of Sett*: Once the portions of rhizomes undergoing propagation start developing buds, the rhizomes are cut into tinier bits termed SETT. Sett is approximately 3cm in length in addition to individual sett having at minimum of a bud. Sets to be propagated are typically stocked pending signs of development. And growths are observed before sowing is implemented. Figure 2.2 shows the ginger plant.
2. *Planting:* Ginger is cultivated by submerging individual set in hole of nearly 3.1 inches (8cm) in depth with the bud of every sett directing skywards inside the soil. A 30×30cm space separately is required for a set. Each sett develops

into a fresh ginger plant. About a month before the rains, planting must be executed (Omeni, 2015; Ag ricInfo, 2011).

3. *Manures and Fertilizers:* Table 2.2 shows manures and fertilizer application for ginger rhizomes in Nigeria. The Data for Area, Production and Yield in Nigeria for ginger rhizomes are shown in Table 2.3 and Figure 2.3.

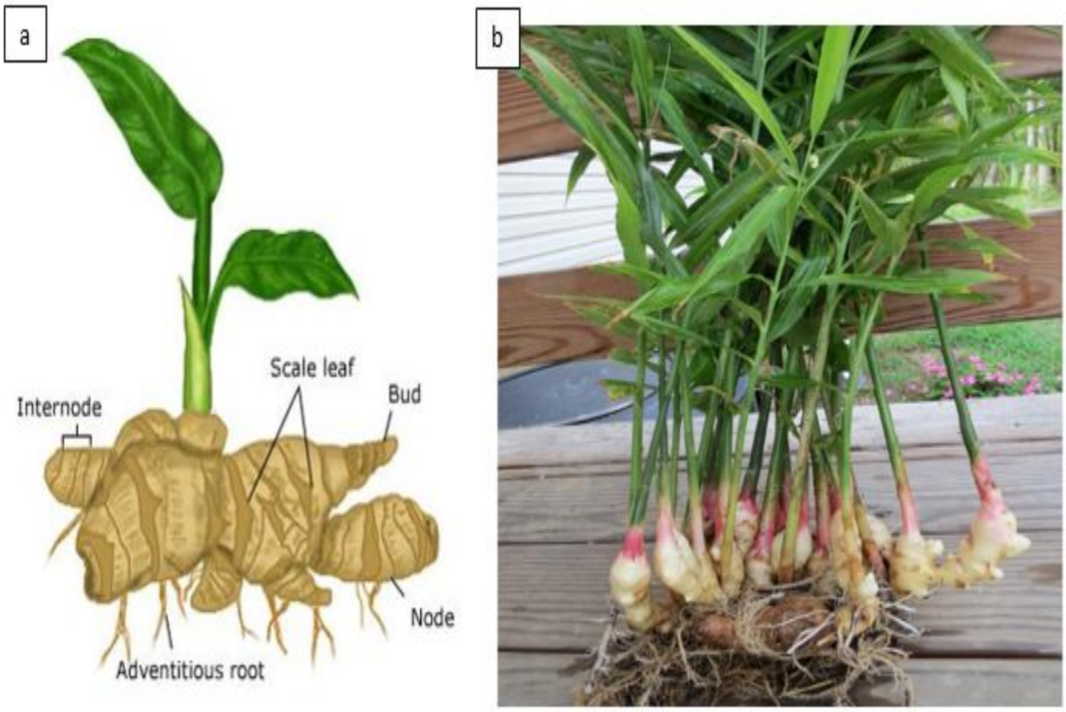


Figure 2.2: a) Diagram outlining the steps taking by the plant to asexually reproduce using the rhizomes (TES Global Limited, 2015) b) Ginger Plant (*Zingiber officinale*) (Ginger plant Network, 2013)

Table 2.2 Manures and Fertilizers applications (AgricInfo, 2011)

Serial Nos.	Time of applications	Farm Yard Manure (ton/ha)	Nitrogen fertilizer (Kg/ha)	Phosphate P205 fertilizer (Jkg/ha)	Potassium sulphate K20 fertilizer (Kg/ha)
1	Preparatory tillage	15	-	-	-
2	At planting	15	60	50	50
3	45 days after planting	-	50	-	-
4	120 days after planting	-	40	-	-
	Total	30	150	50	50

Table 2.3 Area, Production and Productivity of ginger in Nigeria (FAOSTAT, 2012)

Year	Area (Ha)	Production (tones)	Yield (Hg/Ha)
2012	48000	156000	32500
2011	48910	160000	32713
2010	52330	162223	31000
2009	52330	168800	32257
2008	55690	175070	31437
2007	48660	162390	33372
2006	191000	134000	7016
2005	181000	125000	6906
2004	170000	117000	6882
2003	167000	110000	6587
2002	162000	105000	6481
2001	160000	104000	6500
2000	158000	98000	6230
Average	114994	136730	18452

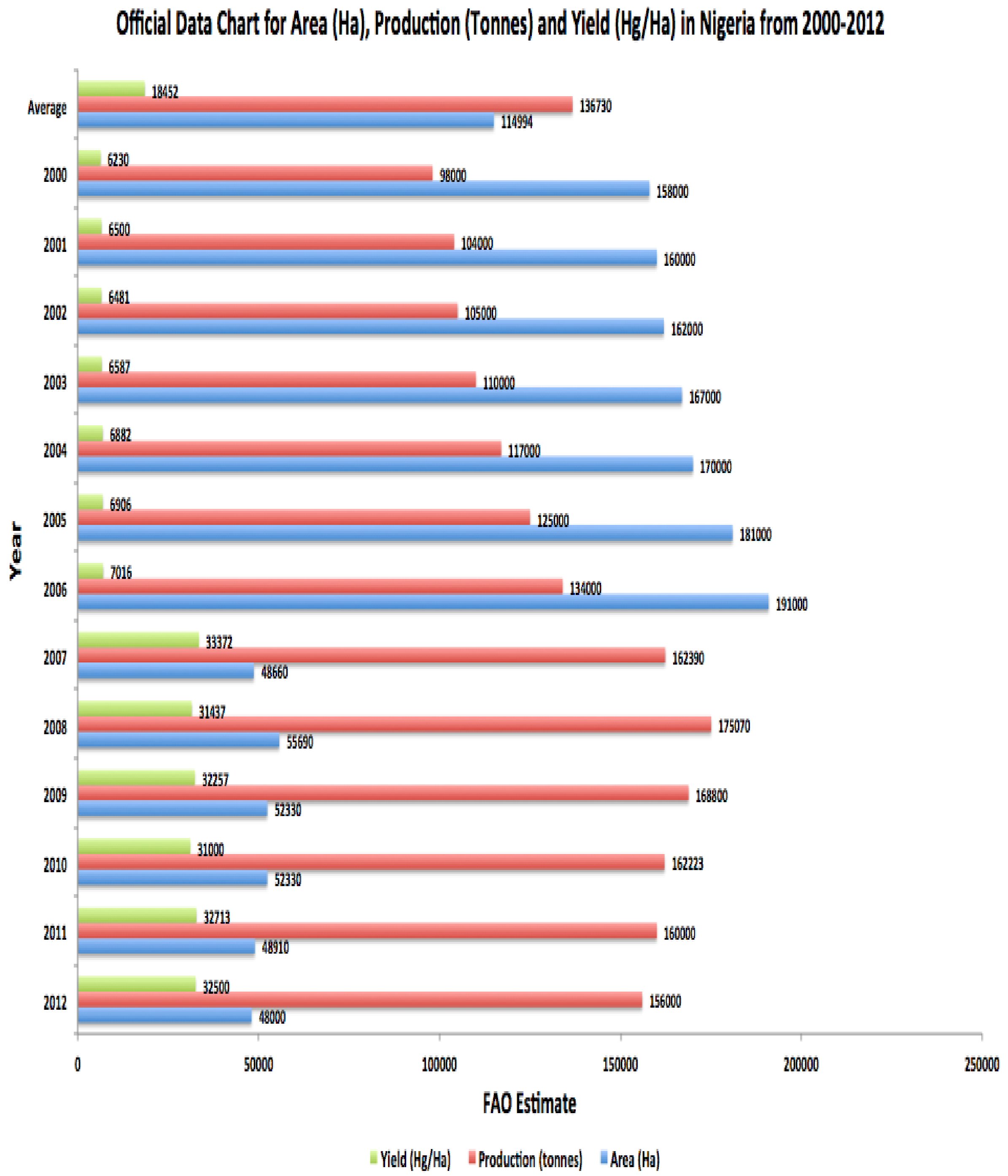


Figure 2.3 Chart of Area (Ha), Production (tons) and Yield for ginger rhizomes in Nigeria (2000-2012) (FAOSTAT, 2012)

2.1.3.2 An Account of Nigeria Ginger Rhizomes Research

Early studies conducted in the 1980s were focused on sun-drying and solar drying methods. Several studies conducted of ginger rhizomes were centered on effects of pricking, sun-drying and sieving on Ginger (*Zingiber officinale Roscoe*) colour and powder (Okafor and Okafor, 2007); Composition of volatile oil (Ekundayo et al., 2006); Bio-chemical changes in ginger during storage (Oti et al., 1988); Development of ginger processing machines (Adeyemi and Onu, 1997; Nwandikom and Njoku, 1998; Onu and Okafor, 2003; Akomas and Oti, 1988; Onu,1997; Egbuchuna and Enujeke, 2013); Efficiency of ginger production in selected local government areas of Kaduna state, Nigeria (NdaNmadu, 2014); Isolation and Characterization Studies of Ginger *(Zingiber officinale)* Root Starch as a Potential Industrial Biomaterial (Afolayan et al., 2014) etc. In those periods, commercial ginger was exploited. The major difficulties encountered were on pests, diseases and pollination. However, there are lots to study on ginger rhizomes. Extensive studies were done in the area of post-harvest chemical dips, improved and controlled air storage, spraying of fungicide, hot water treatment, cool storage, etc.

The moisture content of Ginger rhizomes has a major influence on the difficulties encountered in processing ginger rhizomes produced in Nigeria. Other difficulties include vulnerability to fungal rots and quality of dried ginger using open sun drying and or solar drying. The drier ginger rhizomes overall have lesser occurrence of fungal rots and better capability to produce quality dried ginger in a controlled environment such as the convective drying being studied. The ginger experience moisture content loss either vigorously as a segment of the drying process or flaccidly under controlled storage of the farm produce which will not guarantee it’s freshness after as they are receptive to fungal rots under cold storage facilities. Therefore then have to be dried to assure moisture content of about 20-35%.

Figure 2.4 a) Nigerian Dried Split Ginger(C-Tech Unique Resources, 2015) b) Traditional Sliced and Sun-dried ginger rhizomes (Kamo Ltd, 2015)

2.2 Conceptual Framework

2.2.1 Ginger Rhizome Yields and Returns

The yield information obtained from International Trade Centre shows that China has the highest value and quantity of exported ginger rhizomes in 2013. Nigeria is 5th in the top ten with an annual export value of $20 million compared to China with $400 million (ITC, 2013). This was as a result of losses that accrued from the incorrect drying method of ginger which causes the products to decay and lose it nutrient values. This is also coupled with the low mechanization of ginger production and processing. This causes a decline in the quality of dried ginger with the attendant growth of mold and loss of some important ginger rhizomes qualities.Consequently, the production attracts cheaper price in the world market. The most important form of exported ginger is dried product, followed by the preserved ginger. Trading of fresh ginger is of least significance (Onu and Okafor, 2003). Therefore, there is a dire need for the study of the convective drying of ginger rhizome, although drying processes like the solar, direct sun drying, kinetics, etc. are other common and fundamental method for the preservation of this product. Table 2.4 and figure 2.8 shows world yields for ginger rhizomes exportations in the world.

2.2.2 On-Farm and Additional Processing of Ginger Rhizomes

Ginger processing is a standardized step and incorporates:

- Harvesting
- Sorting
- Washing
- Peeling, blanching, unblanching and unpeeling
- Drying (sun-drying, solar drying etc.)
- Grinding
- Packaging
- Marketing/Exportation(Geta and Kifle, 2011; Queenland Wetlands Program, 2013; Eze and Agbo, 2011)

For the reason that the scope of this research is limited to the convective drying and not on-farm activities and processing, less emphasis will be given to the list above.

Table 2.4 Trade indicators of top 10 exporting countries in 2009 (ITC, 2013)

S/N	Exporters	Value exported in 2013, USD '000	Quantity exported in 2013 (Tones)	Unit value (USD/ Unit)	Annual growth in value 2009-2013(%)	Annual growth in quantity 2009-2013 (%)	Annual growth In value 2012-2013 (%)
1	China	399,885	380,138	1,052	2	8	53
2	Netherlands	56,827	30,157	1,884	21	6	54
3	Thailand	33,383	40,048	834	3	17	53
4	India	27,008	19,935	1,355	26	-5	-37
5	Nigeria	20,125	12,969	1,552	32	30	26
6	Indonesia	14,909	22,472	663	22	25	998
7	Ethiopia	12,553	11,416	1,100	11	9	-23
8	Lithuania	12,001	5,081	2,362	54	1	197
9	Germany	9,302	2,419	3,845	32	60	48
10	Peru	7,994	3,690	2,166	36	33	98
11	World	647,655	570,873	1,134	7	8	42

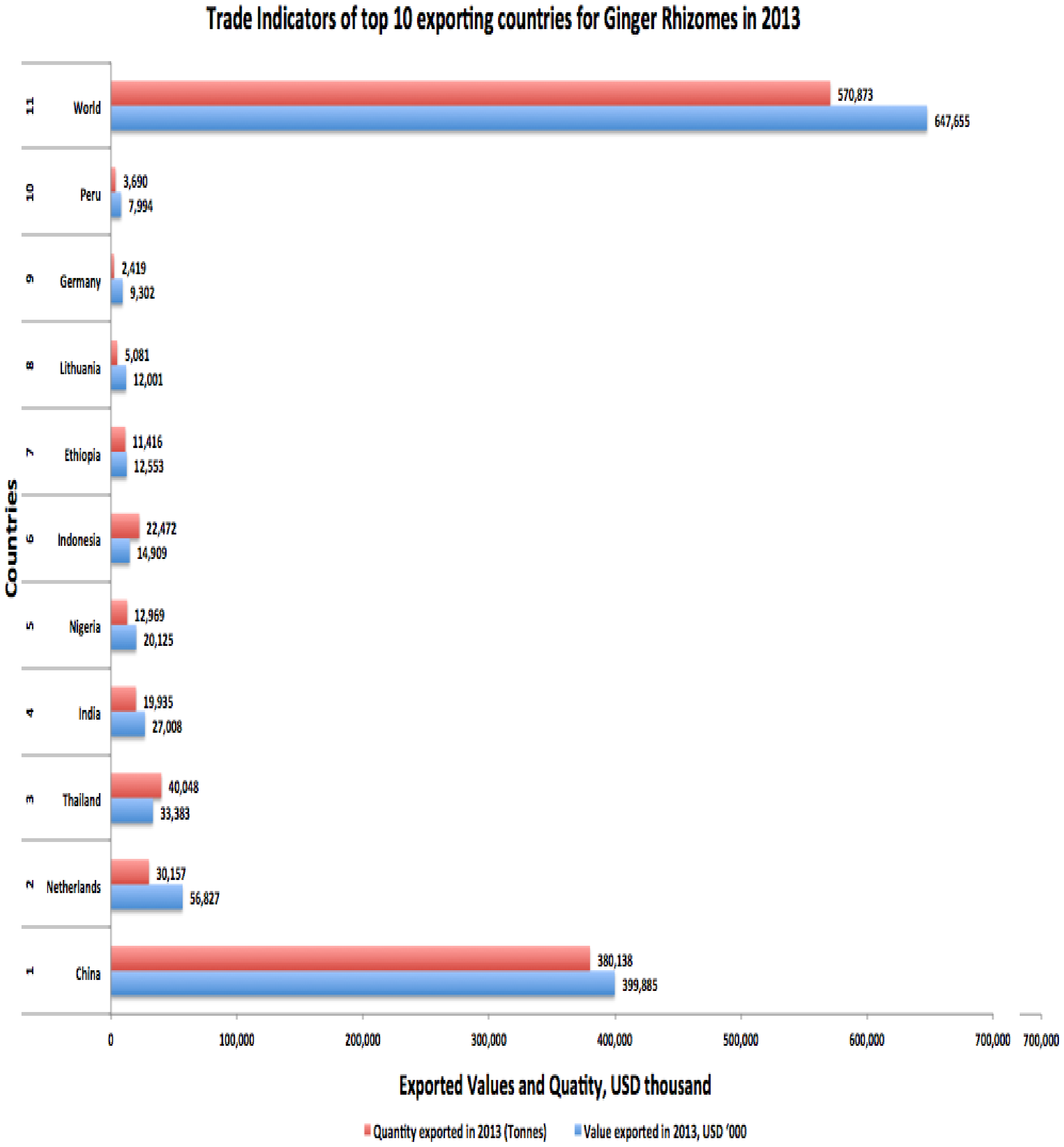


Figure 2.5 Trade indicators of top 10 exporting countries in 2013 (ITC, 2013)

2.2.3 Commercial and Medicinal Uses of Ginger

1. Decoction of dry ginger together with jiggery (a form of crude sugar) relieves dropsy (an excessive accumulation of watery fluid in any of the tissues or cavities of the body).
2. Hot decoction of dry ginger is a stimulant for the stomach and digestive system, and relieves cough, asthma, colic, and angina pectoris.
3. Ginger juice with an equal quantity of milk is indicated in ascites (abnormal accumulation of fluid in the peritoneal cavity). The ghee prepared at 10 times with the ginger juice also has the similar effect.
4. Warm juice of ginger mixed with gingelly oil, honey, and rock salt is a good eardrop in otalgia (pain in the ear).
5. Paste of ginger made with *Ricinus* root decoctions is cooked over red-hot coals after covering with mud, the juice is collected with this special method *(Pudapaka swarasa).* This juice, if taken along with honey, cures the symptoms of rheumatic fever.
6. Juice of ginger with old jiggery cures urticaria (nettle rash) and is digestive.
7. Ghee prepared with ginger juice, ginger paste, and milk relieves edema, sneezing, ascites, and indigestion.
8. Ginger juice along with lemon juice and mixed with little rock salt powder is effective in flatulence (presence of excessive gas in the stomach and intestine), indigestion, and anorexia (having no appetite for food).
9. Dry ginger is effective in all symptoms due to the ingestion of jackfruit.
10. Ginger immersed in lime water (calcium hydroxide) and applied to the skin can remove wart.
11. Ginger juice and clear lime water mixed and applied cures corn (a small painful horny growth on the sole of the foot or the toes).
12. Ginger juice and honey (from *Apis indica)* in equal quantities is hypertensive in action, and of course is excellent for relieving cough.
13. Application of ginger juice around the umbilical region is good for curing diarrhea.

14. Purified ginger juice, onion juice, and honey in equal parts if taken at bedtime are anthelmintic in action.
15. Dry ginger pounded in milk and then the expressed juice used as a nasal drop relieves headache and associated symptoms.
16. Dry ginger powder, tied in a small piece of cloth, if massaged after heating will cure alopecia (loss of hair, a condition in which the hair falls from one or more round or oval areas leaving the skin smooth and white) and promote hair growth.
17. Dry ginger paste, taken along with milk is indicated in jaundice, and when applied to the forehead relieves headache.
18. Dry ginger boiled in buttermilk is anti-poisonous and given for internal use.
19. Dry ginger paste taken internally with hot water and applied over the whole body is the antidote for the toxic effects of *Glorisa* (spider lily).
20. In snake poisoning, the external application with ginger over the bite wound and cold body parts and the drinking of ginger decoction is said to be effective.
21. Ginger juice is an excellent adjuvant for the medicinal preparation *Vettumara* (an ayurvedic preparation), which is indicated in such conditions as fever, chickenpox, and mumps.
22. Ginger juice is used in the purification of cinnabar (HgS) before incinerating it to lessen its toxicity and to make it biologically acceptable.

Ginger forms a component of a large variety of Ayurvedic preparations. However, the following cautions are indicated. Ginger has *ushna* (hot) and *tikshna* (intense-pungent) attributes, and hence is contraindicated in anemia; burning sensation, calculus (a concretion formed in any pair of the body, usually by compounds of salts of organic or inorganic acids), hemorrhage of liver, leprosy, and blood diseases. Its consumption should be reduced or avoided in the hot summer season. Green ginger should not be used for medicinal purposes according to (Nadkarni, 1976). Ginger is also used in homeopathy and the Unani systems of medicine. In the former it is used to treat albuminemia (the presence of serum albumin and serum globulin in the urine), bad breath, dropsy, and retention of urine. In the Unani system, ginger is used for its anthelminric, aphrodisiac, carminative, digestive, and sedative properties; in headache, lumbago, nervous diseases, pains, and rheumatism; and for strengthening of memory (Nadkarni, 1976).

2.2.4 Functions and Clinical uses of Ginger

- Warms the middle body (stomach region) and expels cold. It is also used to warm the spleen and stomach, especially in deficiency cold patterns with such manifestations as pallor, poor appetite, cold limbs, vomiting, diarrhea, cold painful abdomen and chest, a deep, slow pulse, and a pale tongue with a moist, white coating.
- Rescues devastated *Yang* and expel interior cold: used in patterns of devastated or deficient *Yang* with such signs as a very weak pulse and cold limbs.
- Warms the lungs and transforms phlegm: used in cold lung patterns with expectoration of thin, watery, or white sputum.
- Warms the channels and stops bleeding: used for deficiency gold patterns that may present with hemorrhages of various types, especially uterine bleeding. Ginger is used in hemorrhage only if the bleeding is chronic and pale in color and is accompanied by cold limbs, ashen white face, and a soggy, thin pulse.

2.2.5 Major Combinations of Ginger

- With *Radix Glycyrrhizae Uralensis (Gan Cao)* for epigastric pain and vomiting due to cold deficient stomach and spleen.
- With *Rhizoma Alpiniae Officinari (Gao Liang Jiang)* for abdominal pain and vomiting due to cold stomach.
- With *Rhizoma Pintl/iat Ternate (Ban Xia)* for vomiting due to cold-induced congested fluids. Add radix ginseng *(Ren Shen)* for vomiting due to deficiencycold.
- With *Rhizoma Coptidis (Huang Lian)* for epigastric pain and distension, dysentery-like disorders, and indeterminate gnawing hunger. The latter is a syndrome characterized by a feeling of hunger, vague abdominal pain, or

discomfort sometimes accompanied by belching, distension, and nausea, which gradually culminates in pain.

- With *Cortex Magnoliae Officinalis (Hou Po)* for epigastric distension and pain due to cold-induced congealed fluids.
- With *Rhizoma Atractyloids Macrocephalae (Bai Zhu)* for, deficient spleen and diarrhea. If both herbs are charred, they can be used for bloody stool and excessive uterine hemorrhage.
- With *Fructus Schisandrae Chinensis (Wu Wei Zi)* for coughing and wheezing from cold congested fluids preventing the normal descent of lung Qi.
- Compared to *Rhizoma Zingiberis Officinalis Recens (Sheng Jiang), Rhizoma Zingiberis officinalis (Gan Jiang)* is more effective in warming the middle burner and expelling interior cold, whereas *RhizomaZingiberis Officinalls Recms (Sheng Jiang)* promotes sweating and disperses exterior cold.

2.2.6 Health Benefits of Ginger

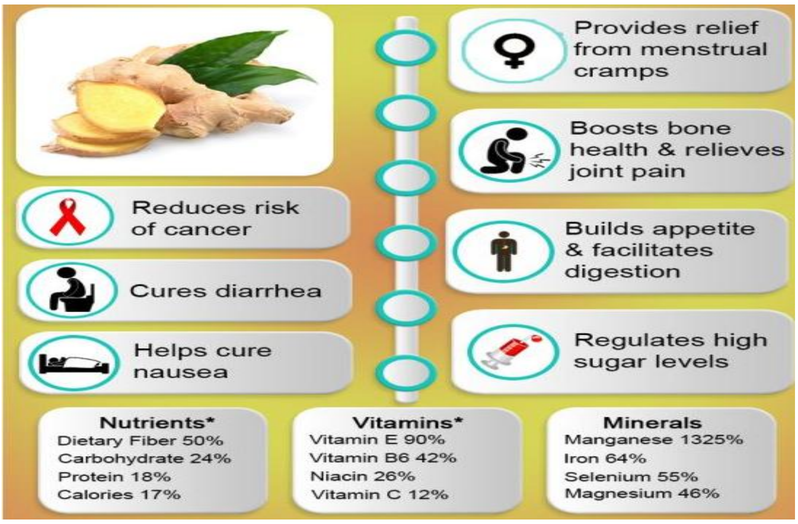


Figure 2.6 Health Benefits and Composition of Ginger Rhizomes (Organic Facts, 2012)

2.2.7 Composition of Ginger Rhizomes

Ginger rhizomes are a very rich source of minerals such as magnesium, manganese and phosphor. It also contains iron, sodium, calcium and small quantities of Vitamins B1, B2, B3 and C. When dried, the Vitamins disappear completely. Ginger rhizomes contain other compositions like lipids, proteins, carbohydrates, crude fibre, cold alcoholic extract, fat, ash protein, essential oil and reducing sugars. Ginger rhizomes in Nigeria are considered to be of high quality and contain 6.5% extract and 2.5% volatile oil (Ugwoke and Nzekwe, 2010; Raina, et al., 2013; Sasidharan and Menon, 2010).

2.3 Theoretical Framework

2.3.1 Theory and Mathematical modelling of Food drying

Drying is a very complex process which involves simultaneous heat and mass transfer. Drying is a challenging concept in engineering, because of the complexities and deficiencies in mathematical formulations. It is a form of unit operation that converts a liquid, solid or semi-solid feed material into a solid product of very low moisture content (Erbay and Icier, 2009). Ginger drying is very complicated because of the differential structure of products. It possesses different segments. The mechanisms used for drying are surface diffusion or liquid diffusion on the pore surfaces, liquid or vapor diffusion due to moisture concentration differences, and capillary action in granular and porous foods due to surface forces (Strumillo and Kundra, 1986; Ozilgen and Ozdemir, 2001).

Drying processes are categorized into two major models:

1. Distributed models: this model considers simultaneous heat and mass transfer. They take into account both the internal and external heat and mass transfers. They predict the temperature and moisture gradient in the product better. The distributed models depend on the Luikov equations that were derived from Fick's second law of diffusion as shown in equation 2.2(Luikov, 1975; Erbay and Icier, 2009).

$$\frac{\partial M}{\partial t} = \nabla^2 K_{11} M + \nabla^2 K_{12} T + \nabla^2 K_{13} P$$

$$\frac{\partial T}{\partial t} = \nabla^2 K_{21} M + \nabla^2 K_{22} T + \nabla^2 K_{23} P$$

$$\frac{\partial P}{\partial t} = \nabla^2 K_{31} M + \nabla^2 K_{32} T + \nabla^2 K_{33} P \qquad (2.2)$$

Where K_{11}, K_{22},K_{33} are the phenomenological coefficients while K_{12},K_{13}, K_{21},K_{23},K_{31},K_{32} are the coupling coefficients (Booker, et al., 1974).

In most of the drying processes, the effects of pressure are negligible compared with the temperature and moisture effect. Hence, Luikov equations reduce to (Booker, et al., 1974; Erbay & Icier, 2009):

$$\frac{\partial M}{\partial t} = \nabla^2 K_{11} M + \nabla^2 K_{12} T$$

$$\frac{\partial T}{\partial t} = \nabla^2 K_{21} M + \nabla^2 K_{22} T \qquad (2.3)$$

Equation 2.3 is the modified form of Luikov equations and may not be solved using analytical methods due to the complexities of real drying mechanisms. However, the modified form can be solved with the Finite Element Method (Ozilgen & Ozdemir, 2001).

2. Lumped parameter models: these models do not consider the temperature gradient in the product and they assume a uniform temperature distribution that equals to the drying air temperature in the product. This assumption reduces the Luikov equation to:

$$\frac{\partial M}{\partial t} = \nabla^2 K_{11} M \qquad (2.4)$$

$$\frac{\partial T}{\partial t} = \nabla^2 K_{22} T \qquad (2.5)$$

The phenomenological coefficient K_{11} is known as effective moisture diffusivity (D_{eff}) and K_{22} is known as thermal diffusivity (α). For constant values of D_{eff} and α, Equations 2.4 and 2.5 can be rearranged as:

$$\frac{\partial M}{\partial t} = D_{eff} \left[\frac{\partial^2 M}{\partial x^2} + \frac{a_1}{x}\frac{\partial M}{\partial x}\right] \qquad (2.6)$$

$$\frac{\partial T}{\partial t} = \alpha \left[\frac{\partial^2 T}{\partial x^2} + \frac{a_1}{x}\frac{\partial T}{\partial x}\right] \qquad (2.7)$$

Where

parameter $\mathrm{a}_1 = 0$ for planar geometries, $\mathrm{a}_1 = 1$ for cylindrical shapes and

$\mathrm{a}_1 = 2$ for spherical geometries (Ekechukwu, 1999).

Assumptions resembling the uniform temperature distribution and temperature equivalent of the ambient air and product were found to cause errors (Erbay and Icier, 2010).

Henderson & Pabis (1961) reported that these errors can be reduced to acceptable values with reducing the thickness of the product. This necessitates the derivation of the thin layer drying equations. In this report, the mathematical expressions were not solved but were presented to alert on the existence of such equations. The work presented is purely experimental.

2.3.2 Thin Layer Drying Equations

The thin layer drying simply means to dry as one layer of sample, particles or slices (Akpinar, 2006). The temperature of thin layers are assumed to be of uniform distribution and very ideal for lumped parameter models (Erbay and Icier, 2010). Several studies show that thin layer drying equations were found to have wide applications due to their ease of use and less data requirements unlike complex data distributed models ((Özdemir and Onur Devres, 1999).

Thin layer drying equations may be expressed in the following models: theoretical, semi-theoretical, and empirical. The theoretical takes into account only the internal resistance to moisture transfer (Parti, 1993) while others are concerned with external resistance to moisture transfer between the product and air (Fortes et al., 1980) The theoretical models explain drying behaviors of the product succinctly and can be employed in all process situations. They also include many assumptions causing significant errors. Fick’s second law of diffusion is used for the derivation of many of the theoretical models. Semi-theoretical models are also derived from Fick’s second law of diffusion and modifications of its simplified forms. They are easier and require fewer assumptions due to use of some experimental data and are valid within the limits of the process conditions applied (Fortes et al., 1980).

2.3.2.1 Basic Thin Layer Drying Conditions

Isothermal conditions involving time change may be assumed to prevail within the product because the heat transfer rate within the product is two orders of magnitude greater than the rate of moisture transfer only with time (Özilgen and Özdemir, 2001).It is assumed that as equation 2.5 describes the mass transfer, it can be solved analytically with the above assumptions and the boundary conditions as shown in Figure 2.7 (Erbay and Icier, 2010):

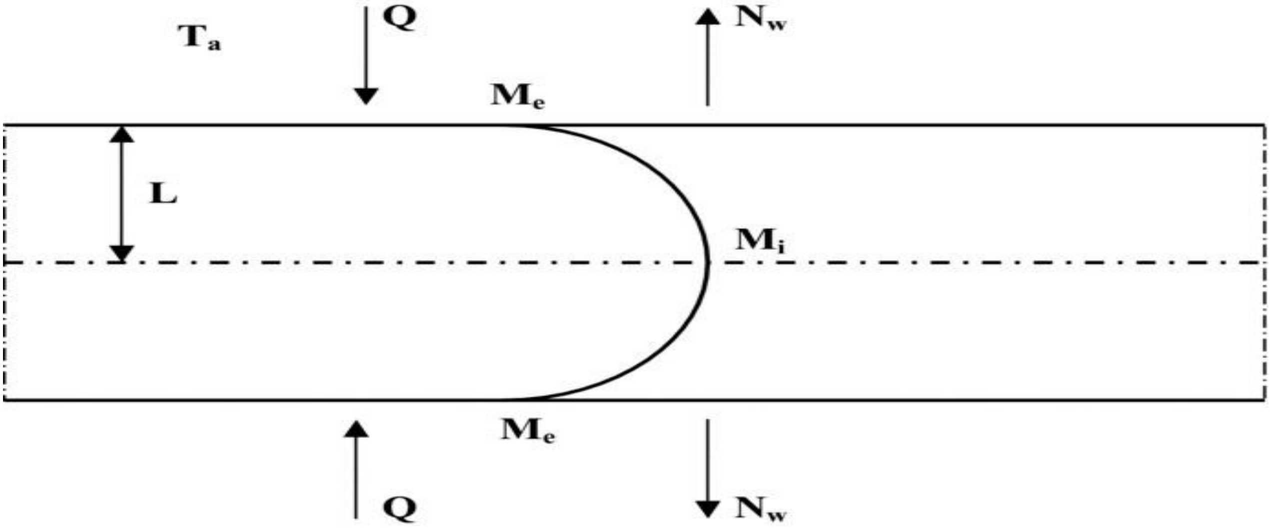


Figure 2.7 Schematic view of thin layer drying, if drying occurs from both sides (Erbay and Icier, 2010)

$$t = 0,\ -L \leq x \leq L,\ M = M_t \tag{2.8}$$

$$t > 0,\ x = 0,\ \ {}^{dM}\!/_{dx} = 0 \tag{2.9}$$

$$t > 0,\ x = L,\ M = M_e \tag{2.10}$$

$$t > 0,\ -L \leq x \leq L,\ T = T_a \tag{2.11}$$

Assumptions made in thin layer equations formulations:

i. The particle is homogenous and isotropic;
ii. The material characteristics were assumed constant and shrinkages neglected;
iii. The variations in pressure were overlooked;
iv. Evaporation occurs only at the surface;
v. At the beginning, moisture distribution is uniform (Eq. 2.8) and symmetrical during process (Eq. 2.9);
vi. Surface diffusion is ended, so the moisture equilibrium arises on the surface (Eq. 2.10);

vii. Temperature distribution is uniform and equals to the ambient drying air temperature, namely the lumped system (Eq. 2.11);

viii. The heat transfer is done by conduction within the product and by convection outside of the product;

ix. Effective moisture diffusivity is constant versus moisture content during drying.

The analytical solutions of Eq. 2.6 are expressed as Eq. 2.12 for finite slab or sphere (Crank, 1975):

$$MR = A_1 \sum_{i=1}^{\infty} \frac{1}{(2i-1)^2} exp\left[-\frac{(2i-1)^2 \pi^2 D_{eff}\, t}{A_2}\right] \quad (2.12)$$

Table 2.5 Some Geometric constants according to product geometry (Erbay and Icier, 2010).

Product Geometry	A_1	A_2 *
Infinite slab	$8/\pi^2$	$4L^2$
Sphere	$6/\pi^2$	$4r^2$
3-dimensional finite slab	$(8/\pi^2)^3$	$1/(L_1^2 + L_2^2 + L_3^2)$

$L*$ is the half thickness of the slice if drying occurs from both sides or L is the thickness of the slice if drying occurs from only one side.

$$MR = A_1 \sum_{i=1}^{\infty} \frac{1}{J_0^2} exp\left[-\frac{J_0^2 D_{eff}\, t}{A_2}\right] \quad (2.13)$$

Where, D_{eff} is the effective moisture diffusivity(m^2/s); t is time (s), MR is the fractional moisture ratio; J_0 is the roots of the Bessel function and A_1 and A_2 are geometric constants.

For multidimensional geometries such as 3-dimensional slab the Newman's rule can be applied (Treybal, 1968).The common geometric constants are shown in Table 2.5. The moisture ratio (MR) of the ginger slices during the thin layer drying experiments is calculated using the following equation (Diamante and Munro, 1993):

$$\boldsymbol{MR} = \frac{\boldsymbol{M_t} - \boldsymbol{M_e}}{\boldsymbol{M_i} - \boldsymbol{M_e}} \qquad (\mathbf{2.14})$$

if the relative humidity of the drying air continuously fluctuates and the moisture equilibrium continuously varies; then MR is determined as in Eq. 2.15 (Diamante and Munro, 1993):

$$MR = \frac{\mathrm{M_t}}{\mathrm{M_i}} \qquad (2.15)$$

Where, $M_t = Anytime\ moisture\ content\ (\%\ )$

$M_e = Equilibrium\ moisture\ content\ (\%\ )$

$M_i = Initial\ moisture\ content\ (\%\ )$

If the food materials dry without a constant rate period, then M_i is equal toM_{cr}, which is defined as the moisture content of a material at the end of the constant rate period of drying; the Eq. 2.14 equals to Eq. 2.16 and MR can be named as the characteristics moisture content($\emptyset$).

$$\emptyset = \frac{(M_t - M_e)}{(M_{cr} - M_e)} \qquad (2.16)$$

Semi-theoretical models

The semi-theoretical models can be classified according to their derivation as:

1. Newton's law of cooling: includes all models derived from the Newton's law of cooling and are sub-classified into:

    a. **Lewis (Newton) model**

This model corresponds to the Newton's law of cooling. Many researchers have named it Newton's model. Lewis (1921) proposed that during the drying of porous hygroscopic materials, the change in moisture content of material in the falling rate period is proportional to the instantaneous difference between the moisture content and the expected moisture content when it comes into equilibrium with drying air. In this proposition, it is assumed that the material is very thin, the air velocity is high and the drying air conditions such as temperature and relative humidity are kept constant.

It is expressed mathematically as (Marinos-Kouris and Maroulis, 2006):

$$\frac{dM}{dt} = -K(M - M_e) \qquad (2.17)$$

Where, K is the drying constant(s^{-1})? In the thin layer drying concept, the drying constant is the combination of drying transport properties such as moisture diffusivity, thermal conductivity, interface heat, and mass coefficients.

If K is independent from M, then Eq.2.17 can be re-expressed as:

$$MR = \frac{M_t - M_e}{M_i - M_e} = exp(-kt) \tag{2.18}$$

Where, k is the drying constant (s^{-1}) obtained from the experimental data in Eq. 2.18 also known as the Lewis (Newton) model?

b. Page model and modified forms

Page (1949) further modified Lewis model to obtain an accurate model by introducing a dimensionless empirical constant (n). This modified model in the drying of shelled corns:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp(-kt^n) \tag{2.19}$$

The following are modified Page models:

i. **Modified Page-I Model:** This form was used to model the drying of soybeans (Overhults et al, 1973). Mathematically expressed in Eq. 2.20 as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp(-kt)^n \tag{2.20}$$

ii. **Modified Page-II Model:** This model was introduced by (White et al., 1976) and is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp - (kt)^n \tag{2.21}$$

iii. **Modified Page equation-II Model:** This model was employed in a study to describe the drying process of sweet potato slices (Diamante and Munro, 1993). It is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = exp - (k/l^2)^n \tag{2.22}$$

Where l is an empirical dimensionless constant?

2. **Fick's second law of diffusion:** the models in this group are derived from Fick's second law of diffusion and are sub-classified into:

c. Henderson and Pabis (Single term exponential) model and modified forms:

This is a drying model obtained from Fick's second law of diffusion and applied on drying corns (Henderson and Pabis, 1961). Eq. 2.12 was employed in the derivation of this model. In this model, for long drying times, only the first term (i=1) of the general series solution of Eq. 2.12 can be utilized with negligible error. In Henderson and Pabis (1961) assumption, Eq. 2.12 can be re-expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = A_1 exp\left(-\frac{\pi^2 D_{eff}}{A_2} t\right) \qquad (2.23)$$

Where D_{eff} is the effective diffusivity (m^2/s).

If D_{eff} is constant during drying, then Eq. 2.23 can be re-arranged by using the drying constant k as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\ exp(-kt) \qquad (2.24)$$

Where a is defined as the indication of shape and generally named as model constant from experimental data. Equation 2.24 is generally known as the Henderson and Pabis model.

Other forms of Henderson and Pabis models includes:

d. Logarithmic (Asymptotic) model

A new logarithmic model of the Henderson and Pabis was proposed by (Chandra and Singh, 1995) and was applied in the drying of laurel leaves (Yagcioglu et al., 1999). This is expressed mathematically as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\ exp(-kt) + c \qquad (2.25)$$

Where c is an empirical dimensionless constant

e. Two-Term Model

Henderson (1974) proposed to use the first two term of the general series solution of Ficks second law of diffusion Eq. (2.26) for correcting the shortcomings of the Henderson and Pabis model. This model was applied in the drying of grain (Glenn, 1978). The model is expressed as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-k_1 t) + b\,exp(-k_2 t) \qquad (2.26)$$

Where a, b are defined as the indication of shape and generally named as model constants and k_1, k_2 are the drying constants (s^{-1}). These constants are obtained from experimental data and equation (2.29) is referred as Two-Term Model.

f. Two-Term Exponential Model

Sharaf-Eldeen et al. (1980) re-expressed the Two-Term Model by cutting down the constant number and organizing the second exponential term's indication of shape constant (b). They stressed that the (b) in the Two-Term Model in Eq. (2.26) should be $(1-a)$ at $t = 0$ to get $MR = 1$ and proposed a modification as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a\exp(-kt) + (1-a)\,exp(-kat) \qquad (2.27)$$

Eq. (2.27) is called the Two-Term Exponential model

g. Wang and Singh Model

Wang and Singh (1978) created a model for intermittent drying of rough rice.

$$MR = 1 + at + bt^2 \qquad (2.28)$$

where, b (s^{-1}) and a (s^{-2}) were constants obtained from experimental data.

h. Diffusion Approach Model

Kaseem (1998) rearranged the Verma model (2.31) by separating the drying constant term k from g and proposed the renewed form as:

$$MR = aexp(-kt) + (1-a)\exp(-kbt) \qquad (2.29)$$

This modified form is known as the Diffusion Approach model. These two modified models were applied for some products' drying at the same time, and gave the same results as expected (Toˇrul and Pehlivan, 2003; Akpinar et al., 2003; Gunhan et al., 2005; Akpinar, 2006; Demir et al., 2007).

i. The Three Term Exponential Models (Modified Henderson and Pabis)

Henderson and Pabis model and the Two-Term Exponential model were improved by adding the third term of the general series solution of Fick's second law of diffusion Eq. (2.6) with the view of amending any defect in the models. Karathanos (1999) stressed that the first term, second term and third term highlighted in details the last, the middle and the initial parts of the drying curve $(MR - t)$ as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a \exp(-kt) + b\ exp(-gt) + +c\ exp(-ht) \qquad (2.30)$$

Where, $a, b, and\ c$ indicates the dimensionless shape constants and $k, g\ and\ h$ are the drying constants (s^{-1}). Equation (2.30) is referred to as the Modified Henderson and Pabis model.

j. Modified Two-Term Exponential Models (Verma et al model)

Verma et al. (1985) in their study modified the second exponential term of the Two-term Exponential model by adding an empirical constant and used it in the drying of rice. The model modified is referred to as the Verma model and expressed mathematically as:

$$MR = \frac{(M_t - M_e)}{(M_i - M_e)} = a \exp(-kt) + (1 - a)\ exp(-gt) \qquad (2.31)$$

k. Midilli et al Model

Midilli et al (2002) modified the Henderson and Pabis by adding extra empirical term that includes t. The model combined the exponential term with a linear term. It was applied to the drying of yellow dent maize and it is expressed as:

$$MR = a. \exp(-kt^n) + bt \qquad (2.32)$$

Developed models from existing models

From Equation (2.19), the following equations were obtained for exponent, n and drying constant, k respectively

$$n = \frac{(M_e - M_t)}{(M_e - M_i)kt} \qquad (2.33)$$

$$k = \frac{(M_e - M_t)}{(M_e - M_i)n} \qquad (2.34)$$

2.3.3 Determination of the most suitable model for drying

Thin layer drying always require a good understanding of the regression and correlation analysis. Linear and non-linear regression analysis are used to ascertain the relationship between variables MR and t in thin layer drying for selected drying models. The recommended models chosen for applications were further validated using correlation analysis, standard error of estimate (SEE) and root mean square error (RMSE) analysis respectively. The major indicator for selecting the best models is the determination coefficient (R^2). The highest determination coefficient and lowest standard error of estimate and RMSE values are used to determine the goodness of fit (Akpinar, 2006; Erbay & Icier, 2010; Verma et al., 1985). The determination coefficient (R^2); standard error of estimate (SEE) and root mean square error (RMSE) calculations can be performed using the following equations:

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pre\,,i})\sum_{i=1}^{N}(MR_i - MR_{exp\,,i})}{\sqrt{\left[\sum_{i=1}^{N}(MR_i - MR_{pre\,,,i})^2\right] - \left[\sum_{i=1}^{N}(MR_i - MR_{exp\,,i})^2\right]}} \qquad (2.33)$$

$$SEE = \frac{\sum_{i=1}^{N}\left(MR_{exp\,,i} - MR_{pre\,,i}\right)^2}{d_f} \qquad (2.34)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre\,,i} - MR_{exp\,,i}\right)^2\right]^{1/2} \qquad (2.35)$$

Where N is the number of observations, $MR_{pre\,,i}$ ith predicted moisture ratio values, $MR_{exp\,,i}$ ith experimental moisture ratio values, and d_f is the number of degree of freedom of regression model.

2.3.4 Moisture Content (%) Calculation Formula

The moisture content of the materials can be calculated by using two methods: wet or dry basis

i. The wet basis is calculated as follows:

$$M_{wb} = \frac{w(i) - w(j)}{w(i)} \qquad (2.36)$$

Where

$M_{wb} = Moisture\ Content, wet\ basis$ (%)

$w(i) = mass\ of\ the\ sample\ before\ drying\ (g)$
$w(j) = mass\ of\ the\ sample\ after\ drying\ (g)$

ii. The dry basis is calculated as follows:

$$M_{db} = \frac{w(t) - d}{d} \tag{2.37}$$

Moisture content, dry basis $\boldsymbol{M_{db}}$, is the amount of water per unit mass of dry solids (bone dry) existing in the sample

Where

$\mathrm{M_{db}} = \mathrm{Moisture\ Content, dry\ basis\ (\%)}$
$\mathrm{w(t)} = \mathrm{mass\ of\ wet\ materials\ at\ instant\ t\ (g)}$
$\mathrm{w} = \mathrm{mass\ of\ wet\ material\ (g)}$
$\mathrm{d} = \mathrm{mass\ of\ dry\ material\ (g)}$

Note that the two moisture contents are related by the following equation:

$$M_{db} = \frac{M_{wb}}{1 - M_{wb}} \tag{2.38}$$

2.3.5 Determination of the effective diffusivity and activation energy

The effective diffusivity of agricultural products can be determined using Fick's Second law for slab geometry(Akpinar and Toraman, 2016; Aregbesola *et al.*, 2015). The common geometries are shown in Table 2.5. The analytical solution of Fick's Second law for infinite slab is expressed as:

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}\,t}{4L^2}\right) \tag{2.39}$$

Where $\boldsymbol{n}$ is a positive integer, $\boldsymbol{L}$ is the half thickness of samples (m).

Eq (2.39) can be modified in a logarithmic form as:

$$ln\ (MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\, t}{4L^2}\right) \tag{2.40}$$

The effective moisture diffusivity can be obtained by plotting $\boldsymbol{ln}(\boldsymbol{MR})$against **drying time**; this gives a straight line with a slope (K) expressed as:

$$K = -\left(\frac{\pi^2 D_{eff}}{4L^2}\right) \tag{2.41}$$

The dependence of the effective diffusivity on temperature is described by the Arrhenius equation as (Akpinar and Toraman, 2016;Aregbesola *et al.*, 2015;Alam *et al.*, 2014) :

$$D_{eff} = D_0 exp\left(-\frac{E_a}{RT}\right) \tag{2.42}$$

Eq. (2.42) can be expressed in the logarithmic form as:

$$\ln D_{eff} = \left(-\frac{E_a}{RT}\right) + \ln D_0 \tag{2.43}$$

Where D_0 is the pre-exponential factor of Arrhenius equation (m^2/s); E_a is the activation energy in (kJ/mol); R is the universal gas constant $8.314 J/molK)$; and T is absolute air temperature (K).

From equation (2.43), plotting of $\mathbf{ln}\, \boldsymbol{D_{eff}}$ against $(\boldsymbol{T})^{-\mathbf{1}}$ would lead to the evaluation of activation energy for diffusion of moisture during drying and $\boldsymbol{E_a}$ is obtained as:$-(\boldsymbol{slope} \times\ R) = \boldsymbol{E_a}$, where $(–E_a/R)$ is the slope of equation (2.43).

2.3.6 Drying Rate

The drying rates at different timing during the environmental chamber can be computed in all experimental conditions using the following relationship (Shalini et al., 2008).

$$\left(\frac{dM}{dt}\right)_{avg} = \frac{M_o - M_t}{t} \tag{2.44}$$

Where $\frac{dM}{dt}$ is drying rate (kg water/kg of materials), t is the time (min) and $M_o\ and\ M_t$ are the initial and final moisture content respectively (Shalini et al., 2008).

The air velocity and temperature effect on the whole drying rate is calculated by statistical method using analysis of variance.

The Overall rate of drying is computed as ratio of difference in the initial and final moisture content to total drying time. The overall drying rate can be expressed as:

$$\left(\frac{dM}{dt}\right)_o = \frac{M_o - M_F}{t_1} \qquad (2.45)$$

The moisture content dry basis could have values greater than 100%, because the volume of water present in a sample could be greater than the volume of dry solids present. Dry basis is often used to approximate the percentage moisture content as the moisture-free material, if inert; it does not lose mass during drying. The bone-dry matter therefore specifies a mass-balance tie over a drying process. However, at times the wet basis moisture content is more suitable for usage (Cletus, 2007).

2.4 Empirical Framework

2.4.1 Review of Drying Kinetics of Ginger Rhizomes (*Zingiber Officinale*) and Comparative Studies of Sun and Solar Drying of Peeled and Unpeeled Ginger

Muller (2007) in his study on the drying characteristics of ginger rhizomes identified experimental studies models for drying kinetics in addition to the damages of the active ingredients in drying at various drying situations. The most important feature is that solar drying leads to significant decrease in drying period and the production of quality dried ginger products. The result of this is that one can obtain the best quality ginger product at higher temperature and this in turn could damage the nutritional contents of the ginger. Özgüven et al. (2007) indicated that solar drying (Figure 2.4a&b) is more superior to sun drying in terms of essential oil ingredients. The low level of mechanization of ginger processing and production with the growth of mold and loss of vital ginger qualities has resulted to a decline of dried ginger (Onu & Okafor, 2003).

Open air sun drying by dehydration is one of the earliest traditional preservation methods for storage of agricultural products and it is still a common technique practiced globally, most especially in Africa and Asia, where solar radiation is suitable (Ganesapillai et al., 2011). However, in conventional drying techniques, heat is transferred from the external to the inside of the material. Continued exposure of the ginger rhizomes to higher drying temperature develops in the decline of cells, significant decline in the quality of the anticipated product inducing the decrease in colour, nutrients, odour, taste, flavour, loss of rehydration capability, case hardening and wettability (Karel, 1991). Drying kinetics of materials could be defined totally by means of their transport properties (moisture diffusivity, thermal diffusivity, interface heat and mass transfer and coefficients of thermal conductivity) together with the drying means and is defined by the thin layer equation (Ganesapillai et al., 2011; Karel, 1991). Several authors have investigated and conducted studies on the drying performance of different food products and materials. More so, numerous mathematical models have been formulated and developed for different food sources such as for figs (Xanthopoulosa et al., 2009), Sweet potato (Diamante & Munro, 1991; Akpinara et al., 2003), garlic slices (Babettoa et al., 2011), red pepper (Doymaz & Pala, 2002; Akpinar, et al., 2003), carrot (Ibrahim, 2004), eggplant (Ertekin & Yaldiz, 2004), apricot (Toğrul & Pehlivan, 2003; Diamante, et al., 2010), green chilli (Hossain & Bala, 2002) etc. However, several studies have been conducted on drying of ginger rhizomes. But there are no published work on the convective drying of ginger rhizomes *(Zingiber Officinale)* to the knowledge of the authors. This work therefore is centered on the convective drying of ginger rhizomes.

The hitherto assumed principal processing of ginger rhizomes involves sorting, washing, soaking, splitting or peeling and drying it to moisture content 7-12% (Eze and Agbo, 2011). The target using the thin layer drying methodology would be 4-7% from initial moisture content of 87-90% (wb)

2.4.2 Review of Thin Layer Drying Methods for Some Aquatic and Agricultural Farm Products

Thin layer drying by convective methods have been used for several aquatic food products example Silver Carp (Hypophthalmichthys molitrix) Fillets (Wang et al.,

2011) and agricultural products example azarole red (Crataegusmonogyna Jacq.) and yellow fruits (Crataegus aronia Bosc.) (Koyuncu et al., 2006), pumpkin (Guiné et al., 2011), Unripe Banana (Zabalaga & Carballo, 2014). Drying could be defined as a process in which moisture is removed from a solid using heat as the energy input (Shi et al., 2008). Drying constitutes an established process for the preservation of food, which prolongs food life. The drying kinetics of farm produce like fruits e.g. unripe banana, pumpkin, red and yellow azarole are necessary to decrease their weight for transportation, storage volume, reduction or decrease in microbial spoilage, deterioration reaction, quality deterioration, and enzymatic activity. (Zabalaga & Carballo, 2014). It is therefore essential to study the drying kinetics of these products in order to provide sufficient information about the time that is required for the product to reach safe and low moisture content including appropriate drying temperatures (Zabalaga & Carballo, 2014; Guiné et al., 2011). The thin layer drying of food using convective method is a difficult thermal process that encompasses the transfer of mass and energy concurrently between the airflow and product (Zabalaga & Carballo, 2014). It utilizes hot air as humidity and heat carrier, through which circumstances such as relative humidity, velocity, temperature and numerous contaminations may perhaps be well-controlled, thereby bringing about great quality dried yields. (Wang et al., 2011; Gwak & Eun, 2010). At present, the drying of agricultural produce is analyzed in terms of drying kinetics and chemical properties. Semi-theoretical models widely used have been proposed to describe the drying process of agricultural materials (Akpinar,2006). Normally, convective drying (thin layer or otherwise) operates at different temperatures from $30℃\ to\ 70℃$, and the products obtained were examined and related with the new product. The drying data contained (moisture content variation along with the drying time) was built-in to various kinetic models discovered in scientific literature. Thin layer drying by convection is stress-free, it is easy to operate, has low cost of investment, and should be an alternative for the preservation and processing of ginger rhizomes (Guiné et al., 2011).

2.4.3 Effect of Temperature on the Physical and Chemical Properties of Ginger Rhizomes (Zingiber Officinale)

Water as one of the major food constituents has a pivotal effect on the durability and quality of food materials through its properties on several biological and physicochemical changes (Fernandesa et al., 2006). The effect of temperature on the physical and chemical properties of ginger rhizomes has been investigated and reviewed by several authors (Ahmed, 2004; Sah, Al-Tamimi et al., 2012; Sukrasno et al., 2014) by the use of numerous methods.

The technique of drying was used to extract moisture from the ginger rhizomes and its chemical composition and antioxidant activity (solvent and aqueous extracts) of the Ginger rhizomes (*Zingiber officinale*) determined are not affected by the high temperature of the convective drying methods and equipment (Shirin & Prakash, 2011). Figure 2.5 shows the drying characteristics of ginger slices by numerous drying techniques. It illustrates ginger rhizomes sliced to different lengths of 5, 10, 15, 20, 30, 40 and 50mm and dried by several drying techniques such as solar tunnel drying, cabinet drying and sun drying at temperatures of 50, 55, 60 and 65°C. The graph figure 2.3a&b shows that drying a whole ginger in open sun takes 9 days while the solar takes 8 days. In mechanical drier, the drying time decreases as the temperature increases (Jayashree et al., 2012).

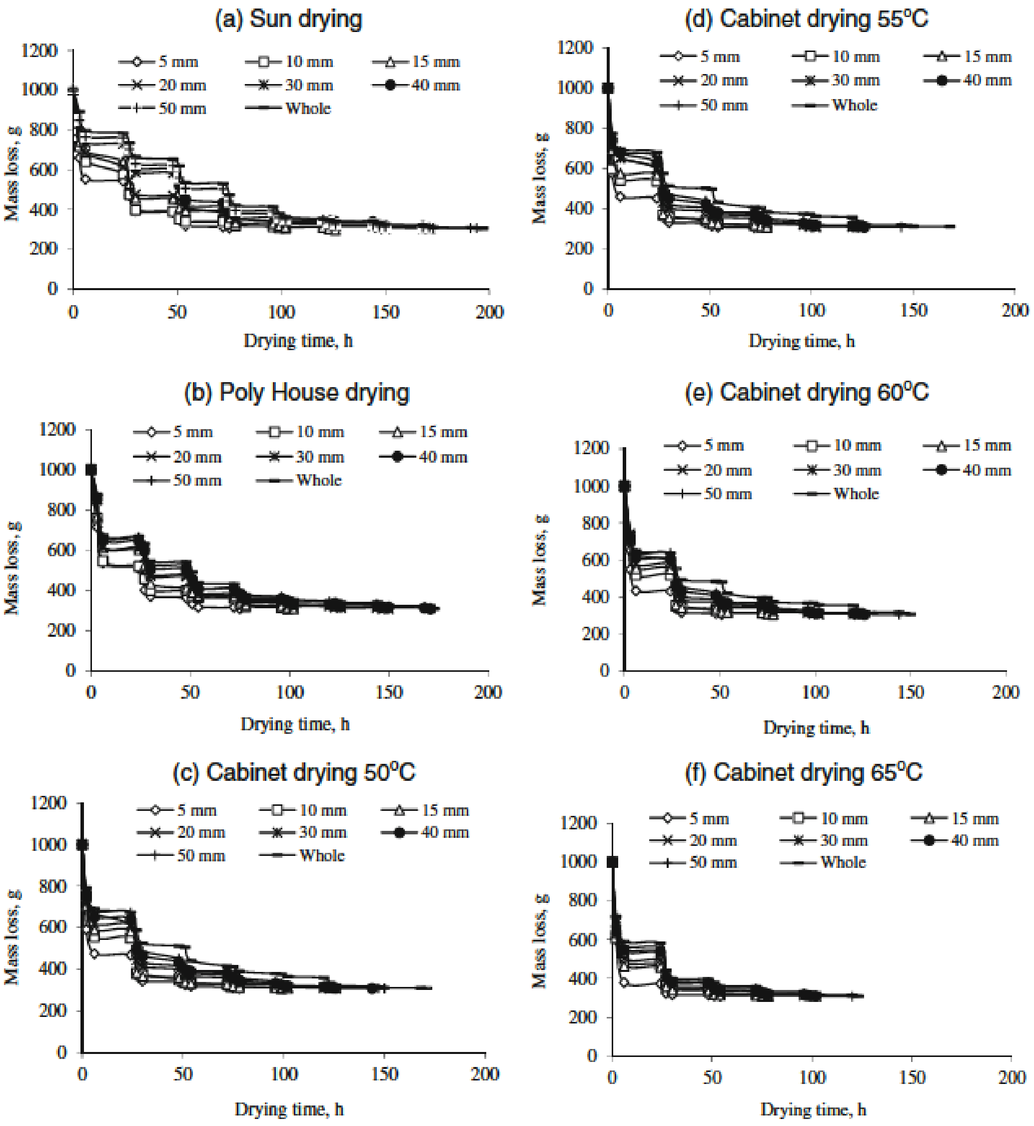


Figure 2.8 Drying characteristics of ginger slices by various drying methods (Jayashree et al., 2012).

2.4.4 Review on Thermal Properties and Effect of Moisture Content on the Thermal Conductivity of Agricultural Products

A thorough knowledge of the thermal properties of agricultural products is important to ensure a cost-effective and resourceful design of all food processing functions involving the transfer of heat. The traditional methods which cover thermal processes such as frying, drying, pasteurization, concentration, cooling, cooking, refrigeration, evaporation, thawing, freezing and heating are frequently used in food transportation, preservation operations and processing (Mahapatra et al., 2013). In addition to thermal properties of these products, the mechanisms and heat transfer rates are in addition very significant in the appropriate design of these procedures and or techniques. The thermal properties of agricultural produce are also important for the prediction and control of various changes occurring in foods during heat transfer processes associated with processing and storage (Fontana et al., 1999). The thermal conductivity of cassava, eggplant, ginger, green pepper, white radish and zucchini were studied under various conditions of moisture content (30 to 94% wb) and temperatures ($5^\circ\mathrm{C} - 40^\circ\mathrm{C}$) (Ali et al., 2002). They developed the changes of thermal conductivity from 0.552 - 0.477 $\frac{W}{m^\circ\mathrm{C}}$ for a change in moisture content from 91% to 62% (wb) and temperature from$6^\circ\mathrm{C}\ to\ 30^\circ\mathrm{C}$.

Ali et al. (2002) reported that moisture content is having vital effect on the thermal conductivity while the effect of temperature is negligible. Subsequently, as the moisture is having important effect on the thermal conductivity. Loha et al. (2012) proposed an equation to calculate the thermal conductivity of sliced ginger with moisture content in the following form:

$$k = 3.098 \times 10^{-006}(M^3) - 0.0004412(M^2) + 0.02294(M) - 0.02775 \qquad (2.46)$$

Figure 2.6a, b & c show variations of thermal conductivity and moisture content for different agricultural products.

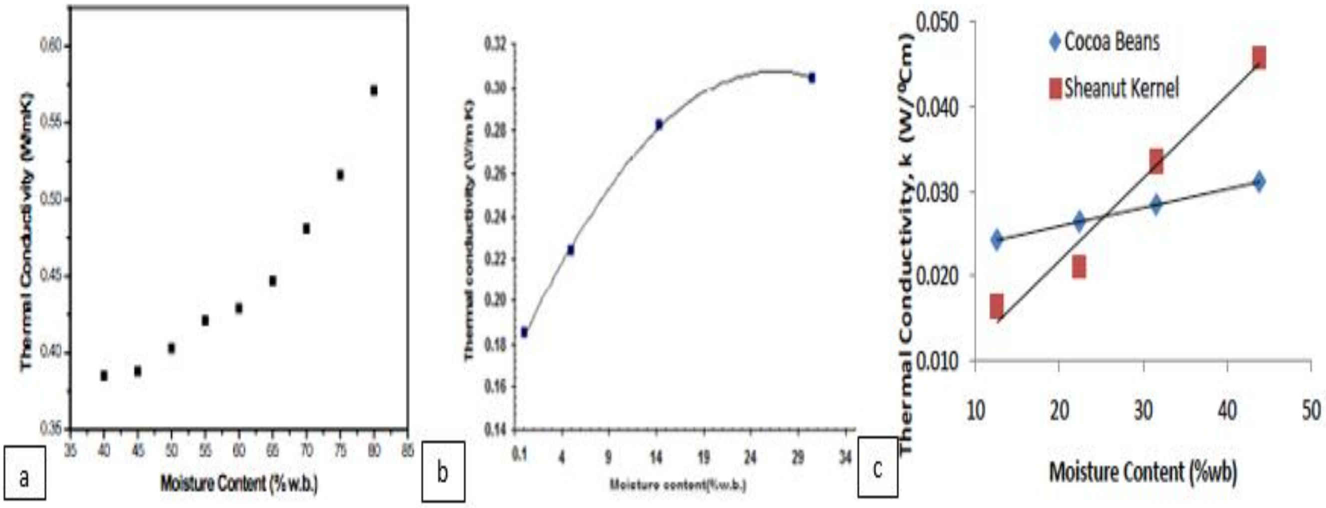


Figure 2.9 a) Thermal conductivity variation of sliced ginger with moisture content at 24℃ (Loha et al., 2012)b) Variation of thermal conductivity of sunflower seed with moisture content(Hosain & Mohammad, 2012) c) Thermal conductivity as a function of moisture content(Bart-Plange et al., 2012).

From figure 2.9, it would be observed that the thermal conductivity increased with decrease in the moisture content % wb. Such variation has been reported for the thermal conductivity of shea nut kernel (Aviara & Haque, 2000). Related trend was observed in the thermal conductivity of soybean (Deshpande et al., 1996), Cumin seed(Singh & Goswani, 2000), guna seed (Aviara et al., 2008), maize and cowpea (Bart-Plange et al., 2009), Melon (John et al., 2014), brown rice (Muramatsu et al., 2007), rough rice (Yang et al., 2003), millet grains(Subramanian & Viswanathan, 2003), and borage seed (Yang et al., 2002) illustrate that an increments in thermal conductivity with moisture content could be accredited to the fact that an increase in the moisture content of a sample increases the quantity of water molecules available to fill the pores within the sample thus increasing the ability of the sample to conduct more heat.

It is very uncommon to see farmers dry their produce without taking into consideration the quantity of heat needed to accomplish the drying process, which in turn affects the market value of the end product. This is because such information on thermal conductivity of local agricultural products is either inadequate or unavailable (Bart-Plange et al., 2012). Figure 2.7 shows that there is a linear relationship and increase of thermal conductivity with moisture content of all the samples shown in the graphs. Other researchers such as (Perusulla et al., 2010) for banana and (Kuroza et al., 2008) for papaya and cashew apple also purportedly assert the connection of the existence of linear relationship between thermal conductivity and moisture content. The thermal conductivity of the three samples shown in figure 2.10 increased progressively with an increase in moisture content (Isa et al., 2014).

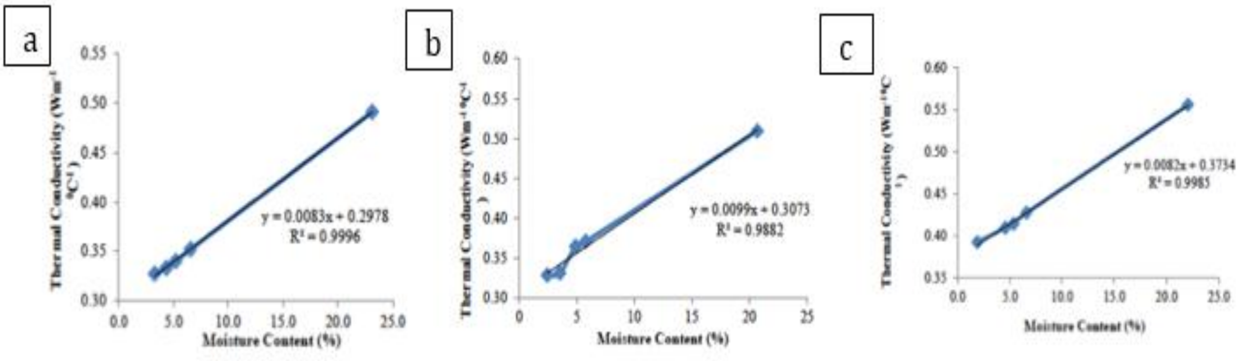


Figure 2.10 (a) Variation of Moisture Content with Thermal Conductivity of Cucumeropsis Mannii (b) Variation of Moisture Content with Thermal Conductivity of Colcynthis Citrullus (c) Variations of moisture content on thermal conductivity of Cucumis melo (Isa et al., 2014)

A comprehensive perception of the elements responsible for the decline in the quality ginger for the duration of the dehydration process is consequently of key significance. One of the vital physical transformations that the ginger suffers through dehydrating is the decrease of its exterior size. The loss of water and heating necessitates stresses in the cellular arrangement of the ginger accelerating a decrease in dimension and variations in shape. Food materials shrinkages have an undesirable concern on the quality of the dehydrated product. Shrinkage analysis of this product is beyond the scope of this research (Mayor & Sereno, 2004).

2.5 The Knowledge Gap in Earlier Investigations

The following knowledge gaps were identified from the literature survey conducted:

1. It is necessary to study the thin layer drying characteristics of ginger rhizomes using controlled environment (Shi et al., 2008).
2. It has been established that thin layer drying by heat convection is a challenging thermal process, additional requirement in the knowledge of the equilibrium characteristics is mandatory. The process entails a multiphase system going through concurrent structural and physical modifications (McMinn & Magee, 1999; Onu, 1998). Consequently, for precise understanding of this combined mass and heat transport process, physical property data and moisture transport characteristics are

necessary. This research investigation examines the thin layer drying for the preservations of the ginger rhizomes grown and produced in Nigeria

3. From existing literatures, no author(s) have developed any computer programme to predict and/or analyze the thin layer drying process of ginger rhizomes. In this study, a computer programme will be developed to address this challenge.
4. Thin layer drying equations, effect of moisture on the drying process and the determination of the seeming moisture diffusivities for ginger rhizomes has been discussed. This gave a clear picture on the factors that affect the drying of ginger rhizomes. Furthermore, the influence of temperature on the physical and chemical properties of ginger rhizomes was described to a minor degree. Several drying studies and investigations have been conducted on different agricultural products subjected to different drying types. Few studies have reported the thin layer drying characteristics of ginger rhizomes (Deshmukh *et al.*, 2014). Effect of physical and chemical factor variations on the efficiency of mechanical slicing of Nigerian ginger (Zingiber officinale) has also been investigated (Eze and Agbo, 2011;Hoque *et al.*, 2013; Ganesapillai et al., 2012;Onu and Okafor, 2003;Geta and Kifle, 2011). However, there are no studies on thin layer drying of ginger rhizomes by convective means and this study presents a unique opportunity for this research investigations.

CHAPTER THREE
MATERIALS AND METHODS

This chapter provides general details of the materials used and the methodologies followed throughout the research.

3.1 Materials

The Ginger rhizomes used in this study were gotten from Kachia in Soutnern Kaduna in Kaduna State of Nigeria and stored at room temperature before being used for the experimentations. Department of Soil Science and Land Resources Management, Faculty of Agriculture, Nnamdi Azikiwe University identified the ginger samples ascontained in Appendix G. The drying experiments were carried out at the Electronic Manufacturing Engineering Laboratory (ERMERG) Hawkes building, University of Greenwich. A brief explanation of methods is given in the succeeding sections.

The ginger rhizomes used for the experiment will be classified under:

- Blanched
- Unblanched
- Peeled
- Unpeeled

3.2 Sample Preparation

Blanched (cleanses the surface of dirts and organisms)

- Fill a large pot with water until half full. Put the pot on a stove, and turn the burner to heat. Add several shakes of salt to the water.
- Strip the ginger of its outer peel by running a knife vertically and horizontally.
- Turn off the burner when the water might have steamed, and put the ginger into the hot water for 3 minutes.
- Remove blanched ginger and drop them into ice cold water.
- Wait for another 3 minutes for the ginger to complete the blanching process. Remove the ginger and place on a paper towel linen plate to dry.

Unblanched

- Fresh unwashed ginger with water

Peeled

- Wash the ginger with water and peel
- Hold a piece of ginger and scrap its edge with a spoon to peel off the skin

Unpeeled

- Washed ginger kept unpeeled

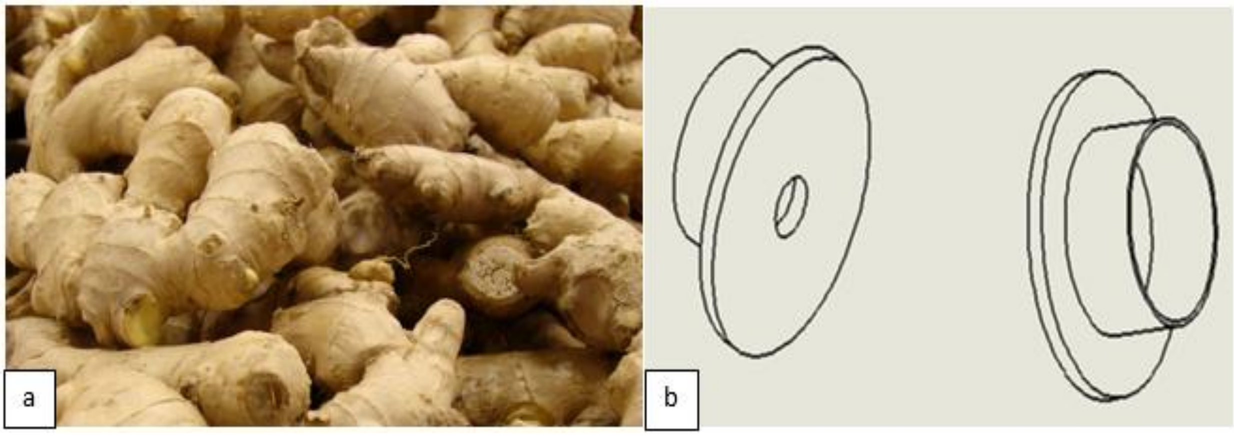


Figure 3.1: a) Raw materials for the experiments (Ginger Rhizomes) b) Device designed for the chopping of ginger rhizomes to the required sizes (18x30mm diameter) for the drying and conduction experiments

Figure 3.1a show some of the Ginger used for the experiment and Figure 3.1b shows the device used to chop the ginger rhizomes into slices.

3.3 Preliminary Scientific Examination Protocols

Proximate and phytochemical analyses of the test sample were conducted.

3.3.1 Moisture Content

Association of Official Agricultural Chemists (AOAC)

Procedure

A petri-dish was washed and dried in the oven

(i) Approximately 1-2g of the sample was weighed into petri dish

(ii) The weight of the petri dish and sample was noted before drying

(iii) The petridish and sample were put in the oven and heated at 105^0C for 2hrs, the result noted. It was heated another 1hr until a steady result is obtained and the weight was noted.

(iv) The drying procedure was continued until a constant weight was obtained including the % moisture content

$$\%\ Moisture\ Content = \frac{W_1 - W_2}{Weight\ of\ sample} X100 \qquad (3.1)$$

where W_1 = weight of petridish and sample before drying

W_2 weigh of petridish and sample after drying.

3.3.2 Carbohydrate Determination

(Differential method)

100 – (%Protein + %Moisture + %Ash + %Fat + %Fibre)

3.3.3 Ash content

(AOAC, 1984)

Principle: The ash of foodstuff is the inorganic residue remaining after the organic matter has been burnt away. It should be noted, however, that the ash obtained is not necessarily of the composition as there may be some from volatilization.

Procedures

(i) Empty platinum crucible was washed, dried and the weight was noted.

(ii) Approximately 1- 2g of sample was weighed into the platinum crucible and placed in a muffle furnace at 550^0C for 3 hours.

(iii) The sample was cooled in a dessicator after burning and weighed.

Calculations

$$\%\ \text{Ash content} = \frac{W_3 - W_1}{W_2 - W_1} X100 \qquad (3.2)$$

Where

W_1 = weight of empty platinum crucible

W_2 = weight of platinum crucible and sample before burning

W_3 = weight of platinum and ash.

3.3.4 Crude Fibre

Procedure :

1. Defat about 2g of material with petroleum ether (if the fat content if more than 10%)
2. Boil under reflux for 30 minutes with 200ml of a solution containing 1.25g of H_2SO_4 per 100ml of solution
3. Filter the solution through linen
4. Wash with boiling water until the items are no longer acidic.
5. Transfer the residue to a beaker and boil for 30 minutes with 200ml of a solution containing 1.25g of carbonate free NaOH per 100ml
6. Filter the final residue through a thin but close pad of washed and ignited asbestos in a Gooch crucible
7. Dry in an electric oven and weigh
8. Incinerate, cool and weigh

The loss in weight after incineration x 100 is the percentage of crude fibre.

$$\% \text{ crude fibre} = \frac{\text{Weight of fibre}}{\text{Weight of sample}} X100 \qquad (3.3)$$

3.3.5 Crude fat

Soxhlet Fat Extraction Method

This method is carried out by continuously extracting the food with non- polar organic solvent such as petroleum ether for about 1 hour or more.

Procedure:

1. Dry 250ml clean boiling flasks in oven at 105 - 110^{0}C for about 30 minutes.
2. Transfer into a dessicator and allow to cool
3. Weigh correspondingly labeled, cooled boiling flasks.
4. Fill the boiling flasks with about 300ml of petroleum ether (boiling point 40 - 60^{0}C)
5. Plug the extraction thimble lightly with cotton wool
6. Assemble the soxhlet apparatus and allow to reflux for about 6 hours
7. Remove thimble with care and collect petroleum ether in the top container of the set – up and drain into a container for re – use.

8. When flask is almost free of petroleum ether, remove and dry at 105^0C - 110^0C for 1hour.
9. Transfer from the oven into a dessicator and allow to cool; then weigh.

$$\%fat = \frac{wt\ of\ flask + oil - wt\ of\ flask}{Wt\ of\ sample} X100 \qquad (3.4)$$

3.3.6 Crude Proteins

(AOAC, 1984)

Principle: The method is the digestion of sample with hot concentrated sulphuric acid in the presence of a metallic catalyst. Organic nitrogen in the sample is reduced to ammonia. This is retained in the solution as ammonium sulphate. The solution is made alkaline, and then distilled to release the ammonia. The ammonia is trapped in dilute acid and then titrated.

Procedures

(i) Exactly 0.5g of sample was weighed into a 30ml Kjeldahl flask (gently to prevent the sample from touching the walls of the side of each and then the flasks were stoppered and shaken). Then 0.5g of the Kjeldahl catalyst mixture was added. The mixture was heated cautiously in a digestion rack under fire until a clear solution appeared.

(ii) The clear solution was then allowed to stand for 30 minutes and allowed to cool. After cooling was made up to 100ml. Distilled water was added to avoid caking then 5ml was transferred to the Kjeldahl distillation apparatus, followed by 5ml of 40% sodium hydroxide.

(iii) A 100ml receiver flask containing 5ml of 2% boric acid and indicator mixture containing 5 drops of Bromocresol blue and 1 drop of methlene blue were placed under a condenser of the distillation apparatus so that the tap was about 20cm inside the solution. Distillation commenced immediately until 50 drops get into the receiver flask, after which it was titrated to pink colour using 0.01N hydrochloric acid.

Calculations

% Nitrogen =Titre value x 0.01 x 14 x 4 (3.5)

% Protein = % Nitrogen x 6.25 (3.6)

3.3.7 Oxalate determination by Titration method

This determination involves three major steps digestion, oxalate precipitation, and permanganate titration.

Digestion

1. i) 2g of sample is suspended in 190ml of distilled water in a 250ml volumetric flask.
2. ii) 10ml of 6m HCl is added and the suspension digested at 100^0C for 1 hour.
3. iii) Cool, then make up to 250ml mark before filtration.

Oxalate precipitation

Duplicate portions of 125ml of the filtrate are measured into beakers and four drops of methyl red indicator added. This is followed by the addition of NH_4OH solution (dropwise) until the test solution changes from salmon pink colour to a faint yellow colour (pH4-4.5). Each portion is then heated to 90^0C, cooled and filtered to remove precipitate containing ferrous ion. The filtrate is again heated to 90^0C and 10ml of 5% $CaCl_2$ solution is added while stirring it constantly. After heating, it is cooled and left overnight at 25^0C. The solution is then centrifuge at 2500rpm for 5minutes. The supernatant is decanted and the precipitate completely dissolved in 10ml of 20% (v/v) H_2S0_4 solution.

Permanganate titration

At this point, the total filtration resulting from digestion of 2g of flour is made up to 300ml. Aliquot of 125ml of the filtrate is heated until near boiling and then titrated against 0.05M standardized $KMnO_4$ solution to a faint pink colour which persists for 30s. The calcium oxalate content is calculated using the formula

$$Calcium\ oxalate\ content = \frac{TX(Vme)(Df)X10^5}{(ME)XMf}\left(\frac{mg}{100g}\right) \qquad (3.7)$$

Where T is the titre of $KMnO_4$(ml), Vme is the volume-mass equivalent (i.e. 1ml of 0.05m $KMnO_4$ solution is equivalent to 0.00225g anhydrous oxalic acid). Df is the dilution factor Vt/A (where Vt is the total volume of titrate (300ml) and A is the aliquot used (125ml)), ME is the molar equivalent of $KMnO_4$ in oxalate ($KMnO_4$ redox reaction) and Mf is the mass of sample used (Harborne, 1993).

3.3.8 Alkaloids Determination

Five grams (5g) of the sample was weighed into a 250ml beaker and 200ml of 20% acetic acid in ethanol was added and covered and allowed to stand for 4 hours at 25^0C. This was filtered with filter paper No.42 (125mm) and the filtrate was concentrated using a water bath (Memmert) to one quarter of the original volume. Concentrated ammonium hydroxide was added dropwise to the extract until the precipitate was complete. The whole solution was allowed to settle and the precipitate was collected and washed with dilute NH_4OH (1% ammonia solution). Then, filter with pre-weighed filter paper. The residue on the filter paper is the alkaloid, which is dried in the oven (precision electrothermal model BNP 9052 England) at 80^0C. The alkaloid content was calculated and expressed as a percentage of the weight of the sample analyzed (Harborne, 1993; Obadoni and Ochuka, 2001).

Calculation:

$$\%\, weight\ of\ alkaloid = \frac{weight\ of\ filter\ paper\ with\ residue - weight\ of\ filter\ paper}{weight\ of\ sample\ analyzed} X100 \quad (3.8)$$

3.3.9 Flavonoids Determination

10g of the plant sample was extracted repeatedly with 100ml of 80% aqueous methanol at room temperature. The whole solution was filtered through whatmann filter paper No. 42. The filtrate was later transferred into a crucible and evaporated into dryness over a waterbath and weighed to a constant weight (Boham and Kocipai, 1994).

Calculation:

$$\%flavonoids = \frac{(Weight\ of\ crucible\ +residue\ )-(Weight\ of\ crucible\ )}{Weight\ of\ sample\ \ analyzed} X100 \qquad (3.9)$$

3.3.10 Determination of Saponin

Exactly 5g of the sample was put into 20% acetic acid in ethanol and allowed to stand in a waterbath at 50^0C for 24hours. This was filtered and the extract was concentrated using a waterbath to one-quarter of the original volume. Concentrated NH_4OH was added drop-wise to the extract until the precipitate was complete. The whole solution was allowed to settle and the precipitate was collected by filtration and weighed. The saponin content was weighed and calculated in percentage (Obadoni and Ochuko, 2001).

Calculation:

$$\%\, saponin\ content = \frac{(weight\ of\ filter\ paper + residue) - (weight\ of\ filter\ paper)}{weight\ of\ sample\ analyzed} X100 \qquad (3.10)$$

3.3.11 Cardiac Glycosides Determination

Wan g and Filled method was used. 1ml of extract was added to 1ml of 2% solution of 3,5-DNS (Dinitro Salicylic acid) in methanol and 1ml of 5% aqueous NaOH. It was boiled for 2minutes (until brick-red precipitate was observed) and the boiled sample was filtered. The weight of the filter paper was weighed before filtration. The filter paper with the absorbed residue was dried in an oven at 50^0C till dryness and weight of the filter paper with residue was noted. The cardiac glycoside was calculated in %.

Calculation:

$$\%\, cardiac\ glycoside = \frac{(weight\ of\ filter\ paper + \ residue) - (weight\ of\ filter\ paper)}{weight\ of\ sample\ analyzed} X100 \qquad (3.11)$$

3.3.12 Tannin Determination by Follins Dennis Titration

The follinsdennis titrating method as described by pearson (1974) was used. To 20g of the crushed sample in a conical flask was added 100mls of petroleum ether and covered for 24hours. The sample was then filtered and allowed to stand for 15 minutes allowing petroleum ether to evaporate. It was then re-extracted by soaking in 100ml of 10% acetic acid in ethanol for 4hrs. The sample was then filtered and the filter ate collected.

25ml of NH_4OH were added to the filter ate to precipitate the alkaloids. The alkaloids were heated with electric hot plate to remove some of the NH_4OH still in solution. The remaining volume was measured to be 33ml. 5ml of this was taken and 20ml of ethanol was added to it. It was titrated wit h 0.1M Na0H using phenolphthalyneasndicator until a pink end point is reached. Tannin content was then calculated in % ($C_1V_1 = C_2v_2$) molarity.

Calculation

Data

C_1 = conc. of Tannic Acid

C_2 = conc. Of Base

V_1 = Volume of Tannic acid

V_2= Volume of Base

Therefore $C_1 = \frac{C_2V_2}{V_1}$ (3.12)

% of tannic acid content =$\frac{C_1\ X\ 100}{weight\ of\ sample\ \ analyzed}$ (3.13)

3.3.13 Phytate Determination

Phytate contents were determined by using the method of Young and Greaves (1940) as adopted by LucasMarkakes (1975). 0.2g of each of the differently processed corns was weighed into different 250ml conical flasks. Each sample was soaked in 100ml of 2% concentrated HCL for 3hr, the sample was then filtered. 50ml of each filtrate was laced in 250ml beaker and 100ml distilled water added to each sample. 10ml of 0.3% ammonium thiocynate solution was added as indicator and titrated with standard iron (111) chloride solution which contained 0.00195g iron per 1ml.

$$Phytic\ acid = \frac{Titre\ \ value\ \ X\ 0.00195\ X\ 1.19}{Wt\ of\ sample}\ X\ 100 \qquad (3.14)$$

3.3.14 Phenol Determination

The quantity of phenol is determined using the spectrophotometer method. The plant sample is boiled with 50ml of $(CH_3CH_2)_20$ for 15min. 5ml of the boiled sample is then pipetted into 50ml flask, and 10ml of distilled water is added. After the addition of distilled water, 2ml of NH_4OH solution and 5ml of concentrated $CH_3(CH_2)_3CH_2OH$ is added to the mixture. The samples is made up to the mark and left for 30min to react for colour development and measured at 505nm wavelength using spectrophotometer.

3.3.15 HeamaglutininDetermination:

Two gram of each of the sample were added 20ml 0f 0.9% NaCL and suspension shaken vigorously for 1minute and the supernatants were left to stand for 1hr. The sample were then centrifuged at 2000 rpm for 10min and the suspension filtered. The supernatants in each were collected and used as crude agglutination extract. Absorbance read at 420nm.

3.3.16 Cynogenic Glycoside

Acid Titration Method

(i) Place 10 -20 sample, ground to pass N0.20 sieve, in 800ml Kjeldahl flask, add 100ml H_2O.

(ii) Macedrate at room temperature for 2hours.

(iii) Add 100ml of H_2O and steam distill, collecting distillate in 20ml 0.02N $AgNO_3$ acidified with 1ml HNO_3. Before distillation adjust appropriately, so that tip of condenser dips below surface of liquid in receiver.

(iv) When 150ml has passed over, filter distillate through gooch wash receiver and gooch with little H_2O.

(v) Titrate excess $AgNO_3$ in combined filtrate and washings with 0.02N KCN, using Fe alum indicator. 1ml 0.02N $AgNO_3$ = 0.54mg HCN.

3.3.17 Trypsin inhibitor

Extraction of sample

i. Weigh out about 1.0g of the test sample and disperse in 50ml of 0.5m NaCl solution.

ii. Stir the mixture for 30min at room temperature and centrifuge

iii. Filter the supernatant

iv. The filterate is used for the assay

Procedure

1. To 10ml of the substrate in a test tube add 2ml of the standard trypsin solution
2. Prepare a blank of 10ml of the same substrate in a test tube but with no extract added
3. Allow the content of test tube to stand for at least 5min and measure spectrophotometrically at 410nm wavelength.

$$TIU/_{mg} = \frac{\text{absorbance of sample X conc of standard}}{\text{Absorbance of standard}} \tag{3.15}$$

3.4 Methods

Thin layer drying was conducted at different conditions. The relative humidity of the heating chamber and the heat transfer coefficients were measured simultaneously during the experiments. The results obtained for the dried gingers were compared in terms of their response to heat by convection and their thermal conductivity.

The Temperature and humidity chamber installed at the Hawke building, University of Greenwich was used for the drying of the ginger rhizomes at temperatures of 10°C - 60°C for drying times of 2, 4, 8, 10, 14, 18 and 24 hours and the Linear Heat Conduction Experiment was used to measure the thermal conductivity of the sample. The ginger were cut into slices of 30mm diameter and 18mm thickness by scoopers designed for this purpose. The moisture content will be determined by using the formula in equation 3.1.

3.4.1 Equipment and Operating Principles

i. Description of ARS-0680 Temperature and Humidity Chamber

ESPEC's ARS-0680 Environmental Humidity and Temperature Chamber as shown in figure 3.2 is used for heating specimen at low or high temperature in controlled humidity. The ESPEC's ARS-0680 Environmental Humidity and Temperature chamber has the following features:

- Internal dimension of W850 x H1000 x D800 and an External dimension of W1050 x H1955 x D1805

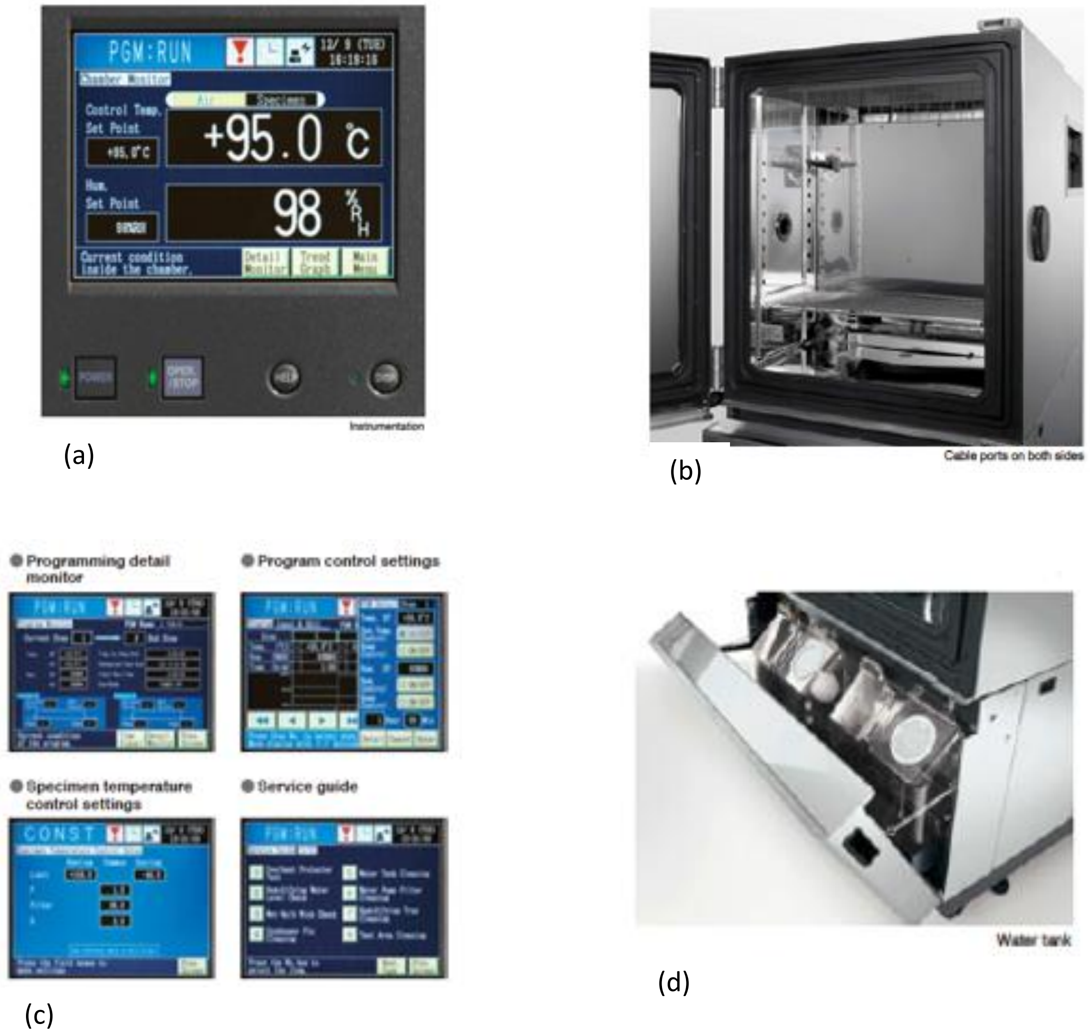
- Operating temperature ranging from$-\mathbf{73}$℃ $\mathbf{to} + \mathbf{180}$℃ $(-\mathbf{103}$℉ $\mathbf{to} + \mathbf{356}$℉$)$
- Temperature function of 0.3K
- Temperature deviation in space of ±1.5K
- Temperature gradient of 3.0K
- Rate of Temperature change 6.0K/min or more while heating and
- Rate of Temperature of change 4.2/min or more while cooling.

ESPEC's Environmental Stress Chambers can withstand heat loads produced by the specimen, improve temperature change rates, and provide expanded ranges for temperature and humidity.

Each chamber is also equipped with a specimen temperature control function to meet stringent testing demands typically required for automotive parts and mobile products (ESPEC, 2015).

The ginger used was cut into slices of 30mm diameter and 18mm thickness by scoopers designed for this purpose and are prepared as Blanched, Unblanched, Peeled and Unpeeled as previously described at a temperature of 10^0C - 60^0C for drying time of 2 and 24 hours and the Linear Heat Conduction Experiment was used to measure the thermal conductivity of the sample.

The temperature and humidity chamber installed at the Hawke building, University of Greenwich was used for the drying of the ginger rhizomes at a minimum temperature of 10^0C; maximum temperature of 60^0C and resident time of 10 minutes starting at a room temperature (RT) of 24^0C in the environmental chamber. A total of 16 samples were placed in the environmental chamber which was programmed to run for 2 to 10hours initially. However, at the end of every cycle, a sample would be retrieved from the environmental chamber for analysis and measurement to evaluate the percentage moisture content and its thermal conductivity using the TD1002A - Linear Heat Conduction Experiment Unit shown in figure 3.3a. Humidity test was totally ignored in this project, as it is not one of the objectives to meet in this study. Figure 3.2 shows the ESPEC's ARS-0680 Environmental Humidity and Temperature Chamber used in the laboratory for this research project.



(a) (b) (c) (d)

Figure 3.2: ARS – 0680 Temperature and Humidity Chamber (ESPEC, 2015)

ii. Methodology of ARS-0680 Temperature and Humidity Chamber

TD1002A - Linear Heat Conduction Experiment

Description of Conduction Equipment – TD1002A

This equipment for Linear Heat Conduction Experiment shown in fig 3.3 (TD1002A) has a wooden bar of circular cross-section made up of two sections with an interchangeable middle section. It is mounted on a base plate with a clear schematic of the experiment layout. The first brass section includes three thermocouples and the electric heater (heat source). The second brass section includes a small water-cooled chamber (heat sink) and three more thermocouples. The interchangeable middle section was manufactured with wood by the author to prevent heat loss during the experiment. Each middle section has a thermocouple. The electric heater and thermocouples connect to sockets on the Heat Transfer experiments base unit, which also supplies the cold water feed and drain for the heat sink. The cooling water flow is turned on and the heater power turned on until the materials attained temperature equilibrium, the temperature was then recorded along the bar. Insulation around the bar reduces heat loss by convection and radiation, so that the results should match the theory for linear conduction. A power of 20Watts would be used throughout the experiment as the cylinder is supplied with this power output. The diameter of the ginger rhizomes chopped out from the gingers supplied were 30mm in diameter and 18mm in thickness. Figure 3.3 shows the set-up of this equipment (Tecquipment, 2015).

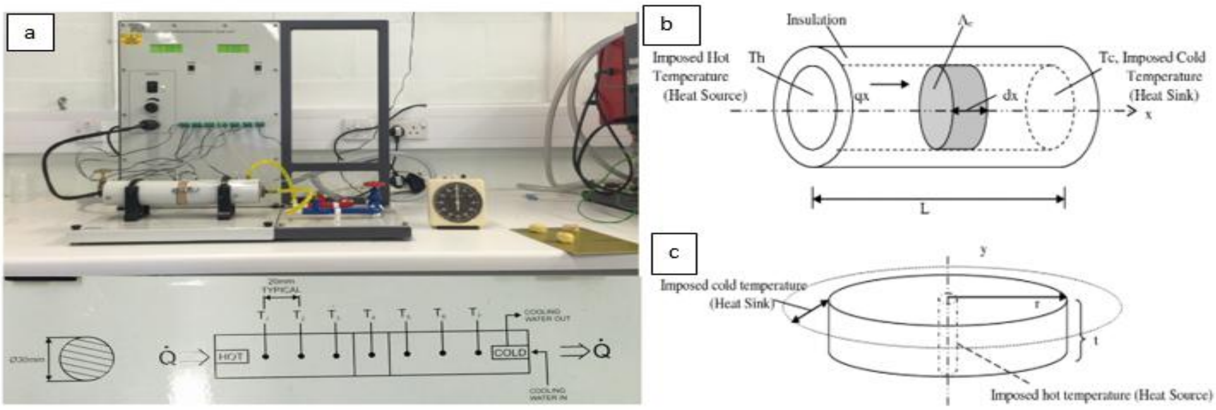


Figure 3.3 a) TD1002A - Linear Heat Conduction Experiment Unit (LHTEU) with TD1002 Heat Transfer Experiments Base Unit (tecquipment, 2015)(UoG Laboratory/Workshop, 2015) **b & c) Diagram for heat conduction along a well-insulated cylindrical rod.**

3.4.2 The Linear Heat Conduction Experiment procedure

- The room temperature was initially measured.
- The clip located in the middle of the insulated wooden rod (cylinder) is opened and the ginger rhizomes inserted if any is removed.
- Thermal paste was applied between the adjacent faces of the wooden material to reduce temperature gradient across the joints and insert the ginger rhizomes into the central section and then insert it into the middle of the cylinder.
- The main water supply was opened. The red valve is completely opened for water inlet to the cylinder.
- The power supply and the control board are switched on.

- The heater is switched on and set it to 20Watts.
- The initial temperatures of the thermocouples $\boldsymbol{T_1}, \boldsymbol{T_2}, \boldsymbol{T_3}, \boldsymbol{T_4}, \boldsymbol{T_5}, \boldsymbol{T_6},$ and$\boldsymbol{T_7}$ were measured.
- The temperature of the thermocouples at different time range were subsequently also measured.
- After the temperature measurements, the heater control was turned to zero; the heater, the control board and the main power supply were switched off. After waiting for approximately five (5) minutes for the temperature of the water in the cylinder to cool down, the red valve and main water supply were turned off

3.4.3 The Ginger Drying Experiment Procedure

The Ginger Drying experiment was conducted according to ASAE Standard S352.2. Before the experiment started, the whole apparatus was operated for at least 15-30 minutes to stabilize the humidity, air temperature and velocity in the dryer. Drying started at 08:00am and continued until the specimen reached the final moisture content at time set for the experiment. The weight losses of the sample in the environmental chamber were recorded during the drying period of 2 and 24 hours with electronic balance (EK-200g, Max 200±0.01g). After the end of drying, the dried sample was collected for the measurement of its’ thermal conductivity using the linear heat conduction equipment.

3.5 Determination of Moisture Contents

Gingers are known for their high initial moisture content in comparison with other agricultural farm produce and the calculation of initial moisture content is a very important characteristic as it affects the dehydration process directly(Cletus, 2007;Eze & Agbo, 2011).In addition, the preliminary moisture content is also essential for demonstrating the drying procedure. The limit is around 87.98% and 84.97% moisture content (wet basis) to 75.73% and 68.70% (wet basis) under blanched condition and to the moisture content 81.98 % (wb) and 77.46% (wb) under non blanched condition after 20 hours in solar dryer at 50°C to 60°C respectively(Hoque *et al.*, 2013). Split ginger rhizomes dried from initial moisture content of 87.98% (wb) to 22.54% and 32.96% (wb) under blanched and unblanched conditions for 32 hours at 50°C. This implies that the drying rate of ginger rhizomes increases with an increase in drying temperature(Hoque *et al.*, 2013). Hence in this study, the initial moisture content and the moisture content determination at different time phases are an essential part of this investigation. In this study, the moisture content dry basis were considered for the calculation of the Moisture ratios (MR) using the relationship discussed in section 2.9.

3.5.1 Procedure for the Determination of Moisture Content

1. The initial mass of the ginger sample was recorded using 0.00001g “Analytical Plus Electronic Balances” in figure 3.4b.
2. The ginger was placed into an environmental chamber at constant temperature of 10°C - 60°C for a time period of 2 and 24 hours.
3. Then the mass of the dried ginger samples was recorded for the time periods 2 and 24 hours.
4. Mass of the ginger samples was examined regularly till they reached an equilibrium value (Final mass).
5. Moisture content of the ginger was computed.

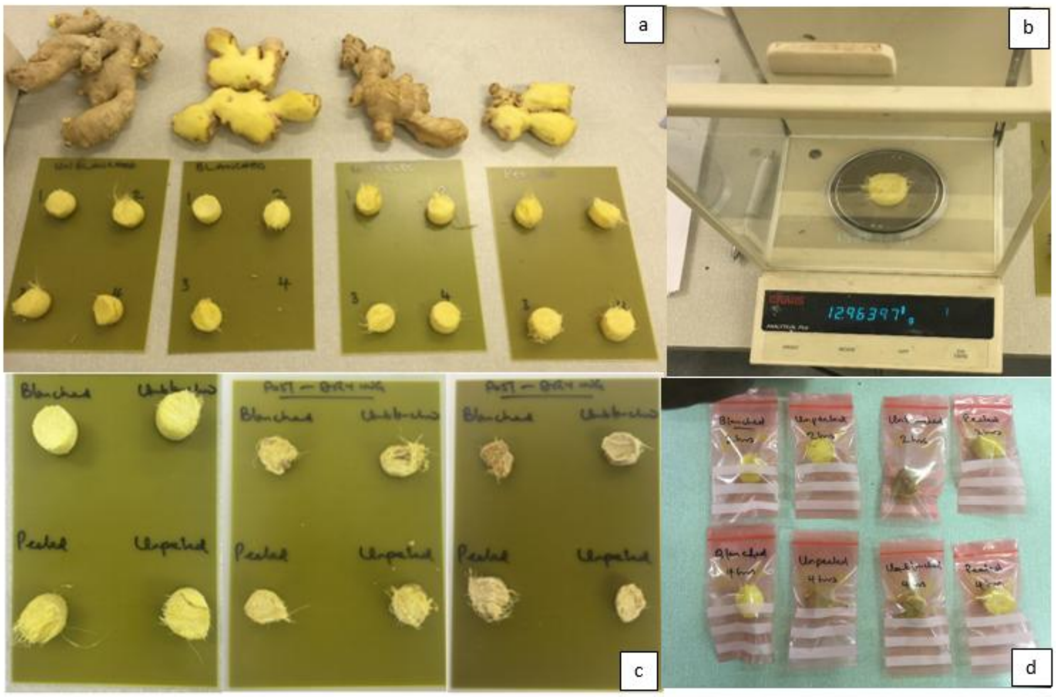


Figure 3.4 Pictures of ginger samples (a) Freshly prepared ginger samples (b) Analytical plus Electronic Balances by Ohaus for measurement of samples (UoG Laboratory/Workshop, 2015)(c) Samples after 14-24 hours and 50℃ - 60℃ (d) Bagged ginger samples after drying.

3.5.2 Determination of Thermal Conductivity

Thermal conductivity is the ability of a material to conduct heat, and it represents the quantity of thermal energy that flows per unit time through a unit area with a temperature gradient of 1° per unit distance (Vengatesan *et al.*, 2018). Thermal conductivity is dependent on the following factors:

- Material structure
- Moisture content
- Density of material
- Pressure and temperature (operating conditions)(Netzsch, 2015)

Figure 3.5 shows the thermal conductivity of some materials and figure 3.6 shows dried and ground (powdered) ginger rhizomes, dried with moisture content of over 91% and thermal conductivity of 0.0503W/m. K

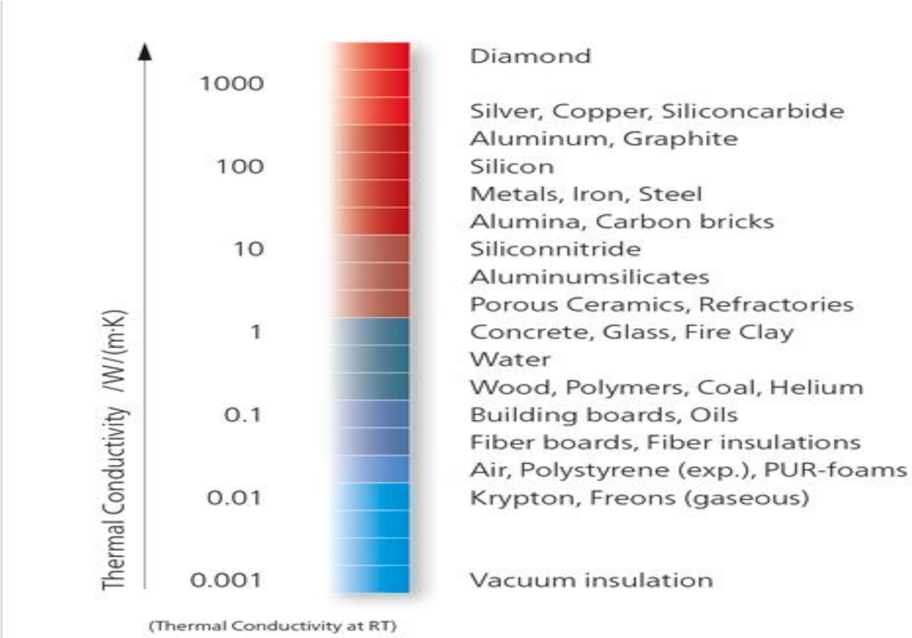


Figure 3.5 Thermal conductivity – insulation materials are characterized by low values, metals by high values. Diamond has the highest thermal conductivity (Netzsch, 2015)

The thermal conductivity is mathematically expressed as:

$$k = \frac{QL}{A\Delta T} \tag{3.16}$$

where

$k = Thermal\ conductivity\ (\frac{W}{mK})$

$Q = Amount\ of\ heat\ transfered\ \ through\ the\ material\ \left(\frac{J}{s}\right) or\ (Watts)$

$\Delta T = Change\ in\ temperature\ (℃\ or\ K)$

$L = Distance\ between\ T_i - T_j\ (m)$

$A = Cross - sectional\ area\ (m^2)$

Figure 3.6 Powdered ginger rhizomes with Thermal Conductivity of 0.0503W/m.K

3.6 Development of Computer programme for Analysing the Ginger Drying

A computer programme was developed in MATLAB for analysing the drying of the ginger rhizomes. The detailed programme is shown in the Appendix D.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter gives a detailed explanation of the experimental results. Both the preliminary scientific examination and the main results are presented. The discussions are presesented alongside with results. Also graphs are used for comparisons and elucidation of results.

4.1 Result of Preliminary Scientific Examination of Ginger (Zingiber Officinarum Roscoe)

Preliminary scientific examinations were conducted to ascertain the proximate and phytochemical composition of the test sample. The promate analysis is presented in table 4.1 while the phytochemical result is presented in table 4.2.

Table 4.1 Proximate Analysis of Ginger-(Zingiber Officinarum Roscoe)

	Nutritional Composition (%)					
Conc (%)	**Moisture Content**	**Ash Content**	**Fat Content**	**Fibre Content**	**Protein Content**	**Carbohydrate Content**
1st	30.3	5.963	3.2	3.648	7.7	49.186
2nd	30.348	6.338	3.4	3.053	8.05	48.811
Mean	30.326	6.16	3.3	3.36	7.88	48.998

Table 4.1 reported the proximate composition of the plant for the study Ginger (Zingiber Officinarum Roscoe), analyzed were moisture, ash, fat, fiber, protein and carbohydrate composition. The macromolecule that recorded the highest concentration was carbohydrate with 49%, while that having the least concentrate was fat with 3.3%. In order of decreasing concentration, we had carbohydrate, moisture, protein, ash, fiber and fat. Very important to the project work is the moisture content of this plant which is a little over 30%. This represents the substance with the second highest concentration in the ginger. The high moisture content of ginger makes it imperative that adequate drying should be carried out to avoid its decay and rancidity which may affect the medicinal value. Fat which is another macromolecule that can bring about rancidity of the finished product is the least in concentration (a little over 3%). This does not pose serious threat because drying to the appropriate temperature will also

take care of fatty content. With this high concentration of moisture (30%) the need to dry to suitable temperature to avoid rancidity and putrefaction of the medicinal value is absolute.

Table 4.2 Phytochemical Examination of the Research material Ginger-(Zingiber Officinarum Roscoe)

	Phytochemical Content									
Conc (%)	**Flavonoid**	**Alkaloid**	**Tannin**	**Phytate**	**Cardiac Glycoside**	**Heamaglutinin**	**Cyanogenic Glycoside**	**Trypsin Inhibitor**	**Saponin**	**Steroid**
1st	3.5	4.05	13.5	3.25	6.5	3.02	4.184	36.6	6.2	11.028
2nd	3.54	4.1	13.4	3.13	6.6	3.06	4.968	30.4	5.9	11.188
Mean	3.52	4.08	13.5	3.19	6.6	3.04	4.576	33.5	6.1	11.108

Table 4.2 report the phytochemical composition of the plant for the study Ginger (Zingiber Officinarum Roscoe) phytochemical encountered in decreasing concentration were as follows: Trypsin inhibitor (33.5%). Tannin (13.5%), Steroids (11.11%) Cardiac glycoside (6.6%) Saponin (6.1%) Cyanogenic glycoside (4.58%) Alkaloid (4.08%) Flavonoid (3.52%) Phytate (3.19%) and Heamaglutinin (3.04%). From Table 4.2, the presence and concentration of phytochemical which are the bed rock of the medical plant particularly steroids, Saponin, cardiac Glycoside, Tannin and Alkaloids is relatively significant. The compositions of ginger indicate that it has medicinal as well as culinary benefits. Ginger has proven to be a good herbal remedy.

4.2 Experimental Results and Drying Curves at Various Drying Temperatures

Appendix B shows the detailed calculations for these values in tabular form. Tables 4.3-4.26 show the experimental results obtained during the whole experiments. This study investigated two important features of thin layer drying of ginger rhizomes slices:

1. moisture content characteristics
2. thermal conductivity of each sample at varying drying time and temperature using the linear heat conduction's experimental unit in a convective chamber.

Experimental drying curves at various conditions were employed to study the drying characteristics of ginger rhizomes. Drying curves were studied for time period of 2 – 24hours for an average moisture content varying from 11.26% (wet basis) at 10°C to final moisture content of 94.02% (wet basis) at 60°C. The samples were then used to determine the individual thermal conductivity content for the product. The research also investigated the influence of moisture ratio on the thermal conductivity with time.

4.2.1 Experimental Results at Temperature of 10℃

Table 4.3 shows the results obtained for moisture ratios and thermal conductivity of the unblanched and peeled ginger at a drying temperature of 10°C

Table 4.3 Table of moisture ratio (%) and thermal conductivity (W/m. K) at drying temperature of 10℃

Unblanched				**Peeled**			
Sample S/Nos.	Time (Hour)	Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	88.64	0.4064	1	2	88.74	0.3768
2	4	84.75	0.3188	2	4	82.95	0.3004
3	8	78.28	0.2657	3	8	77.29	0.2623
4	10	73.67	0.2303	4	10	63.58	0.2115
5	14	65.22	0.1834	5	14	60.65	0.1919
6	16	51.1	0.1727	6	16	57.47	0.1658
7	24	49.55	0.1607	7	24	55.91	0.1449
Blanched				**Unpeeled**			
Sample S/Nos.	Time (Hour)	Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	84.58	0.3290	1	2	91.08	0.3397
2	4	78.58	0.2878	2	4	83.91	0.3093
3	8	63.21	0.1993	3	8	82.07	0.2657
4	10	62.45	0.1901	4	10	73.41	0.2329
5	14	53.42	0.1699	5	14	68.77	0.2205
6	16	47.02	0.1558	6	16	64.68	0.2093
7	24	41.13	0.1400	7	24	62.22	0.1713

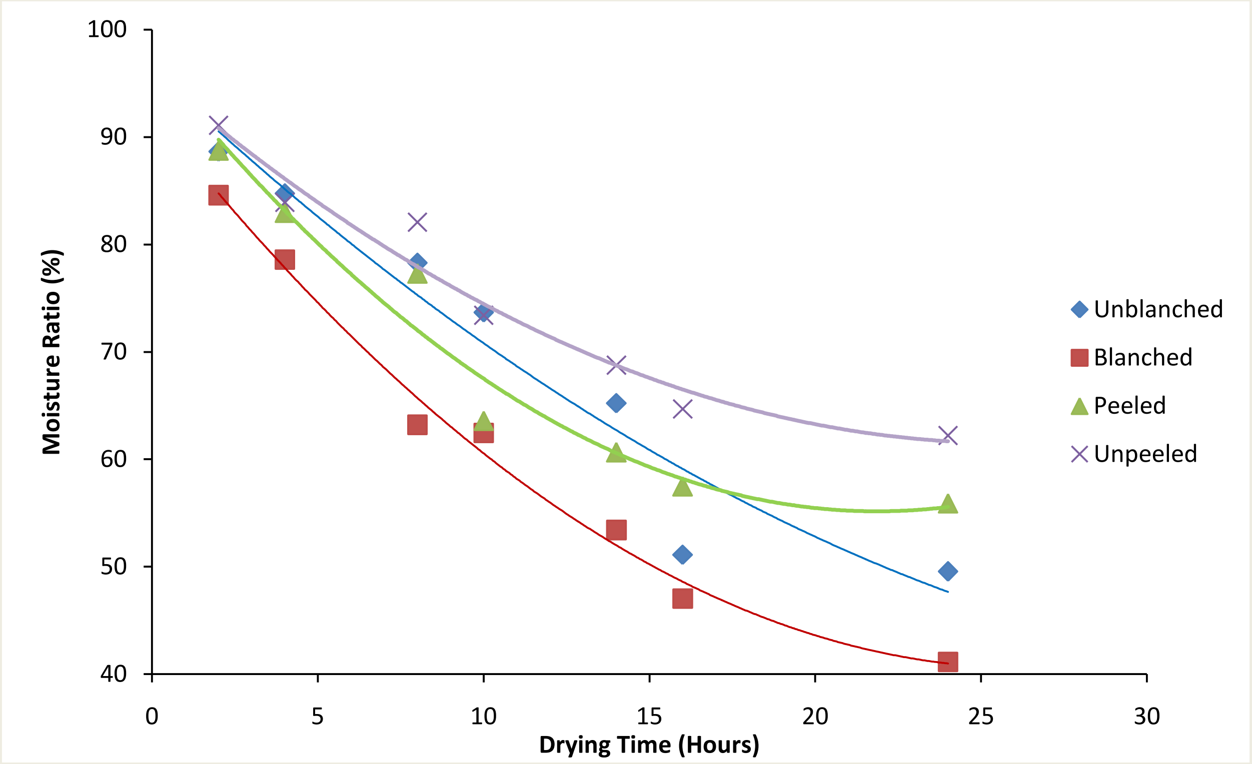


Figure 4.1 Drying Curve of Variation of Moisture Ratio with Drying Time at 10^0C

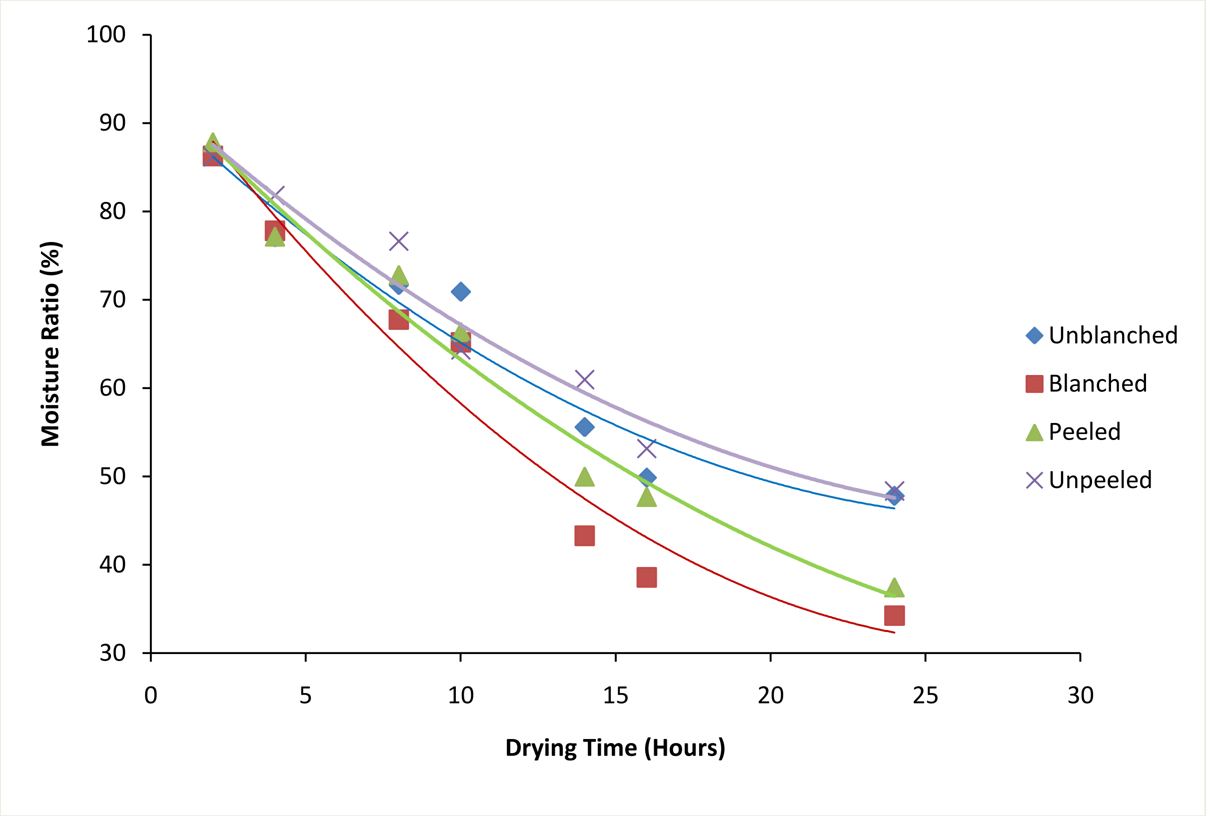
Figure 4.1, drying curves show the variation of moisture ratio with drying time at temperature of 10°C for variously treated ginger samples. The unblanched ginger sample had moisture ratio of about 88.64% before drying commenced, it lost moisture smoothly untill 14hours (constant rate period) where the moisture ratio reduced to 65.22%. It then drop abruptly to 51.1% within two hours (falling rate period) and continued dropping till 24hours. The blanched ginger sample had an initial moisture ratio of 84.58%, it lost moisture gradually till the end of the drying process with final moisture ratio of 41.13%. It lost about 43.45% of moisture within twenty four hours. Peeled and unpeeled treated samples lost 32.87% and 28.86% of moisture respectively within the twenty four hours of drying. From figure 4.1, it could be deduced that blanched ginger sample lost highest amount of moisture with time while unpeeled lost least amount of moisture within the drying duration. Generally, the moisture ratio decreases with time for the variously treated ginger samples.

4.2.2 Experimental Results at Temperature of 20℃

Table 4.4 shows the results obtained for moisture ratios and thermal conductivity of the unblanched and peeled ginger at a drying temperature of 20°C

Table 4.4 Table of moisture ratio (%) and thermal conductivity (W/m. K) at drying temperature of 20℃

Unblanched				**Peeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	86.35	0.4064	1	2	87.85	0.3768
2	4	77.07	0.3188	2	4	77.18	0.3238
3	8	71.67	0.2382	3	8	72.83	0.2839
4	10	70.92	0.1974	4	10	66.39	0.2115
5	14	55.60	0.1901	5	14	50.00	0.1818
6	16	49.87	0.1658	6	16	47.71	0.1594
7	24	47.81	0.1491	7	24	37.49	0.1391
Blanched				**Unpeeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	86.29	0.2919	1	2	86.17	0.3454
2	4	77.81	0.2527	2	4	81.82	0.3343
3	8	67.75	0.2228	3	8	76.63	0.2839
4	10	65.19	0.1742	4	10	64.34	0.2329
5	14	43.29	0.1570	5	14	60.97	0.2205
6	16	38.58	0.1449	6	16	53.16	0.1802
7	24	34.26	0.1312	7	24	48.36	0.1713



Fgure 4.2 Variation of Moisture Ratio with Drying Time at 20^{0}C

Figure 4.2 presents the variation of moisture ratio of variously treated ginger sample with drying time at temperature of 20°C. All the samples had almost the same initial moisture ratio of about 86%. Unblanched treated ginger sample lost about 38.54% of moisture, blanched treated sample lost about 52.03%, peeled treated sample lost about 50.36% and unpeeled treated sample lost about 37.81%. As previously observed at drying temperature at 10°C, also at drying temperature of 20°C blanched treated ginger sample lost the highest amount of moisture and unpeeled treated ginger sample lost the least amount of moisture.

4.2.3 Experimental Results at Temperature of 30℃

Table 4.5 shows the results obtained for moisture ratios and thermal conductivity of the unblanched and peeled ginger at a drying temperature of 30°C

Table 4.5 Table of moisture ratio (%) and thermal conductivity (W/m. K) at drying temperature of 30℃

Unblanched				**Peeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	87.34	0.1074	1	2	87.95	0.1459
2	4	80.81	0.0996	2	4	80.12	0.1132
3	8	76.18	0.0987	3	8	74.83	0.0909
4	10	72.15	0.0955	4	10	66.33	0.0776
5	14	47.60	0.0809	5	14	45.73	0.0715
6	16	45.05	0.0785	6	16	38.35	0.0693
7	24	39.55	0.0677	7	24	27.76	0.0652
Blanched				**Unpeeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	86.65	0.1006	1	2	87.71	0.1126
2	4	78.52	0.0913	2	4	81.89	0.1021
3	8	65.23	0.0810	3	8	74.17	0.0810
4	10	62.35	0.0800	4	10	68.97	0.0740
5	14	30.50	0.0761	5	14	48.42	0.0658
6	16	24.49	0.0732	6	16	43.42	0.0630
7	24	17.48	0.0689	7	24	31.15	0.0611

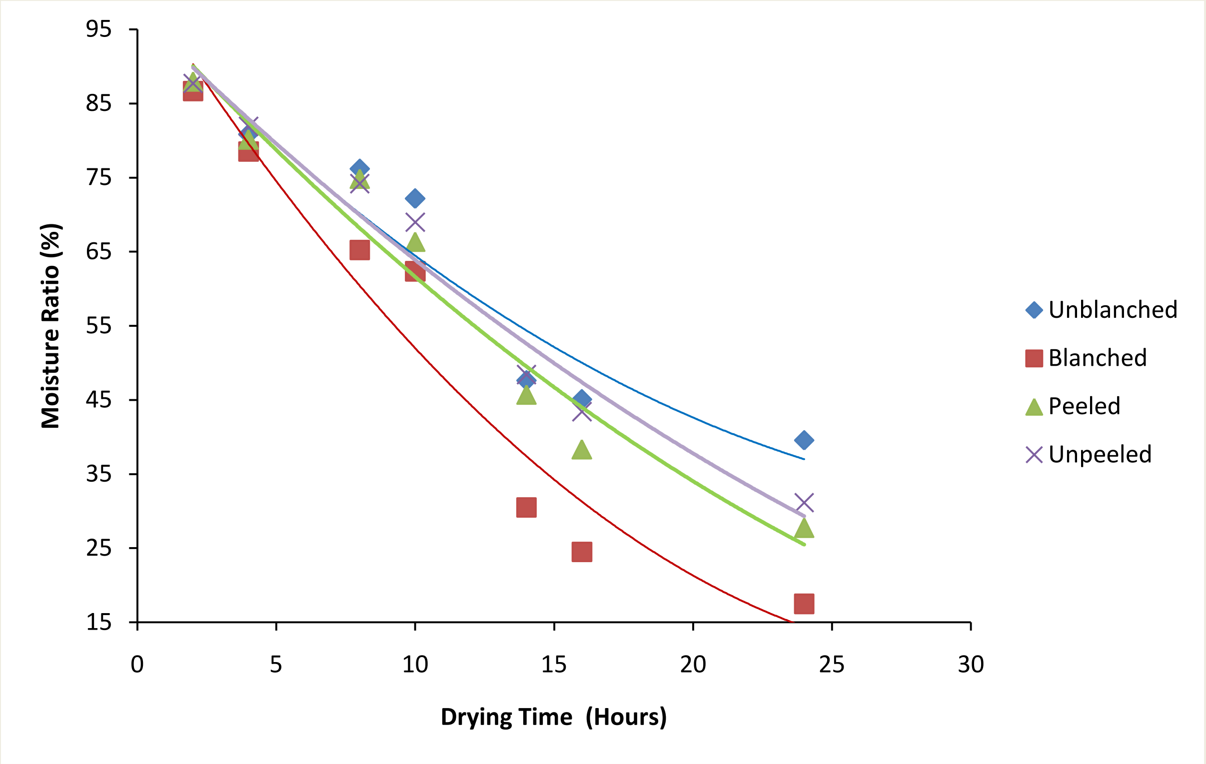


Figure 4.3 Variation of Moisture Ratio with Drying Time at 30^{0}C

Figure 4.3 presents the variation of moisture ratio of variously treated ginger sample with drying time at temperature of 30°C. All the samples had almost the same initial moisture ratio of about 87%. Unblanched treated ginger sample lost about 47.79% of moisture, blanched treated sample lost about 69.17%, peeled treated sample lost about 60.16% and unpeeled treated sample lost about 56.56%. The blanched treated ginger sample has the highest amount of lost while the unblanched treated ginger sample has the least amount of lost.

4.2.4 Experimental Results at Temperature of 40℃

Table 4.6 shows the results obtained for moisture ratios and thermal conductivity of the unblanched and peeled ginger at a drying temperature of 40°C

Table 4.6 Table of moisture ratio (%) and thermal conductivity (W/m. K) at drying temperature of 40℃

Unblanched				**Peeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	79.32	0.0756	1	2	75.93	0.0717
2	4	67.33	0.0691	2	4	60.47	0.0710
3	8	54.64	0.0660	3	8	49.39	0.0662
4	10	44.36	0.0638	4	10	47.08	0.0624
5	14	41.33	0.0608	5	14	30.59	0.0590
6	16	37.03	0.0581	6	16	27.01	0.0548
7	24	30.12	0.0557	7	24	23.92	0.0516
Blanched				**Unpeeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	70.11	0.0707	1	2	81.46	0.0717
2	4	54.37	0.0662	2	4	70.55	0.0658
3	8	40.6	0.0648	3	8	57.36	0.0611
4	10	27.84	0.0636	4	10	38.15	0.0572
5	14	23.65	0.0606	5	14	35.26	0.0560
6	16	18.83	0.0574	6	16	32.5	0.0557
7	24	17	0.0562	7	24	26.3	0.0543

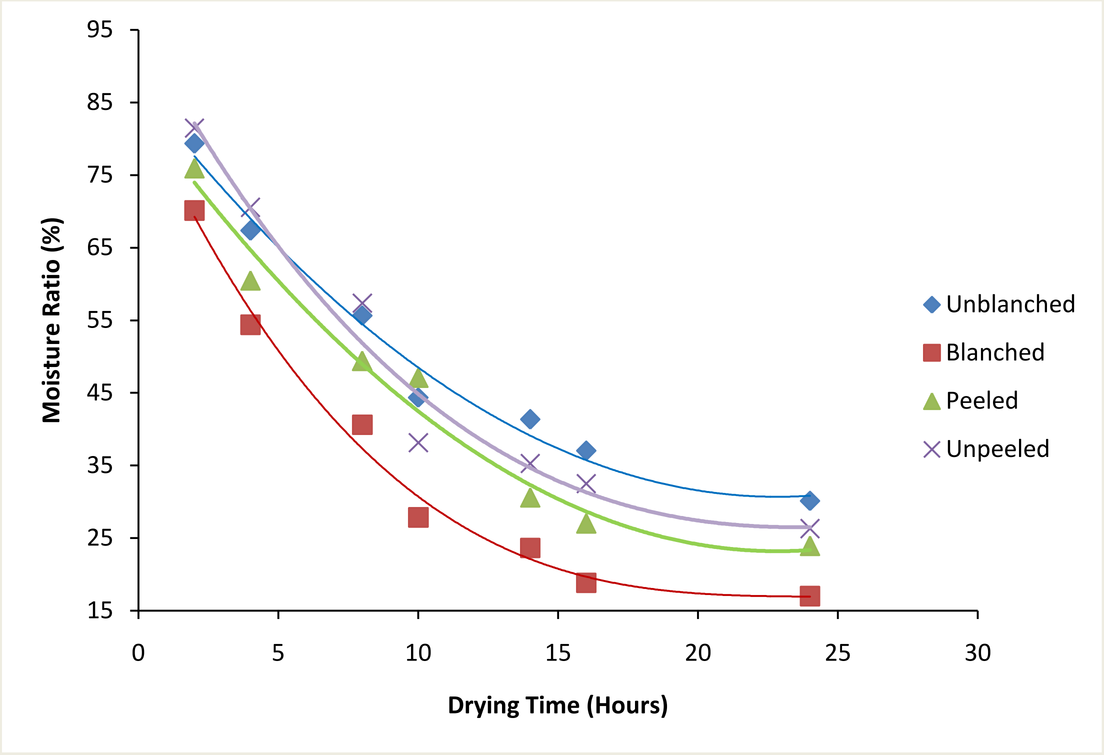


Figure 4.4 Variation of Moisture Ratio with Drying Time at 40^{0}C

Figure 4.4 presents the variation of moisture ratio of variously treated ginger sample with drying time at temperature of 40^{o}C. Unblanched treated ginger sample lost about 49.20% of moisture, blanched treated sample lost about 53.11%, peeled treated sample lost about 52.01% and unpeeled treated sample lost about 55.16%. It can be observed that unpeeled treated ginger sample experienced the highest moisture lost, but blanched treated ginger sample attended the lowest moisture ratio of 17%.

4.2.5 Experimental Results at Temperature of 50℃

Table 4.7 shows the results obtained for moisture ratios and thermal conductivity of the unblanched and peeled ginger at a drying temperature of 50°C

Table 4.7 Table of moisture ratio (%) and thermal conductivity (W/m. K) at drying temperature of 50℃

Unblanched				**Peeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	71.65	0.0715	1	2	65.5	0.0759
2	4	58.38	0.0698	2	4	58.91	0.0695
3	8	42.51	0.0675	3	8	39.79	0.0634
4	10	37.55	0.0652	4	10	27.99	0.0571
5	14	28.44	0.0582	5	14	18.68	0.0555
6	16	25.53	0.0563	6	16	16.5	0.0543
7	24	17.95	0.0541	7	24	13.21	0.0519
Blanched				**Unpeeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	66.64	0.0730	1	2	67.85	0.0776
2	4	51.57	0.0650	2	4	57.92	0.0710
3	8	44.89	0.0626	3	8	41	0.0622
4	10	31.78	0.0610	4	10	39.92	0.0596
5	14	14.42	0.0584	5	14	32.2	0.0540
6	16	12.79	0.0581	6	16	23.71	0.0465
7	24	10.25	0.0556	7	24	15.49	0.0460

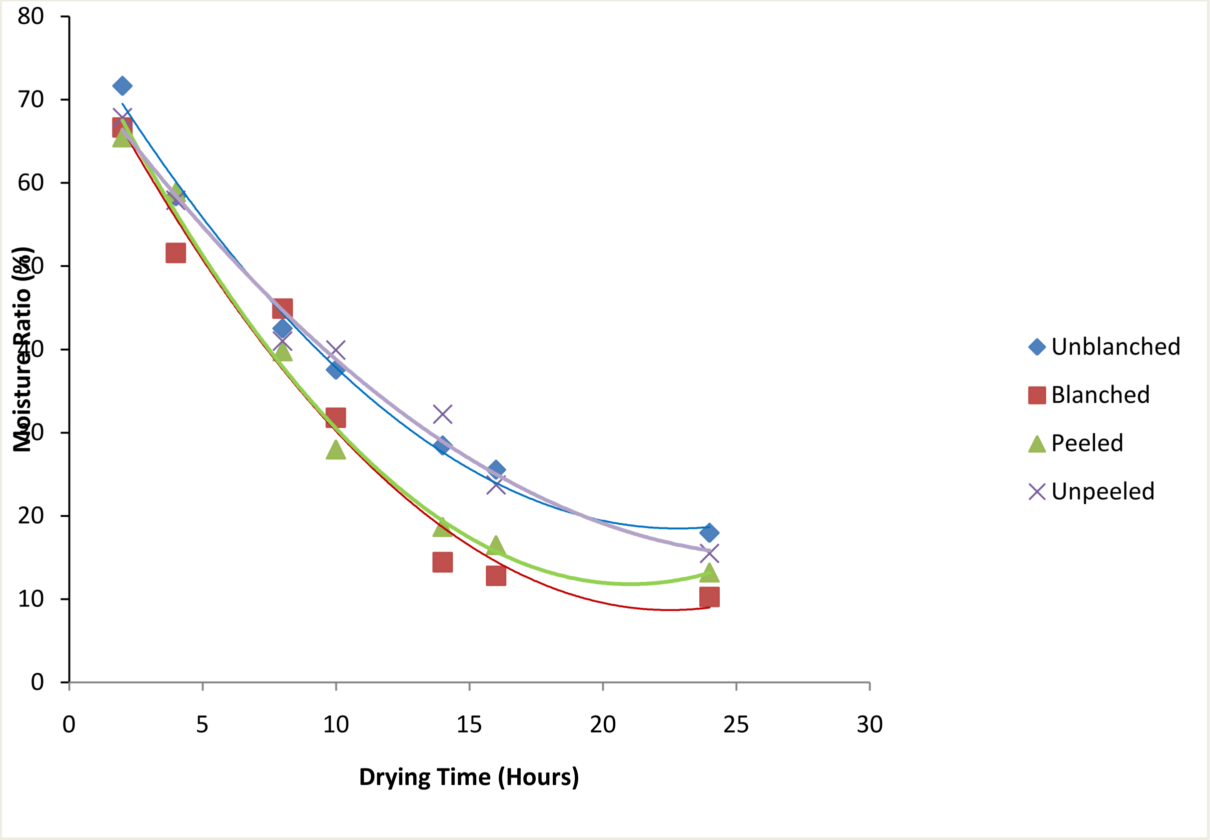


Figure 4.5 Variation of Moisture Ratio with Drying Time at 50^{0}C

Curves in Figure 4.5 presents the variation of moisture ratio of variously treated ginger sample with drying time at temperature of 50°C. Unblanched treated ginger sample lost about 53.70% of moisture, blanched treated sample lost about 56.39%, peeled treated sample lost about 52.29% and unpeeled treated sample lost about 52.36%. It can be observed that blanched treated ginger sample experienced the highest moisture lost and also attended the lowest moisture ratio of 10.25%.

4.2.6 Experimental Results at Temperature of 60℃

Table 4.8 shows the results obtained for moisture ratios and thermal conductivity of the unblanched and peeled ginger at a drying temperature of 60°C

Table 4.8 Table of moisture ratio (%) and thermal conductivity (W/m. K) at drying temperature of 60℃

Unblanched				**Peeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	74.16	0.0762	1	2	70.75	0.0791
2	4	52.92	0.0720	2	4	46.68	0.0727
3	8	42.16	0.0695	3	8	29.89	0.0664
4	10	33.33	0.0691	4	10	24.17	0.0611
5	14	16.49	0.0652	5	14	13.82	0.0557
6	16	14.88	0.0644	6	16	11.54	0.0534
7	24	6.63	0.0553	7	24	8.56	0.0483
Blanched				**Unpeeled**			
Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hour)	Initial Moisture Ratio (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
1	2	63.11	0.0836	1	2	74.36	0.0776
2	4	47.27	0.0762	2	4	59.27	0.0689
3	8	26.49	0.0732	3	8	46.56	0.0622
4	10	17.71	0.0576	4	10	31.13	0.0596
5	14	14.15	0.0566	5	14	24.49	0.0540
6	16	10.32	0.0536	6	16	13.69	0.0465
7	24	9.04	0.0516	7	24	5.98	0.0460

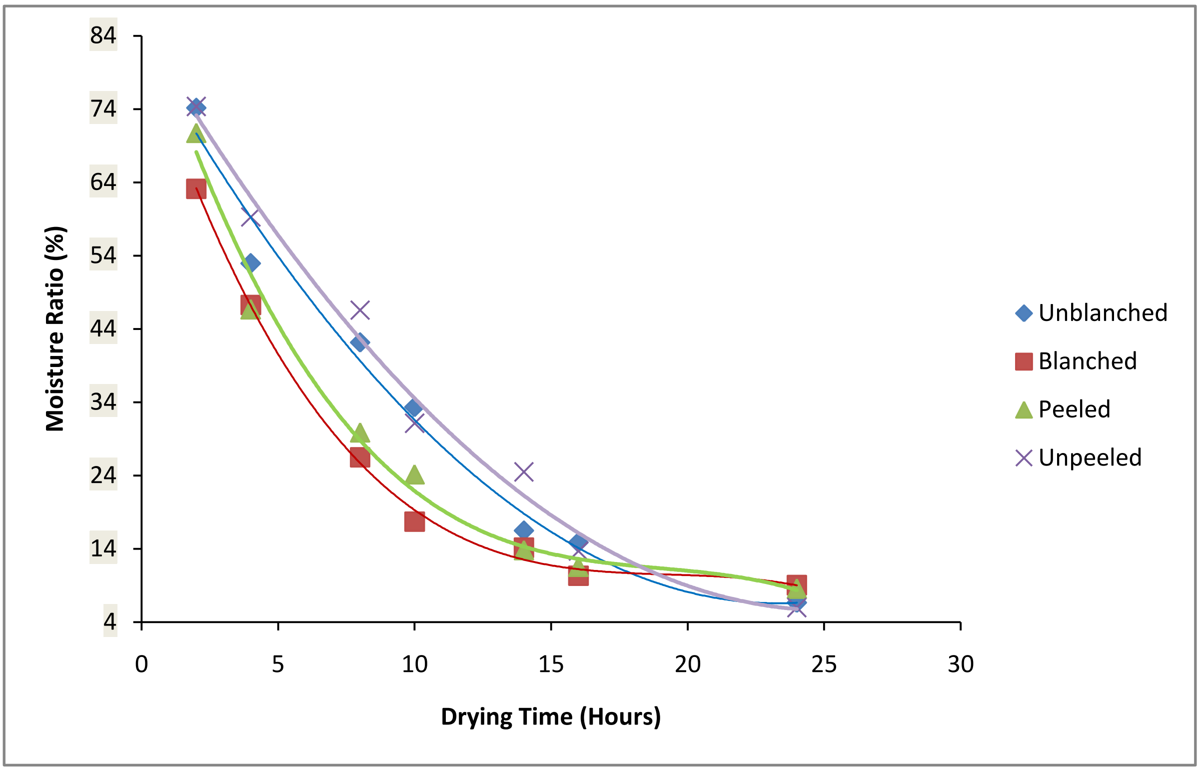


Figure 4.6 Variation of Moisture Ratio with Drying Time at 60^{0}C

The curves in Figure 4.6 presents the variation of moisture ratio of variously treated ginger sample with drying time at temperature of 60°C. Unblanched treated ginger sample lost about 67.53% of moisture, blanched treated sample lost about 54.07%, peeled treated sample lost about 62.19% and unpeeled treated sample lost about 68.38%. It could be observed that unpeeled treated ginger sample experienced the highest moisture lost.

Generally, the thermal conductivity decreases with the moisture ratio as the drying time progresses as shown in Tables 4.3-4.8. In Figures 4.1-4.6 the moisture ratio of the blanched ginger samples decreased the most when compared to other ginger samples while the unpeeled decreased the least. This could be as a result of the morphology of the ginger samples.

The respective ginger rhizome samples were dried at temperatures of 10°C, 20°C, 30°C, 40°C, 50°C and 60°C. Figures 4.1-4.6 show the relative drying curves of ginger rhizomes at periods of 2 - 24 hours and the effect of temperature for different shapes and sizes of ginger rhizomes on drying characteristics under blanched, unblanched, peeled and unpeeled conditions. As expected, there is a decrease in the moisture ratio with increase in drying temperature. Drying of ginger at excessive temperature could result to severe quality loss and shrinkages. Drying at above 60°C shows extensive discoloration of the samples which indicates that ginger rhizomes drying at a higher temperature is susceptible to colour and shape changes when dried at this temperature. Moreover, research report and practical experience recommends 60°C as upper limit for drying ginger rhizomes and affirms that drying rate is relatively high at 70°C using the solar hybrid dryer (Hoque *et al.*, 2013). The effect of drying parameters and conditions were determined at variable temperature and time. Tables 4.3-4.8 indicate the data obtained from the experiments conducted on the variously treated ginger rhizomes samples. Temperature was found to have strongest effect on the drying of ginger rhizomes.

4.3 Drying Rate of Ginger Rhizome

Equation 2.44 shows that the average drying rate for ginger samples could be deducted from Figures 4.1-4.6. Drying rate is the slope of the plot of moisture ratio against drying time. The values of the drying rate for the variously treated ginger samples at different temperatures level were presented in Table 4.9; also, the averages for the four treatments were presented in Table 4.9. The negative value for the drying rate is as a result of loss of mass (water content escaping from the ginger during drying). The banched samples recorded the highest average drying rate indicating that it dries faster than the other samples, while the unblanched samples recorded the least average drying rate.

Table 4.9: Average drying rate for variously treated ginger samples

Samples	**dM/dt**						
	10°C	20°C	30°C	40°C	50°C	60°C	**Average**
Unblanched	-1.967	-1.839	-2.433	-2.177	-2.37	-2.98	**-2.2943**
Blanched	-2.026	-2.568	-3.495	-2.365	-2.683	-2.366	**-2.5838**
Peeled	-1.598	-2.341	-2.956	-2.359	-2.547	-2.614	**-2.4025**
Unpeeled	-1.351	-1.844	-2.768	-2.554	-2.339	-3.126	**-2.3303**

The highest drying rate found could be traced to diffusion for the sliced ginger sample as a result of its two surfaces with small diffusion length travelling towards the cut surfaces. As reported in a similar research, blanching increases the drying rate (Bala, 1999). There are significant differences between the drying curves for unblanched, blanched, peeled and unpeeled samples at which the difference becomes minimal at temperature of 50°C - 60°C. These differences could be due to the fact that during blanching, the samples are moderately exposed to hot water and some cells might be loosened or disrupted; the result of which causes the moisture diffusion to be higher and as a result the drying rate is higher. The effect of this becomes noticeable with the increase of temperature from 40°C - 60°C. Similar results were reported for red chilli (Hossain & Bala, 2007) and for pear fruit (Lahsasni et al., 2004). For agricultural products such as fruits and vegetable, both external factors and internal mechanisms control the drying process and determines the overall drying rate of products (Gigler et al., 2000; Ekechukwu, 1999). The results obtained indicated the use of the environmental chamber for drying has minimized the drying time as compared to published reports on drying of peeled and unpeeled ginger where it took 11 days to achieve a moisture content of 17% using the open sun drying and 7.8% with the solar dryer (Eze and Agbo, 2011). Although samples in the solar dryer dries faster than those in the open-air sun, the convective drying methodology is a better time saving measure. This observation agrees with some published reports (Desrosier & Desrosier, 2006; Wang et al., 2011; Koyuncu et al., 2006).

4.4 Effect of Drying Time on Thermal Conductivity

Drying time is an important factor in agro-based industial process. Most agricultural products come in wet conditions and need to be dried to required standard moisture content at a given time interval. Variations in thermal conductivity of the variously treated ginger samples at various drying temperatures with respect to drying time are shown in tables 4.10 to 4.15. Figures 4.7 to 4.12 present the effect of drying time on the thermal conductivities of the variously treated ginger samples.

Table 4.10 Variations in Thermal Conductivity of the variously treated ginger samples at drying temperature of 10℃

Time (Hour)	Thermal Conductivity (unblanched) $\left(\frac{W}{m.K}\right)$	Thermal Conductivity (blanched) $\left(\frac{W}{m.K}\right)$	Thermal Conductivity (unpeeled) $\left(\frac{W}{m.K}\right)$	Thermal Conductivity (peeled) $\left(\frac{W}{m.K}\right)$
2	0.4064	0.329	0.3397	0.3768
4	0.3188	0.2878	0.3093	0.3004
8	0.2657	0.1993	0.2657	0.2623
10	0.2303	0.1901	0.2329	0.2115
14	0.1834	0.1699	0.2205	0.1919
16	0.1727	0.1558	0.2093	0.1658
24	0.1607	0.14	0.1713	0.1449

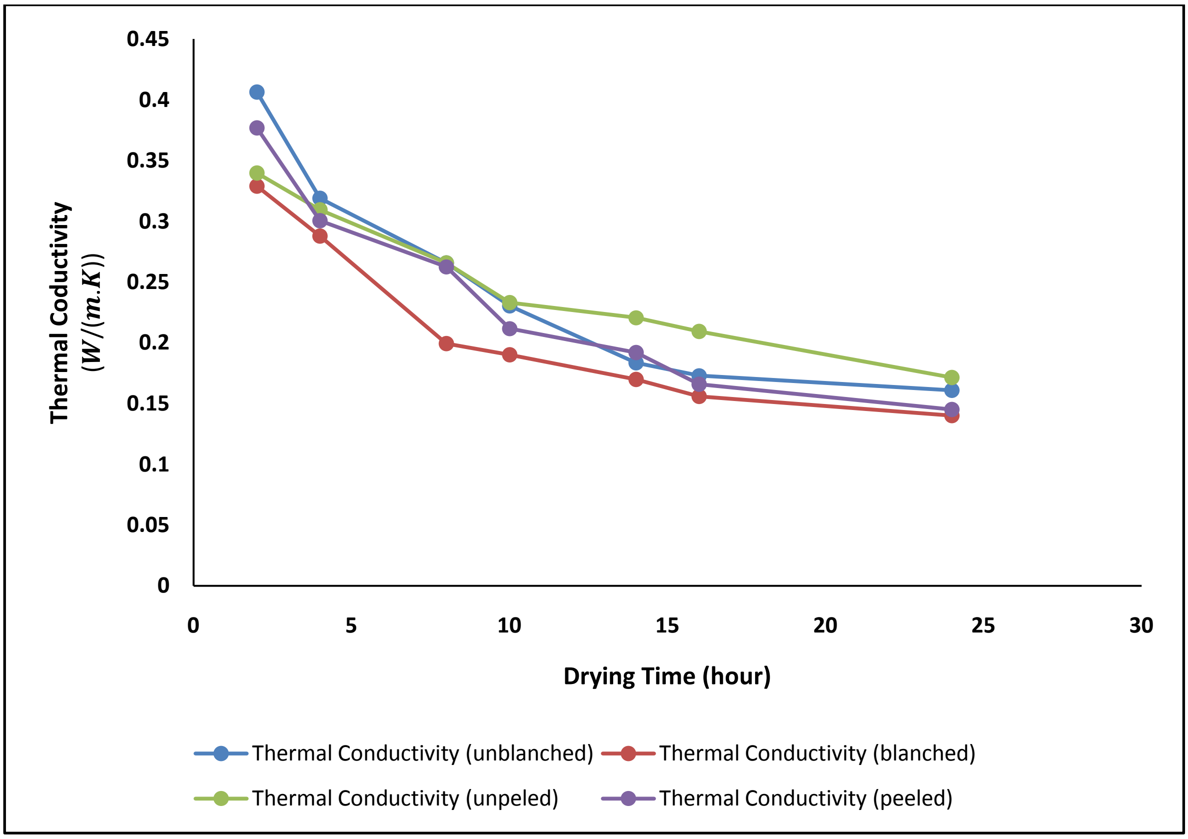


Figure 4.7 Variations of Thermal Conductivities of the Ginger samples at a drying temperature of 10^{0}C

Figure 4.7 present the variations of thermal conductivity with drying time at drying temperature of 10ºC. The best fit to the data was found to be logarithmic and polynomial of second order trend. The thermal conductivities for the variously treated samples decrease with time, which implies that as time progresses, less amount of moisture is lost. The thermal conductivity of unblanched treated sample reduced from 0.4064W/mK to 0.1607W/mK within the twenty four hours drying time. The thermal conductivity of blanched treated sample reduced from 0.3397W/mK to 0.1713W/mK within the twenty four hours drying time. The thermal conductivity of unpeeled treated sample reduced from 0.329W/mK to 0.14W/mK within the twenty four hours drying time. The thermal conductivity of peeled treated sample reduced from 0.3768W/mK to 0.1449W/mK within the twenty four hours drying time.

Table 4.11 Variations in Thermal Conductivity of the ginger samples at drying temperature of 20℃

Time(Hour)	Thermal Conductivity (unblanched) $\left(\frac{W}{m.K}\right)$	Thermal Conductivity (blanched) $\left(\frac{W}{m.K}\right)$	Thermal Conductivity (unpeeled) $\left(\frac{W}{m.K}\right)$	Thermal Conductivity (peeled) $\left(\frac{W}{m.K}\right)$
2	0.4064	0.2919	0.3454	0.3768
4	0.3188	0.2527	0.3343	0.3238
8	0.2382	0.2228	0.2839	0.2839
10	0.1974	0.1742	0.2329	0.2115
14	0.1901	0.157	0.2205	0.1818
16	0.1658	0.1449	0.1802	0.1594
24	0.1491	0.1312	0.1713	0.1391

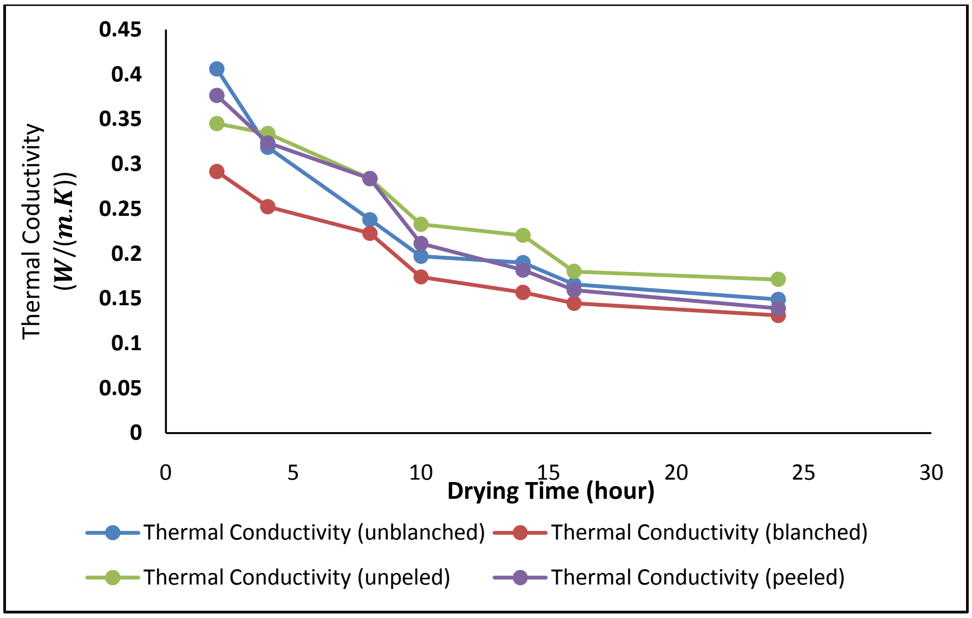


Figure 4.8 Variations of Thermal Conductivities of the Ginger samples at a drying temperature of 20^{0}C

Figure 4.8 present the variations of thermal conductivity with drying time at drying temperature of 20°C. Also, the best fit to the data was found to be logarithmic and polynminal of second order trend. Also, the thermal conductivities for the variously treated samples decrease with time. It could be seen that as time increases, the thermal conductivity of blanched treated sample reduced as low as 0.1312W/mK.

Table 4.12 Variations in Thermal Conductivity of the ginger samples at drying temperature of 30℃

Time(Hour)	Thermal Conductivity (unblanched)	Thermal Conductivity (blanched)	Thermal Conductivity (unpeeled)	Thermal Conductivity (peeled)
2	0.1074	0.1006	0.1126	0.1459
4	0.0996	0.0913	0.1021	0.1132
8	0.0987	0.081	0.081	0.0909
10	0.0955	0.08	0.074	0.0776
14	0.0809	0.0761	0.0658	0.0715
16	0.0785	0.0732	0.063	0.0693
24	0.0677	0.0689	0.0611	0.0652

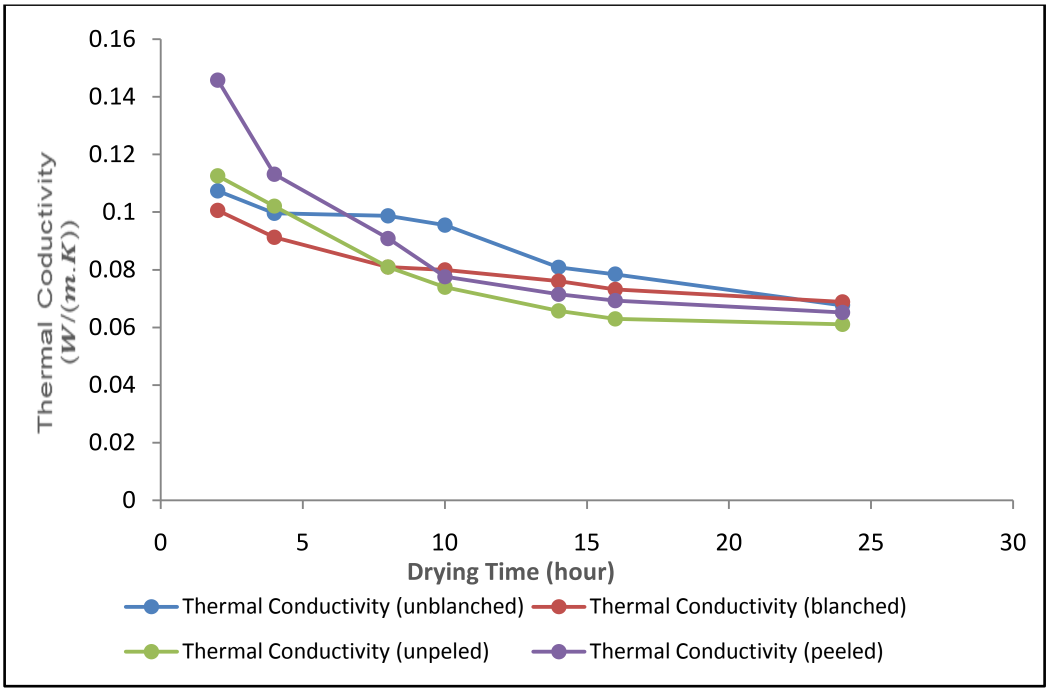


Figure 4.9 Variations of Thermal Conductivities of the Ginger samples at a drying temperature of 30^{0}C

The variations of thermal conductivity with drying time at drying temperature of 30°C is shown in figure 4.9. Also, the best fit to the data was found to be logarithmic and polynminal of second order trend. As expected the thermal conductivities for the variously treated samples decrease with time. It could be seen that as time increases, the thermal conductivity of unpeeled treated sample reduced as low as 0.0611W/mK.

Table 4.13 Variations in Thermal Conductivity of the ginger samples at drying temperature of 40℃

Time(Hour)	Thermal Conductivity (unblanched)	Thermal Conductivity (blanched)	Thermal Conductivity (unpeeled)	Thermal Conductivity (peeled)
2	0.0756	0.0707	0.0717	0.0717
4	0.0691	0.0662	0.0658	0.071
8	0.066	0.0648	0.0611	0.0662
10	0.0638	0.0636	0.0572	0.0624
14	0.0608	0.0606	0.056	0.059
16	0.0581	0.0574	0.0557	0.0548
24	0.0557	0.0562	0.0543	0.0516

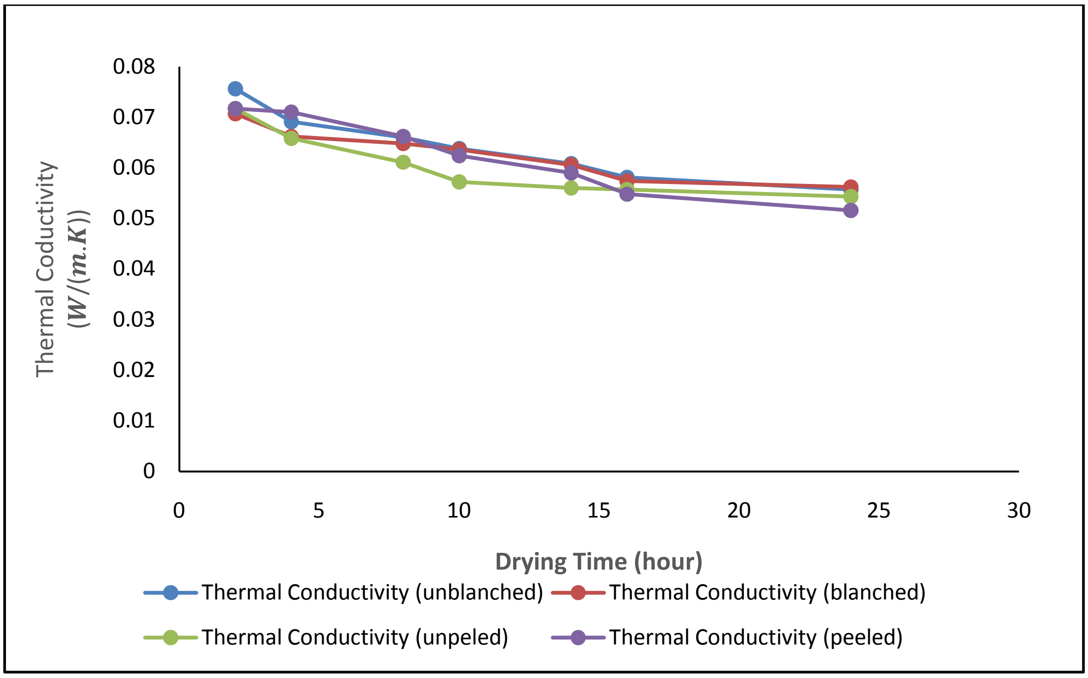


Figure 4.10 Variations of Thermal Conductivities of the Ginger samples at a drying temperature of 40^{0}C

The variations of thermal conductivity with drying time at drying temperature of 40°C is shown in figure 4.10. The best fit to the data was found to be logarithmic and polynminal of second order trend. As expected the thermal conductivities for the variously treated samples decrease with time. It shows that as time increases to twenty fours, the thermal conductivity of peeled treated sample reduce to 0.0516W/mK.

Table 4.14 Variations in Thermal Conductivity of the ginger samples at drying temperature of 50℃

Time(Hour)	Thermal Conductivity (unblanched)	Thermal Conductivity (blanched)	Thermal Conductivity (unpeeled)	Thermal Conductivity (peeled)
2	0.0715	0.073	0.0776	0.0759
4	0.0698	0.065	0.071	0.0695
8	0.0675	0.0626	0.0622	0.0634
10	0.0652	0.061	0.0596	0.0571
14	0.0582	0.0584	0.054	0.0555
16	0.0563	0.0581	0.0465	0.0543
24	0.0541	0.0556	0.046	0.0519

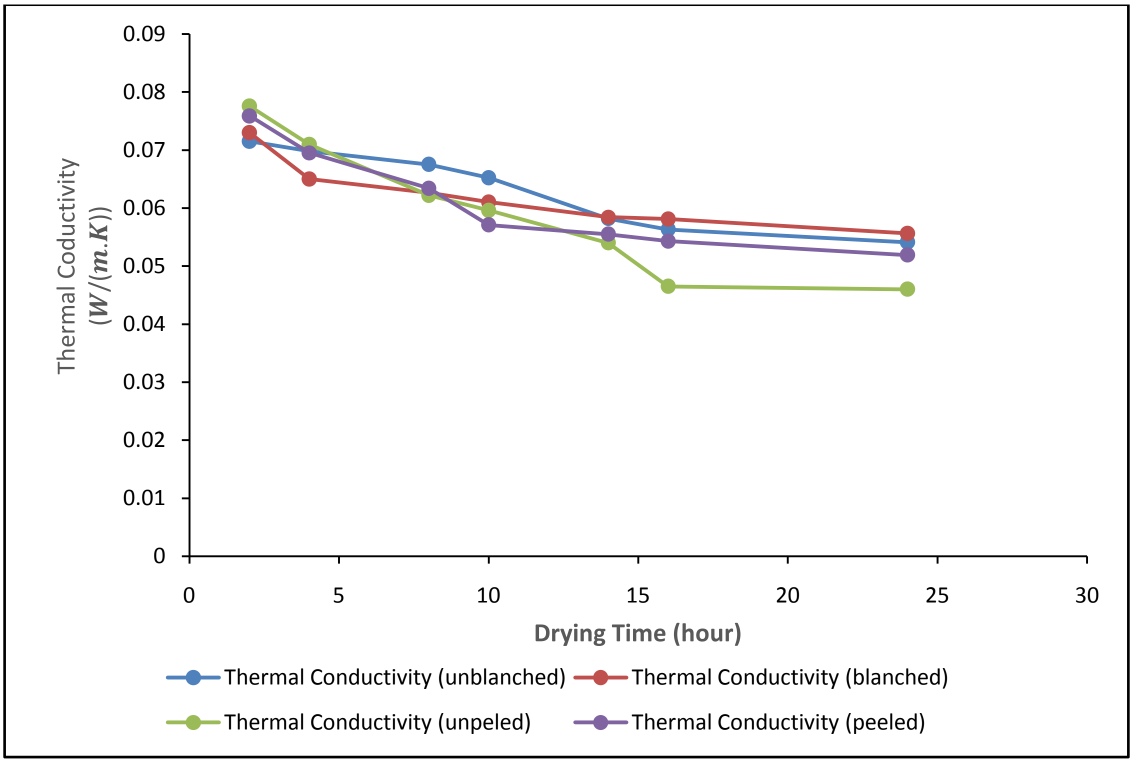


Figure 4.11 Variations of Thermal Conductivities of the Ginger samples at a drying temperature of 50^{0}C

Figure 4.11 present the variations of thermal conductivity with drying time at drying temperature of 50°C. The best fit to the data was found to be logarithmic and polynminal of second order trend. The thermal conductivities for the variously treated samples decrease with time, while unpeeled treated sample exhibited the least value of thermal conductivity.

Table 4.15 Variations in Thermal Conductivity of the ginger samples at drying temperature of 60℃

Time(Hour)	Thermal Conductivity (unblanched)	Thermal Conductivity (blanched)	Thermal Conductivity (unpeeled)	Thermal Conductivity (peeled)
2	0.0762	0.0836	0.0776	0.0791
4	0.072	0.0762	0.0689	0.0727
8	0.0695	0.0732	0.0622	0.0664
10	0.0691	0.0576	0.0596	0.0611
14	0.0652	0.0566	0.054	0.0557
16	0.0644	0.0536	0.0465	0.0534
24	0.0553	0.0516	0.046	0.0483

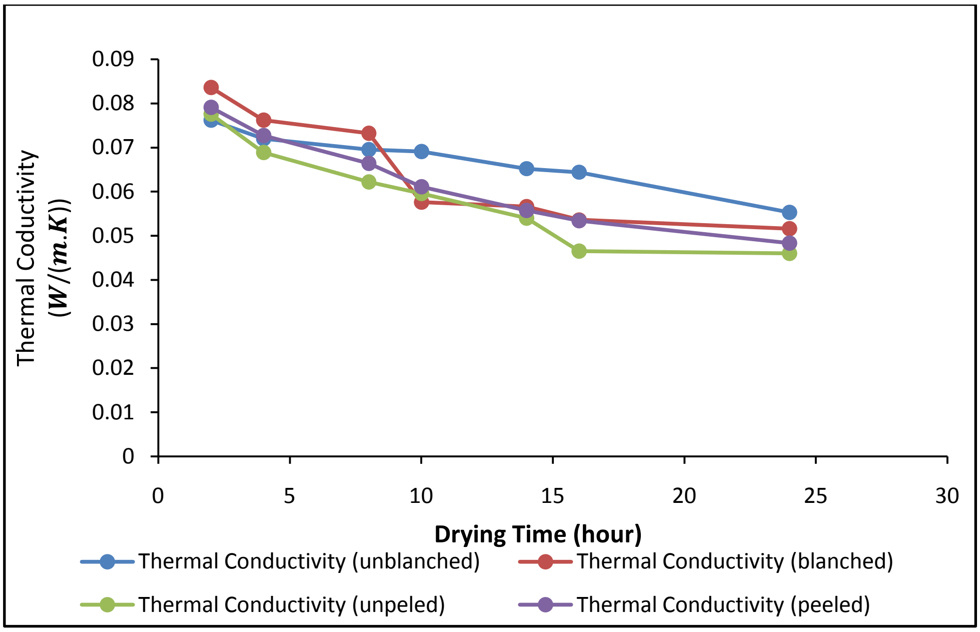


Figure 4.12 Variations of Thermal Conductivities of the Ginger samples at a drying temperature of 60^{0}C

Figure 4.12 present the variations of thermal conductivity with drying time at drying temperature of 60^{o}C. The best fit to the data was found to be logarithmic and polynminal of second order trend. The thermal conductivities for the variously treated samples decrease with time. Also, the initial thermal conductivities for the various treatments decrease with temperature. The thermal conductivity is highest at 2 hours and falls significantly until it reaches a drying time of 24 hours. The trend is highest at 10°C - 20°C and fall significantly at 30°C - 60°C for the various samples**.**

The drying characteristics of Nigeria ginger rhizomes investigated showed that the drying process employed could be accelerated only during the early stages of the drying process where air and mass movement are external factors which influence the drying rate. The unpeeled and blanched ginger rhizomes are also influenced by the presence of moisture barrier such as the unpeeled skins. As the study reveals, drying of ginger rhizomes at low temperatures of 10°C – 20°C does not have much significance on drying behaviour as it maintains high initial moisture content and high thermal conductivity. However, as the temperature increases above 60°C ginger rhizomes becomes sensitive to temperature both in texture and color. The author opines that drying of ginger rhizomes could be accomplished at a temperatures between 50°C to 60°C in order to maintain the desired drying criteria.

4.5 Variations in Moisture Ratio of the Ginger Samples with Temperature

From Figures 4.13-4.14 and Tables 4.16-4.17, the moisture ratio decreases with drying time. The data on moisture contents of ginger rhizomes dried for 2 hours and for 24 hours respectively were plotted in figures 4.13 and 4.14 as a function of temperature. The best fit to the data was found to be a straight line. These figures represent the drying curves in terms of the moisture content. The reduction of moisture with increase in temperature is evidence of drying. The drying rate is given in moisture reduction per degree rise in temperature. The characteristics of these curves are given in Table 4.18.

Table 4.16 Variations in moisture ratio of the ginger samples with temperature at drying time of 2 hours

	Moisture Ratio			
Temperature (^oC)	Unblanched	Blanched	Peeled	Unpeeled
10	88.64	84.58	88.74	91.08
20	86.35	86.29	87.75	86.17
30	87.34	86.65	87.95	87.71
40	79.32	70.11	75.93	81.46
50	71.65	66.64	65.5	67.85
60	74.16	63.11	70.75	74.36

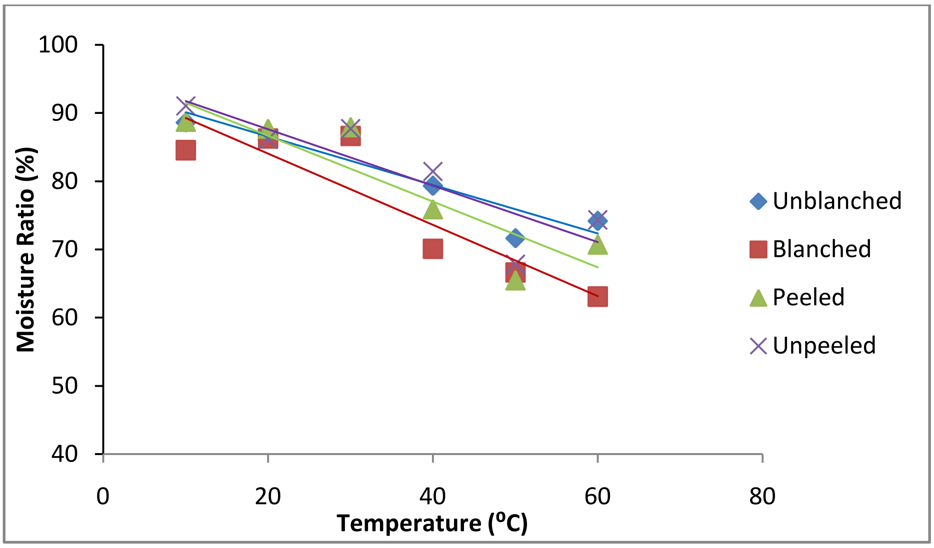


Figure 4.13 Moisture ratio of rhizomes dried for 2 hours, plotted as a function of temperature.

Table 4.17 Variations in moisture ratio of the ginger samples with temperature at drying time of 24 hours

	Moisture Ratio			
Temperature (^oC)	Unblanched	Blanched	Peeled	Unpeeled
10	49.55	41.13	55.91	62.22
20	47.81	34.26	37.49	48.36
30	39.55	17.48	27.76	31.15
40	30.12	17	23.92	26.3
50	17.95	10.25	13.21	15.49
60	6.63	9.04	8.56	5.98

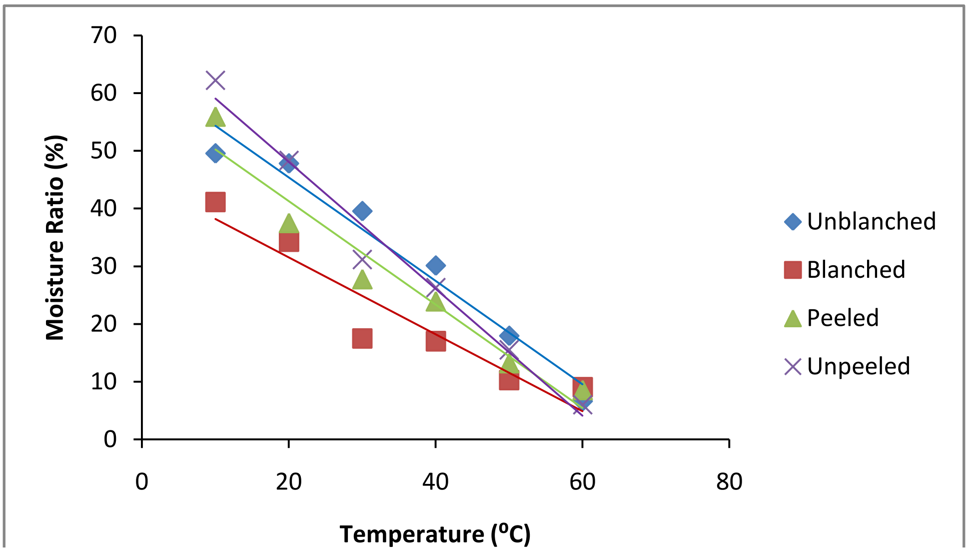


Figure 4.14 Moisture ratio of rhizomes dried for 24 hours, plotted as a function of temperature.

Table 4.18: Data for moisture ratio

Drying time		Slope	Intercept	R-squared
2 Hrs	Unbleached	-0.3558	93.70	0.8395
	Blanched	-0.5224	94.51	0.8219
	Peeled	-0.4829	96.36	0.7974
	Unpeeled	-0.4137	95.92	0.7693
Average		-0.4437	95.12	0.807
24 Hrs	**Unbleached**	**-0.896**	**63.30**	**0.9627**
	Blanched	-0.6656	44.82	0.8949
	Peeled	-0.8955	59.15	0.9469
	Unpeeled	-1.099	70.05	0.9774
Average		-0.8890	59.33	0.9455

Table 4.18 shows as expected that the ginger rhizomes dried for a longer time have higher average reduction in moisture given by the slopes of the graphs as 0.889/°C for 24 hours drying and 0.4437/°C for 2 hours drying, giving 50.1% in moisture reduction rate. The intercept which theoretically gives the terminal moisture ratio (at 60°C) is lower at 24 hours drying (59.33%) compared to 95.12% on dry basis at 2 hours of drying, as expected. This final moisture ratio is rather higher than expected. This shows that either more time is given for the drying or drying temperature is increased. The preliminary moisture contents are however higher as expected. The goodness of fit, on the average is higher for ginger dried for 24 hours than for that dried for 2 hours. All these show the superiority of higher temperature drying. These also show

that the results vary with the methods of preparation of the ginger. The unpeeled ginger gave the highest results while the blanched ginger gave the lowest results for 24 hour drying. The results at 2 hours drying are not consistent as the shortness of the time prevented the attainment of equilibrium.

Cletus, (2007) and Eze & Agbo, (2011) demonstrated that the preliminary moisture content is essential for demonstrating the drying procedure. The limit is around 87.98% and 84.97% moisture content (wet basis) to 75.73% and 68.70% (wet basis) under blanched condition and to the moisture content 81.98 % (wb) and 77.46% (wb) under non blanched condition after 20 hours in solar dryer at 50°C to 60°C respectively (Hoque *et al.*, 2013). Split ginger rhizomes dried from initial moisture content of 87.98% (wb) to 22.54% and 32.96% (wb) under blanched and unblanched conditions for 32 hours at 50°C. This implies that the drying rate of ginger rhizomes increases with an increase in drying temperature (Hoque *et al.*, 2013). In this study, the results of final moisture content (dry basis) can be seen to be higher than the literature values.

The results for the thermal conductivities are presented in figures 4.15 and 4.16. The curves were fitted to polynomial functions of order two and the resulting equations are given on Table 4.21.

Table 4.19: Variations in thermal conductivity of the ginger samples with temperature at drying time of 2 hours

	Thermal Conductivity @2 Hrs			
Temperature (°C)	Unblanched	Blanched	Peeled	Unpeeled
10	0.4064	0.329	0.3768	0.3397
20	0.4064	0.2919	0.3768	0.3454
30	0.1074	0.1006	0.1459	0.1126
40	0.0756	0.0707	0.0717	0.0717
50	0.0715	0.073	0.0759	0.0776
60	0.0762	0.0836	0.0791	0.0776

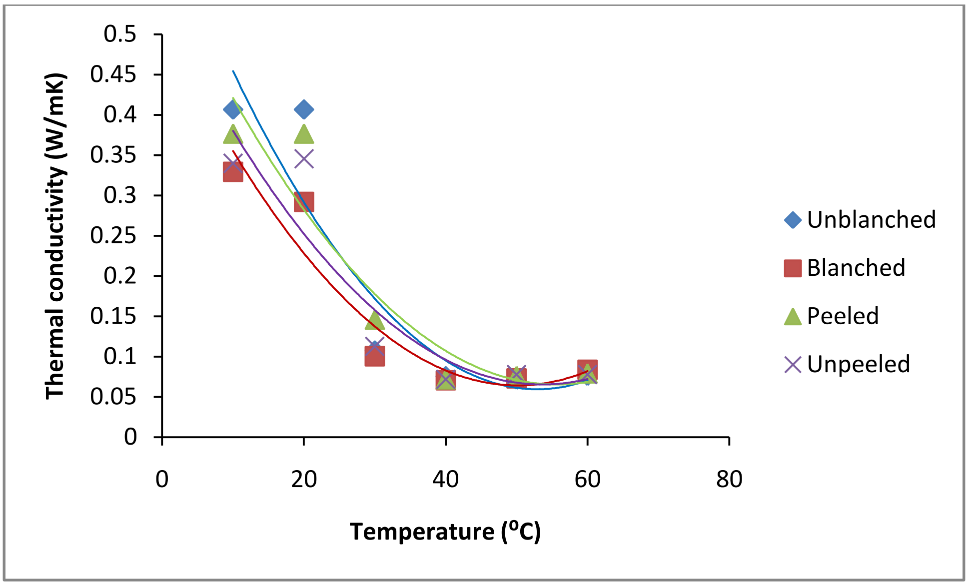


Figure 4.15 Effects of temperature on the thermal conductivities of ginger rhizomes dried for 2 hours

Table 4.20 Variations in thermal conductivity of the ginger samples with temperature at drying time of 24 hours

	Thermal Conductivity @24Hrs			
Temperature (^{o}C)	Unblanched	Blanched	Peeled	Unpeeled
10	0.1607	0.14	0.1449	0.1713
20	0.1491	0.1312	0.1391	0.1713
30	0.0677	0.0689	0.0652	0.0611
40	0.0557	0.0562	0.0516	0.0543
50	0.0541	0.0556	0.0519	0.046
60	0.0553	0.0516	0.0483	0.046

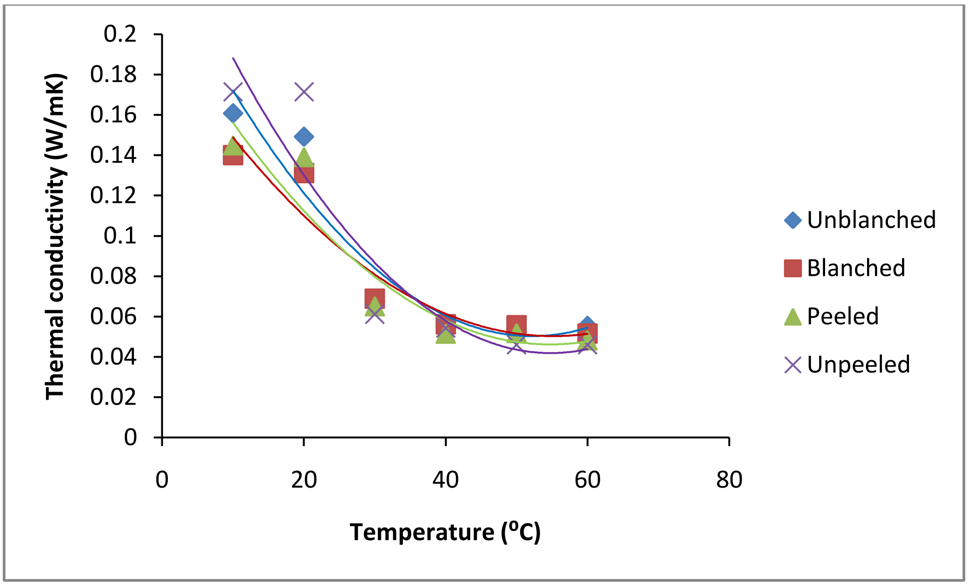


Figure 4.16 Effects of temperature on the thermal conductivities of ginger rhizomes dried for 24 hours

Table 4.21a: For products dried for 2 hours (figure 4.15)

Unblanched	K =	$0.0002T^2 - 0.0227T + 0.6588$	$R^2 = 0.6588$
Blanched	K =	$0.0002T^2 - 0.0181T + 0.5184$	$R^2 = 0.9106$
Peeled	K =	$0.0002T^2 - 0.019T + 0.5937$	$R^2 = 0.8804$
Unpeeled	K =	$0.0002T^2 - 0.0178T + 0.5409$	$R^2 = 0.8551$

Table 4.21b: For products dried for 24 hours (figure 4.16)

Unblanched	K =	$7x10^{-5}T^2 - 0.0071T + 0.2367$	$R^2 = 0.9067$
Blanched	K =	$5x10^{-5}T^2 - 0.0054T + 0.1974$	$R^2 = 0.9139$
Peeled	K =	$5x10^{-5}T^2 - 0.0058T + 0.2074$	$R^2 = 0.8875$
Unpeeled	K =	$7x10^{-5}T^2 - 0.008T + 0.2602$	$R^2 = 0.8614$

Figures 4.15 and 4.16 have similar shapes and can be seen as drying curves. The thermal conductivities were high at low drying times as was the case with moisture contents and decreased to almost asymptotic values at higher drying times at 60°C. The intercepts which gave the expected conductivities at zero degrees centigrade were higher for a 2 hour-dried ginger at the average of 0.578 W/mK than at 24 hours of drying, on the average of 0.225 W/mK, by a factor of 61.1%. The thermal conductivity for a 24 hour-dried ginger at 60°C approximates to the thermal conductivity of dried ginger and it is 0.050 W/mK on the average, with unpeeled ginger giving the lowest value of 0.046 W/mK and unblanched ginger giving the highest value of 0.055 W/mK. For 2 hours of drying, the average value was 0.079 W/mK while the unblanched ginger gave the lowest and blanched the highest. Previous studies concluded that peeled and blanched ginger allow a decrease in the resistance of this product to water transportation within the internal and external part because the outer skin of the rhizomes as observed from the unblanched and unpeeled provides slight resistance due to its' non-permeability which causes rigidity during the drying process therefore disallowing water easy transportation through it.

4.6 Determination of Activation Energy

Activation energy that must be available for drying to occur was determined using equation 2.43. Figure 4.23 shows the plot of the natural logarithm of the diffusivity of the variously treated ginger samples with the inverse of the absolute temperature. The slope of the plot gives $–E_a/R$ and the intercept gives the pre-exponential factor of Arrhenius equation. The activation was obtained as –(slope X R). The effective moisture diffusivity of ginger rhyzome was determined using equation 4.1. The effective moisture diffusivities of variously treated ginger rhizome at different drying temperatures were obtained by plotting *In(MR)* against drying time, figures 4.17 to 4.22. These plots gave straight lines with slopes of $-(\pi^2 D_{eff}/4L^2)$. The effective diffusivity was evaluated from the slope. Figures 4.17 to 4.22 were plotted using tables 4.22 to 4.27 while figure 4.23 was plotted using table 4.35. Tables 4.22 to 4.27 present the natural logarithm of moisture ratio of the variously treated ginger samples at different drying temperatures.

Table 4.22 The Natural Logarithm of Moisture ratio of the gingers at 10℃

Time (Secs)	Unblanched	Blanched	Peeled	Unpeeled
7200	-0.1206	-0.1675	-0.1195	-0.0934
14400	-0.1655	-0.2411	-0.1869	-0.1754
28800	-0.2449	-0.4587	-0.2576	-0.1976
36000	-0.3056	-0.4708	-0.4529	-0.3091
50400	-0.4274	-0.6270	-0.5001	-0.3744
57600	-0.6714	-0.7546	-0.5539	-0.4357
86400	-0.7022	-0.8884	-0.5814	-0.4745

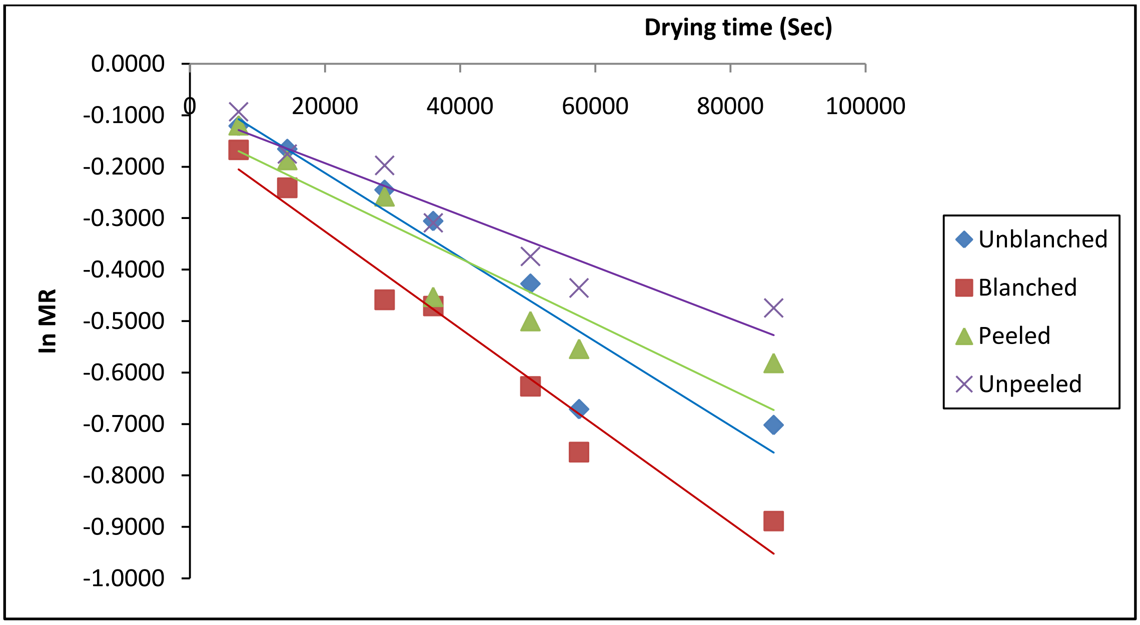


Figure 4.17 Plot of ln MR against Drying Time for Ginger dried at 10℃

Figure 4.17 present the plot of the natural logarithm of moisture ratio against the drying time at drying temperature of 10°C for the variously treated ginger samples. The best fit to the data was found to be a straight line. These figures represent the dependence of effective diffusivity on drying time at temperature of 10°C.

Table 4.23 The Natural Logarithm of Moisture ratio of the gingers at 20℃

Time (Hrs)	Unblanched	Blanched	Peeled	Unpeeled
7200	-0.1468	-0.1475	-0.1295	-0.1488
14400	-0.2605	-0.2509	-0.2590	-0.2006
28800	-0.3331	-0.3893	-0.3170	-0.2662
36000	-0.3436	-0.4279	-0.4096	-0.4410
50400	-0.5870	-0.8372	-0.6931	-0.4948
57600	-0.6958	-0.9524	-0.7400	-0.6319
86400	-0.7379	-1.0712	-0.9811	-0.7265

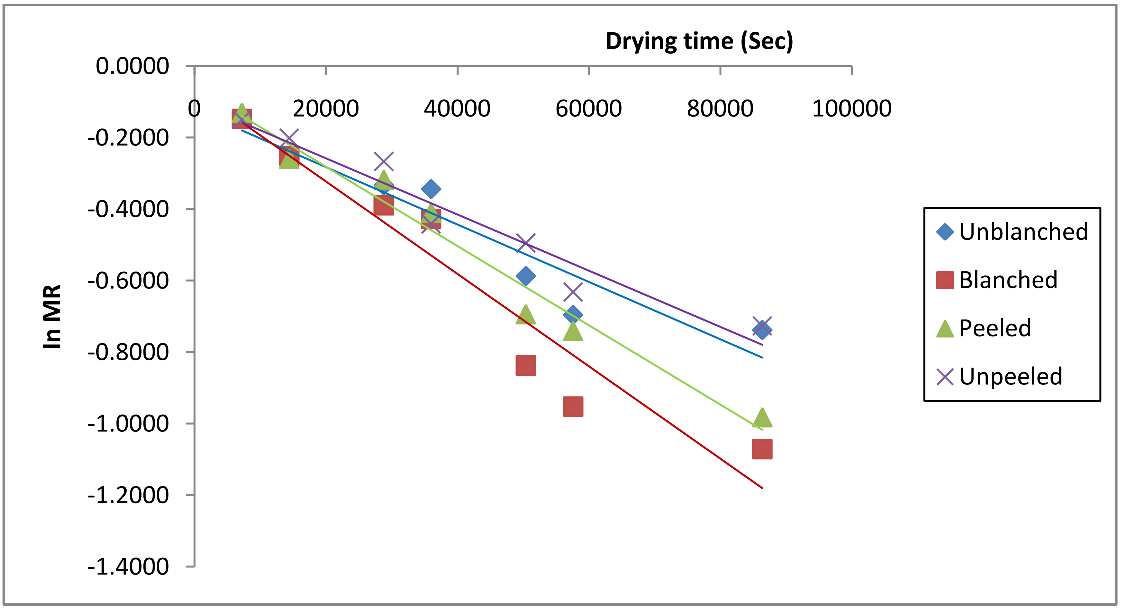


Figure 4.18 Plot of ln MR against Drying Time for Ginger dried at 20℃

Figure 4.18 present the plot of the natural logarithm of moisture ratio against the drying time at drying temperature of 20°C for the variously treated ginger samples. The best fit to the data was found to be a straight line. These figures represent the dependence of effective diffusivity on drying time at temperature of 20°C.

Table 4.24 The Natural Logarithm of Moisture ratio of the gingers at 30℃

Time (Sec)	Unblanched	Blanched	Peeled	Unpeeled
7200	-0.1354	-0.1433	-0.1284	-0.1311
14400	-0.2131	-0.2418	-0.2216	-0.1998
28800	-0.2721	-0.4273	-0.2900	-0.2988
36000	-0.3264	-0.4724	-0.4105	-0.3715
50400	-0.7423	-1.1874	-0.7824	-0.7253
57600	-0.7974	-1.4069	-0.9584	-0.8343
86400	-0.9276	-1.7441	-1.2816	-1.1664

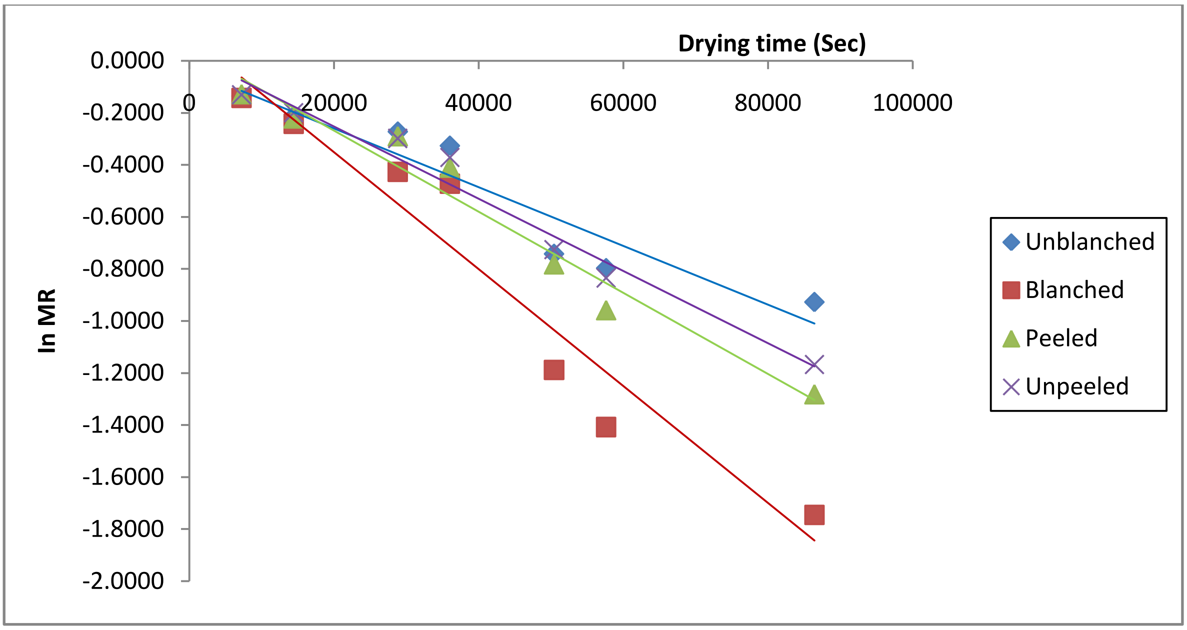


Figure 4.19 Plot of ln MR against Drying Time for Ginger dried at 30℃

Figure 4.19 present the plot of the natural logarithm of moisture ratio against the drying time at drying temperature of 30°C for the variously treated ginger samples. The best fit to the data was found to be a straight line. These figures represent the dependence of effective diffusivity on drying time at temperature of 30°C.

Table 4.25 The Natural Logarithm of Moisture ratio of the gingers at 40℃

Time (Sec)	Unblanched	Blanched	Peeled	Unpeeled
7200	-0.2317	-0.3551	-0.2754	-0.2051
14400	-0.3956	-0.6094	-0.5030	-0.3488
28800	-0.5863	-0.9014	-0.7054	-0.5558
36000	-0.8128	-1.2787	-0.7533	-0.9636
50400	-0.8836	-1.4418	-1.1845	-1.0424
57600	-0.9934	-1.6697	-1.3090	-1.1239
86400	-1.2000	-1.7720	-1.4305	-1.3356

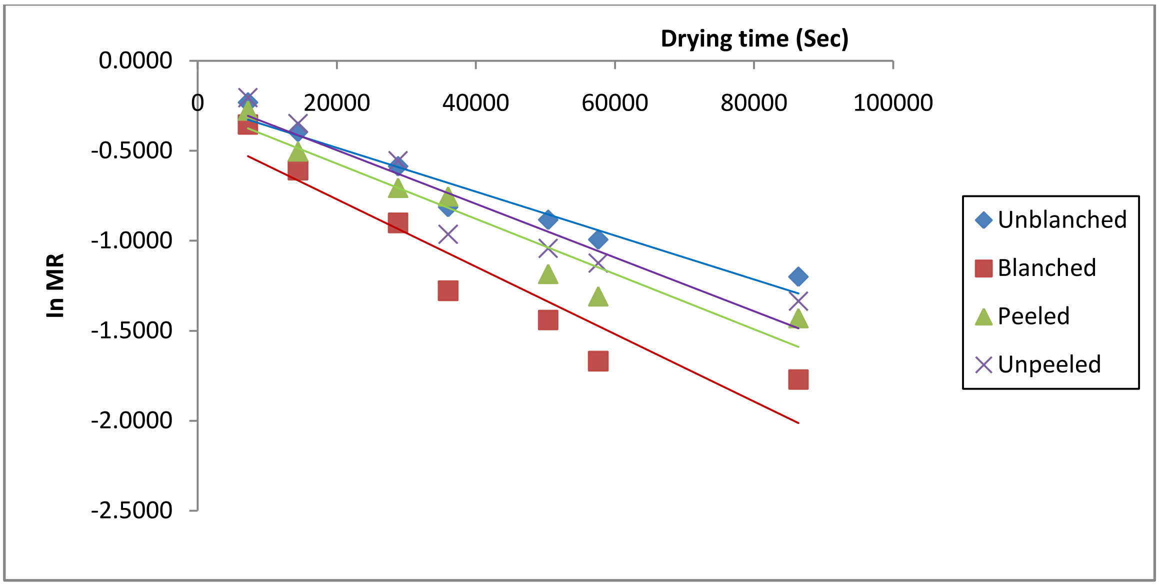


Figure 4.20 Plot of ln MR against Drying Time for Ginger dried at 40^{o}C

The plot of the natural logarithm of moisture ratio against the drying time at drying temperature of 40^{o}C for the variously treated ginger samples is shown in figure 4.20. The best fit to the data was found to be a straight line. These figures represent the dependence of effective diffusivity on drying time at temperature of 40^{o}C.

Table 4.26 The Natural Logarithm of Moisture ratio of the gingers at 50℃

Time (Sec)	Unblanched	Blanched	Peeled	Unpeeled
7200	-0.3334	-0.4059	-0.4231	-0.3879
14400	-0.5382	-0.6622	-0.5292	-0.5461
28800	-0.8554	-0.8010	-0.9216	-0.8916
36000	-0.9795	-1.1463	-1.2733	-0.9183
50400	-1.2574	-1.9366	-1.6777	-1.1332
57600	-1.3653	-2.0565	-1.8018	-1.4393
86400	-1.7176	-2.2779	-2.0242	-1.8650

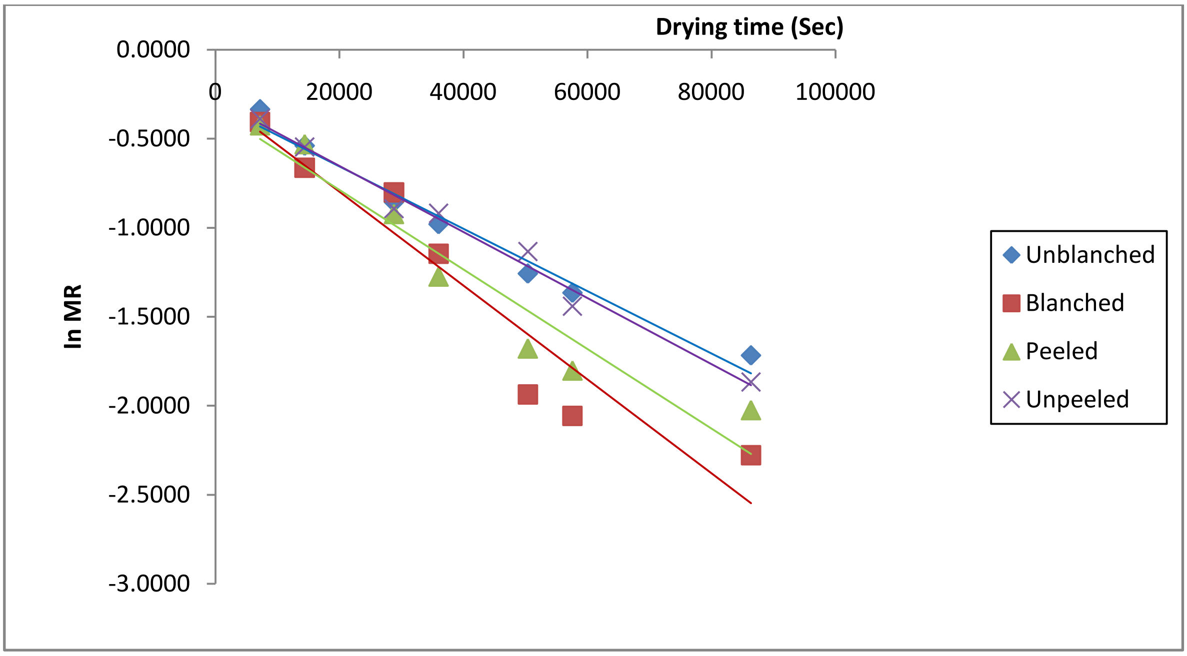


Figure 4.21 Plot of ln MR against Drying Time for Ginger dried at 50℃

The plot of the natural logarithm of moisture ratio against the drying time at drying temperature of 50°C for the variously treated ginger samples is shown in figure 4.21. The best fit to the data was found to be a straight line. These figures represent the dependence of effective diffusivity on drying time at temperature of 50°C.

Table 4.27 The Natural Logarithm of Moisture ratio of the gingers at 60℃

Time (Sec)	Unblanched	Blanched	Peeled	Unpeeled
7200	-0.2989	-0.4603	-0.3460	-0.2963
14400	-0.6364	-0.7493	-0.7619	-0.5231
28800	-0.8637	-1.3284	-1.2076	-0.7644
36000	-1.0987	-1.7310	-1.4201	-1.1670
50400	-1.8024	-1.9555	-1.9791	-1.4069
57600	-1.9052	-2.2711	-2.1594	-1.9885
86400	-2.7136	-2.4035	-2.4581	-2.8167

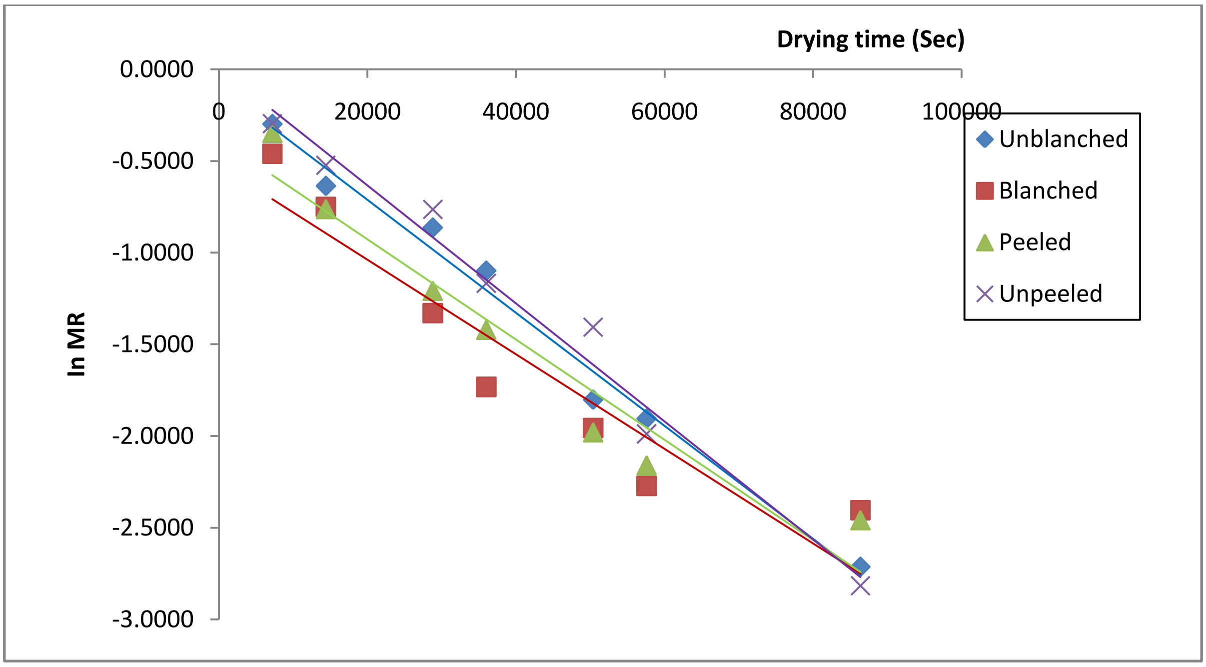


Figure 4.22 Plot of ln MR against Drying Time for Ginger dried at 60℃

The plot of the natural logarithm of moisture ratio against the drying time at drying temperature of 60°C for the variously treated ginger samples is shown in figure 4.22. The best fit to the data was found to be a straight line. These figures represent the dependence of effective diffusivity on drying time at temperature of 60°C.

The slope, K as represented in Tables 4.25-4.30 was obtained from the graphs *In MR vs. t* as shown in figures 4.17-4.22, while D_{eff} $(m^2 s^{-1})$ is obtained from equation 2.41.

$$D_{eff} = -\left(\frac{4L^2 K}{\pi^2}\right) \qquad (4.1)$$

Where L is half the thickness of the samples in metres, the thickness of the samples is 18mm.

Table 4.28 The slope, K and Effective moisture diffusivities, D_{eff} of the Ginger samples at 10℃

Ginger Sample	Slope	Intercept	R-squared	D_{eff} (m^2s^{-2})
Unbleached	$-8X10^{-6}$	-0.048	0.91	2.67503E-10
Blanched	$-9X10^{-6}$	-0.136	0.96	3.00941E-10
Peeled	$-6X10^{-6}$	-0.124	0.85	2.00627E-10
Unpeeled	$-5X10^{-6}$	-0.092	0.91	1.6719E-10
Average	-0.000007	-0.1	0.9075	2.34065E-10

Table 4.29 The slope, K and Effective moisture diffusivities, D_{eff} of the Ginger samples at 20℃

Ginger Sample	Slope	Intercept	R-squared	D_{eff} (m^2s^{-2})
Unbleached	$-8X10^{-6}$	-0.121	0.91	2.67503E-10
Blanched	$-1X10^{-5}$	-0.064	0.92	3.34379E-10
Peeled	$-1X10^{-5}$	-0.059	0.97	3.34379E-10
Unpeeled	$-8X10^{-6}$	-0.100	0.94	2.67503E-10
Average	-0.000009	-0.086	0.935	3.00941E-10

Table 4.30 The slope, K and Effective moisture diffusivities, D_{eff} of the Ginger samples at 30℃

Ginger Sample	Slope	Intercept	R-squared	D_{eff} (m^2s^{-2})
Unbleached	$-1X10^{-5}$	-0.034	0.90	3.34379E-10
Blanched	$-2X10^{-5}$	0.097	0.94	6.68758E-10
Peeled	$-2X10^{-5}$	0.043	0.96	6.68758E-10
Unpeeled	$-1X10^{-5}$	0.024	0.97	3.34379E-10
Average	-0.000015	0.0325	0.9425	5.01569E-10

Table 4.31 The slope, K and Effective moisture diffusivities, D_{eff} of the Ginger samples at 40℃

Ginger Sample	Slope	Intercept	R-squared	D_{eff} (m^2s^{-2})
Unbleached	$-1X10^{-5}$	-0.239	0.94	3.34379E-10
Blanched	$-2X10^{-5}$	-0.395	0.89	6.68758E-10
Peeled	$-2X10^{-5}$	-0.264	0.92	6.68758E-10
Unpeeled	$-1X10^{-5}$	-0.198	0.90	3.34379E-10
Average	-0.000015	-0.274	0.9125	5.01569E-10

Table 4.32 The slope, K and Effective moisture diffusivities, D_{eff} of the Ginger samples at 50℃

Ginger Sample	Slope	Intercept	R-squared	D_{eff} (m^2s^{-2})
Unbleached	$-2X10^{-5}$	-0.304	0.98	6.68758E-10
Blanched	$-3X10^{-5}$	-0.269	0.91	1.00314E-09
Peeled	$-2X10^{-5}$	-0.339	0.92	6.68758E-10
Unpeeled	$-2X10^{-5}$	-0.281	0.99	6.68758E-10
Average	-0.0000225	-0.29825	0.95	7.52353E-10

Table 4.33 The slope, K and Effective moisture diffusivities, D_{eff} of the Ginger samples at 60℃

Ginger Sample	Slope	Intercept	R-squared	D_{eff} (m^2s^{-2})
Unbleached	$-3X10^{-5}$	-0.094	0.99	1.00314E-09
Blanched	$-3X10^{-5}$	-0.523	0.89	1.00314E-09
Peeled	$-3X10^{-5}$	-0.38	0.94	1.00314E-09
Unpeeled	$-3X10^{-5}$	0.010	0.98	1.00314E-09
Average	-0.00003	-0.24675	0.95	1.00314E-09

Akpinar and Toraman, (2016) determined the drying kinetics and convective heat transfer coefficients of ginger slices. The average effective diffusion coefficient for their studies samples for temperature range of 40°C to 70°C were 4.48x$10^{-10}$$m^2$/s, 4.96 x$10^{-10}$$m^2$/s and 5.31 x$10^{-10}$$m^2$/s for 0.8, 1.5 and 3m/s drying air velocity respectively. These values closely agreed with the values of effective diffusion coefficients obtained in this work for the variously treated ginger rhizomes as presented in Table 4.34.

Table 4.34 Moisture diffusivities, D_{eff} of the Ginger samples at various temperatures

	D_{eff}			
Temp (K)	Unblanched	Blanched	Peeled	Unpeeled
283	2.67503E-10	3.00941E-10	2.00627E-10	1.6719E-10
293	2.67503E-10	3.34379E-10	3.34379E-10	2.67503E-10
303	3.34379E-10	6.68758E-10	6.68758E-10	3.34379E-10
313	3.34379E-10	6.68758E-10	6.68758E-10	3.34379E-10
323	6.68758E-10	1.00314E-09	6.68758E-10	6.68758E-10
333	1.00314E-09	1.00314E-09	1.00314E-09	1.00314E-09

Table 4.35 Natural log of Moisture diffusivities, D_{eff} of the Ginger samples at various temperatures

	ln(D_{eff})			
1/Temp (K^{-1})	Unblanched	Blanched	Peeled	Unpeeled
0.00353357	-22.0419	-21.9241	-22.3296	-22.5119
0.00341297	-22.0419	-21.8187	-21.8187	-22.0419
0.00330033	-21.8187	-21.1256	-21.1256	-21.8187
0.00319489	-21.8187	-21.1256	-21.1256	-21.8187
0.00309598	-21.1256	-20.7201	-21.1256	-21.1256
0.003003	-20.7201	-20.7201	-20.7201	-20.7201
Slope	**-2471**	**-2524**	**-2763**	**-3132**
E_a (kJ/mol)	**20.54**	**20.98**	**22.97**	**26.04**

From equation 2.43, plotting of In D_{eff} againt the inverse of the absolute temperature (figure 4.23) led to the evalution of activation energy for diffusion of moisture during drying. The activation energy is obtained by the negative product of the slope of the plot and the universal gas constant (R). The values of activation energies for diffusion of moistue during drying for the variously treated ginger rhizome slices are presented at the bottom of Table 4.35. Akpinar and Toraman, (2016) reported activation energies of ginger slices for 0.8m/s, 1.5m/s and 3m/s air velocities as 19.313kJ/mol, 20.153kJ/mol and 22.722kJ/mol respectively. It could be seen that their values and the values obtained in this study are within the same range. Unpeeled treated ginger has the highest value of activation energy of 26.04kJ/mol while unblanced treated recorded the least value of activation energy of 20.54kJ/mol.

Activation energy is the energy that must be available for any chemical, nuclear or physical phenomenon to occur. Any phenomenon exhibitng negative activation energy is taken as barrierless phenomenon. As expected, the activation energies in this work are positve implying that increase in temperature favours high rate of molecular activities within the sliced ginger rhizomes. This high rate of molecular activities lead to high rate of collosion as the miosture tries to vapourized into the environment.

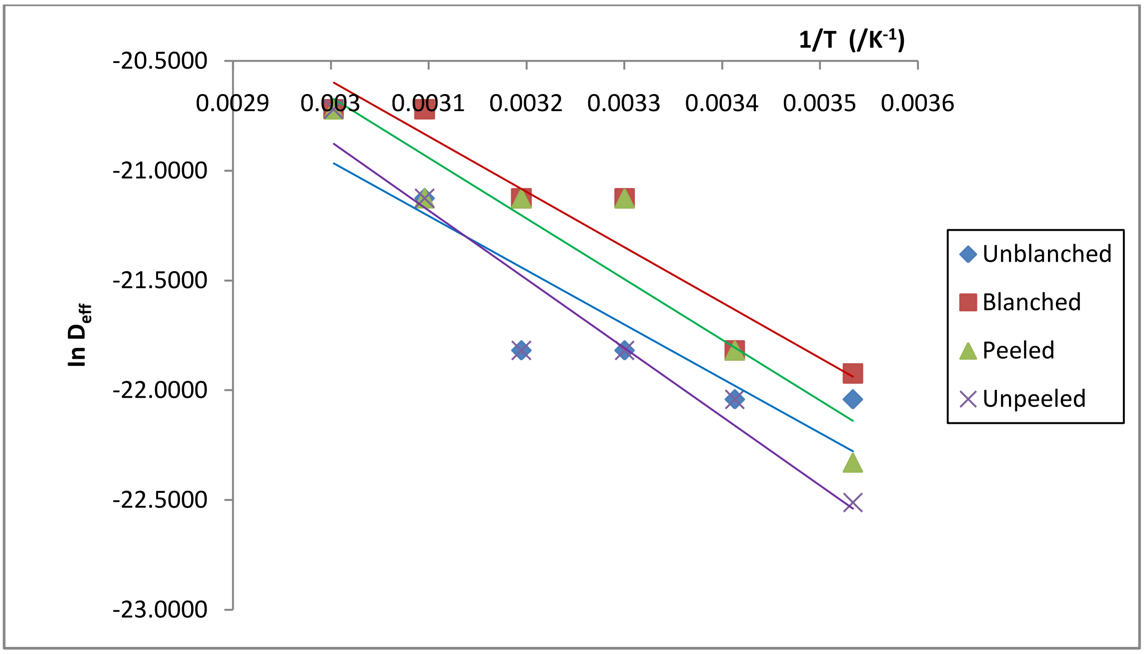


Figure 4.23: Variation of the natural log of the diffusivity of the sample with temperature

4.7 Heat transfer of the Ginger rhizomes using MATLAB Partial Differential Equation Toolbox™ (PDE Toolbox) and Computer programme developed.

The MATLAB Partial Differential Equation Toolbox™ have the capabilities of solving partial differential equations (PDEs) in 2-D, 3-D and time using finite element analysis. It can specify and mesh 2-D and 3-D geometries and formulate boundary conditions and equations. The PDE Toolbox was employed to PDEs for diffusion, heat transfer, structural mechanics, electrostatics, magnetostatics, and AC power electromagnetics, as well as custom, coupled systems of PDEs. In this study, the Boundary condition chosen for the heat transfer problem is the Dirichlet Boundary condition and the PDE specification employed is the elliptic which are mathematically expressed as:

Dirichlet Boundary Condition: $hu = r$ (4.2)

Where h is a matrix, u is the solution vector, and r is a vector.

Elliptic PDE specification: $-div(k * grad(T) = Q + h * (T_{ext} - T)$ (4.3)

Where T is temperature, Q is heat source, k is the coefficient of heat condition, h is the convective heat transfer coefficient, T_{ext} is the external temperature.

A computer programme was also developed in MATLAB to easily compute, analyse and conduct simulations for the ginger drying. The details are contained in Appendix D.

Figure 4.24 show the discretized meshed of the ginger rhizome in line with the cut geometry for the different case under study. The discretized samples have 545 nodes and 1024 triangle elements.

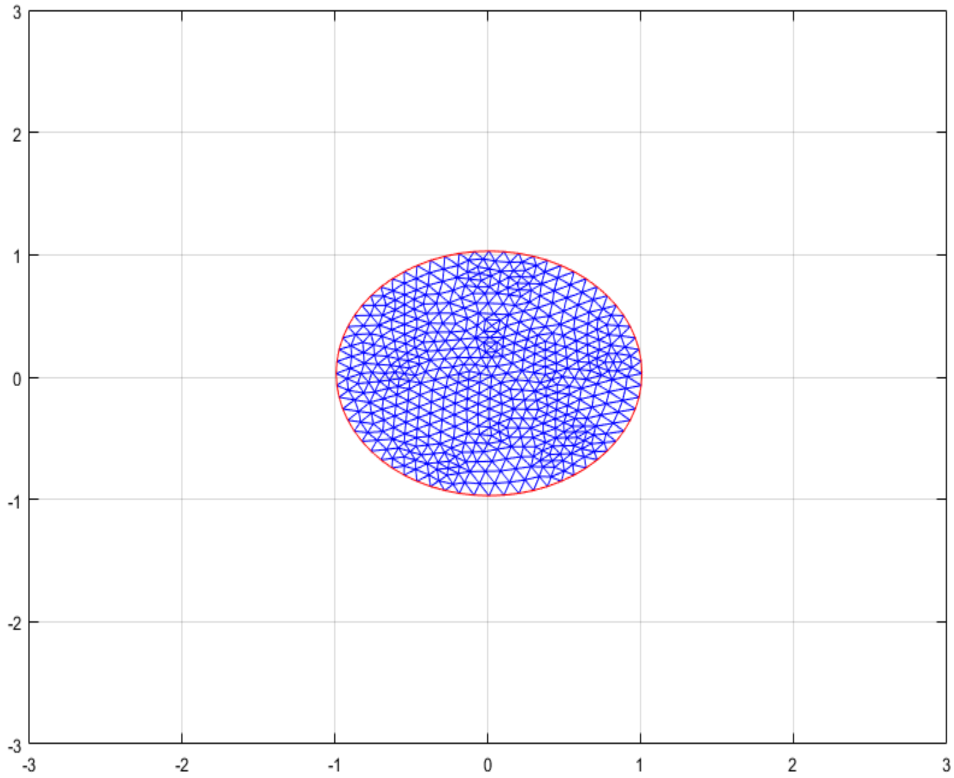


Figure 4.24 Discretized mesh with 545 nodes and 1024 triangles

Figures 4.25-4.26 and Appendix D1-D22 describe the temperature distribution of unblanched, blanched, peeled and unpeeled ginger samples at temperatures: 10°C, 20°C, 30°C, 40°C, 50°C and 60°C. In Figure 4.25, the temperature distribution for the unblanched ginger at 10°C transmits heat radially from 10°C to a final peak temperature of 60°C. For the blanched ginger as shown in figure 4.26, the heat is transmitted radially from 10°C to a final peak temperature of 70°C. In Figure D1, at 10°C for the peeled ginger rhizome. It can be clearly seen that the temperature distribution is radial from 10°C to a final peak temperature of 60°C while for the unpeeled ginger rhizomes in Figure D2, the distribution radiates from 10°C to a final peak temperature of 70°C.

Similarly, at a temperature of 20°C. The temperature distribution in figures D3 and D5, the unblanched and peeled rhizomes respectively, looks alike as both figures radiates from 10°C to a final peak temperature of 60°C. In contrast, the temperature in figure

D4 radiates from 10℃ to a final peak temperature of 80℃ while in figure D6, the temperature rose steadily from 10℃ to 70℃.

For the temperature distributions at 30℃ to 60℃ as typified in figures D7-D22, the peak radial temperatures were seen to higher than what was obtained initially at 10℃ and 20℃. A thorough look in figures D7-D22 show that the temperature distribution at 40℃ was remarkably higher than those obtained at 30℃ and 60℃ but compare relatively to the values obtained at 50℃. The high temperature distribution could be responsible to the colour change obtained for the final product.

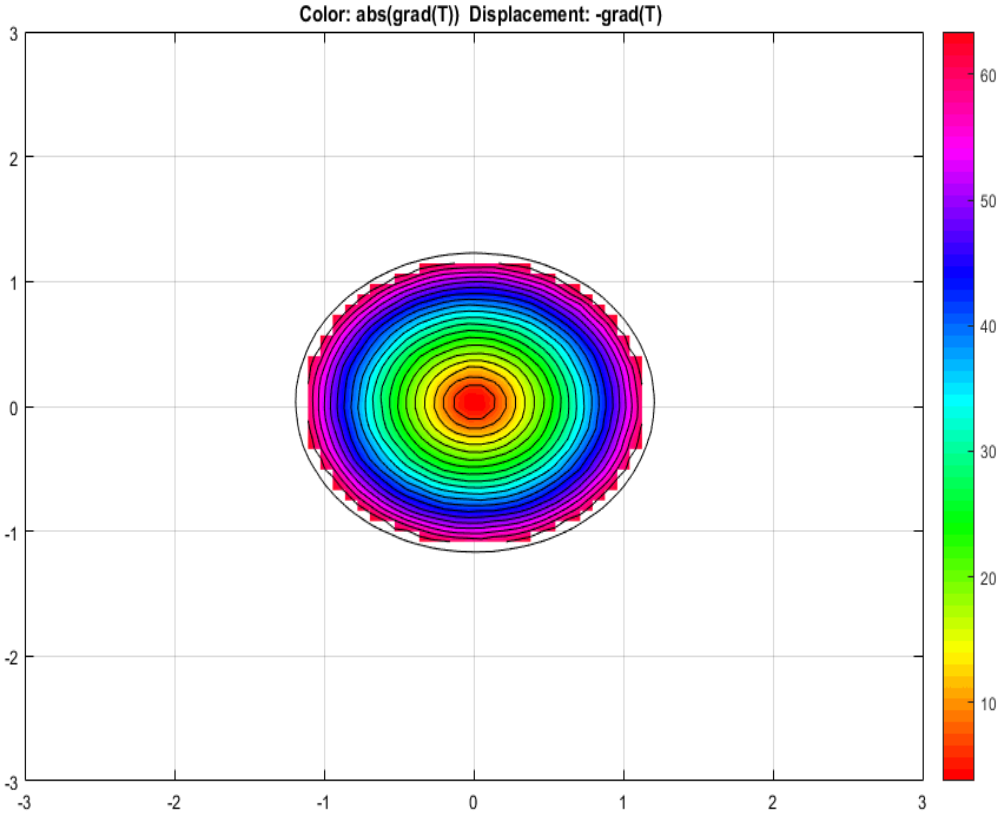


Figure 4.25 Temperature distribution for the Unblanched at 10℃

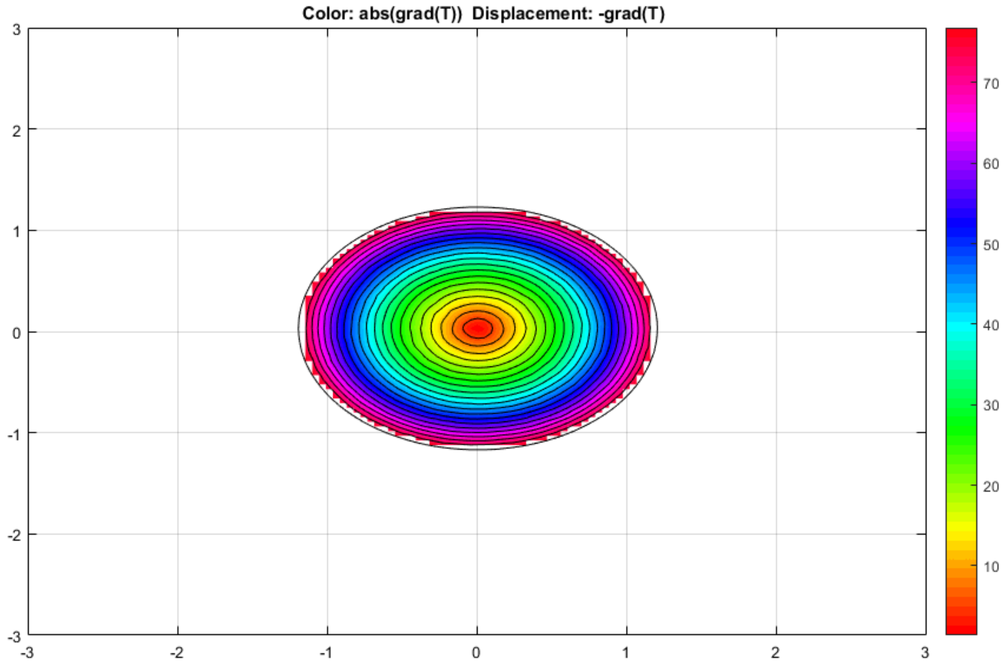


Figure 4.26 Temperature distributions for the Blanched at 10℃

Figures 4.25, 4.26, D1 to D22 presented the Matlab generated temperature distribution profiles for variously treated ginger samples at different temperature levels. The profile showed that temperature increased from the core to the outermost contour.This is clearly demonstrated in figures 4.27 to 4.32. The diameter of the samples were 30mm and the thickness were 18mm. The distance from the outermost contour to the core of the sample is about 15mm. The Matlab simulated temperature distribution showed that at chamber temperature of 10°C, the core temperature of blanched ginger sample was 10°C and that of other treatments were below 10°C (figure 4.27). Also from figure 4.27, it could be observed that the temperature increasesed linearly from the center (core) to the outermost contour. Similar trend could be noticed for other chamber temperatures (see figures 4.28 to 4.32).

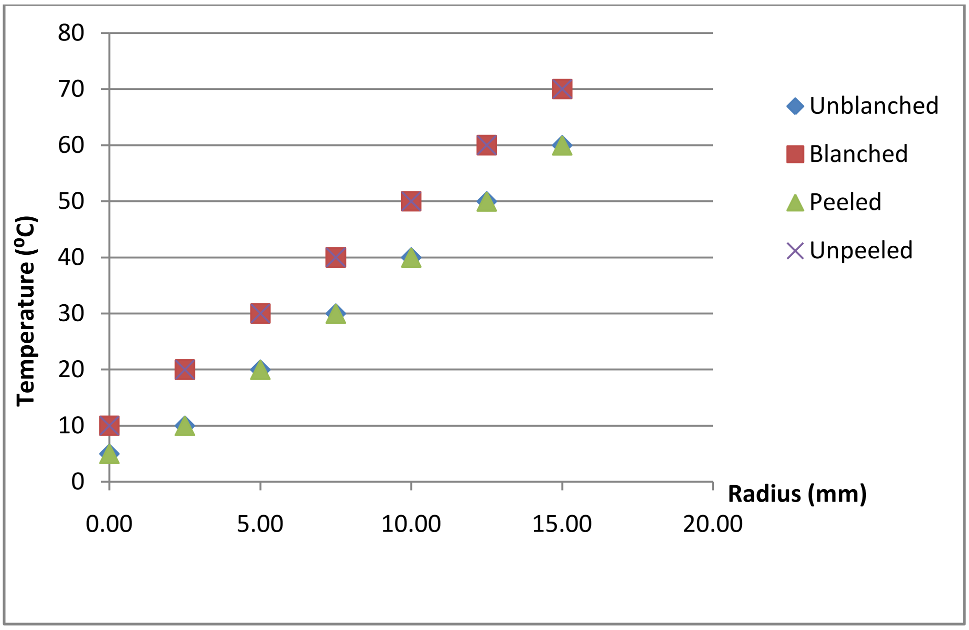


Figure 4.27: Simulated temperature distribution for variously treated ginger samples at 10^{0}C

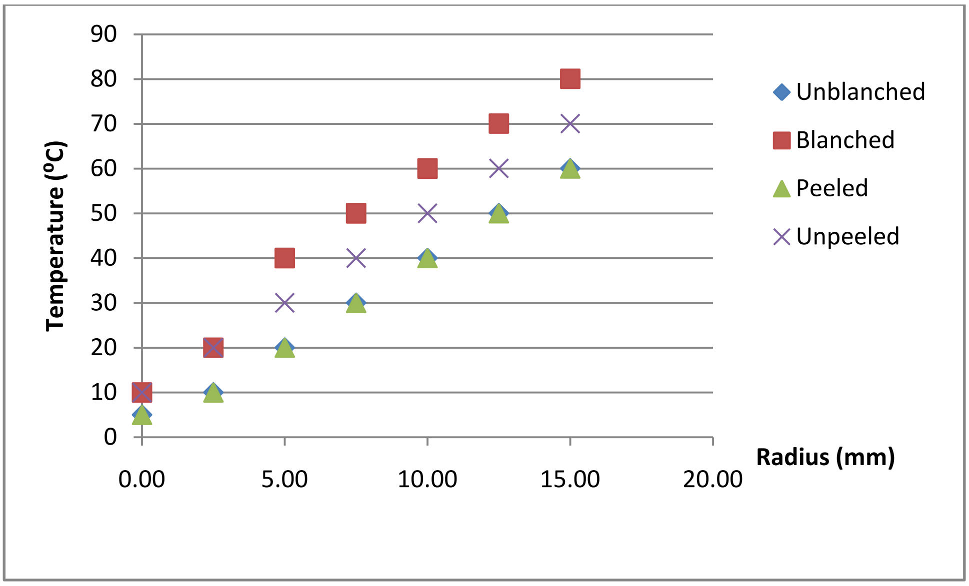


Figure 4.28: Simulated temperature distribution for variously treated ginger samples at 20^{0}C

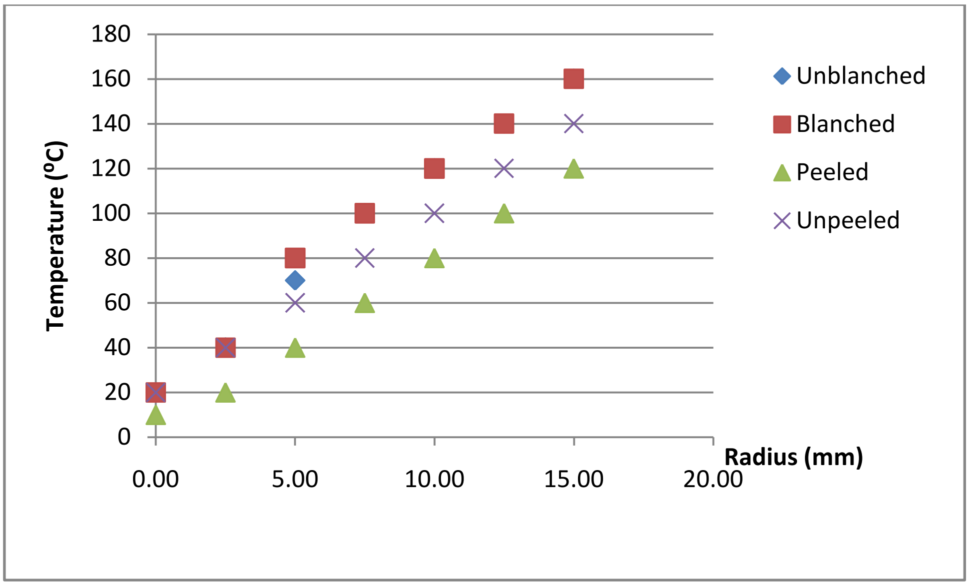


Figure 4.29: Simulated temperature distribution for variously treated ginger samples at 30^{o}C

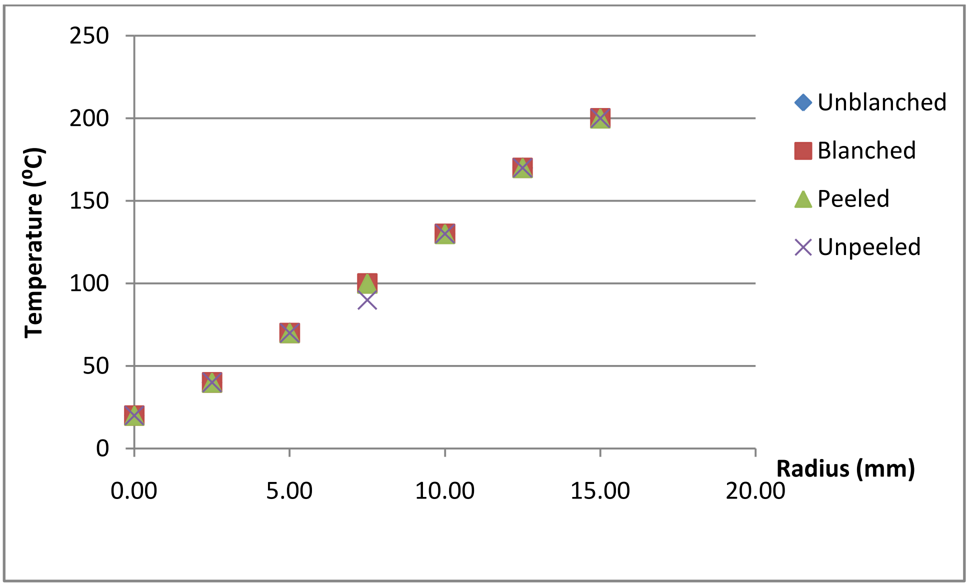


Figure 4.30: Simulated temperature distribution for variously treated ginger samples at 40^{0}C

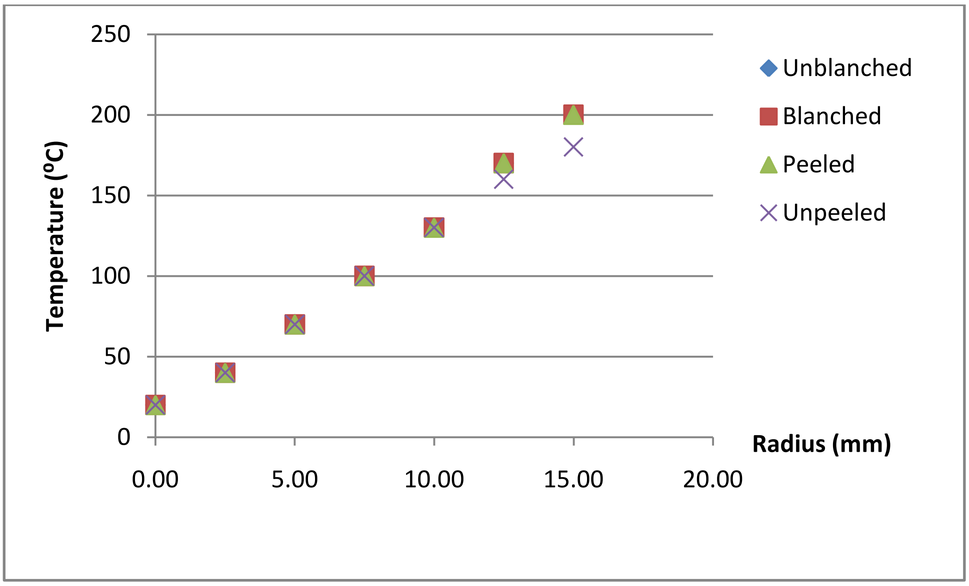


Figure 4.31: Simulated temperature distribution for variously treated ginger samples at 50^{0}C

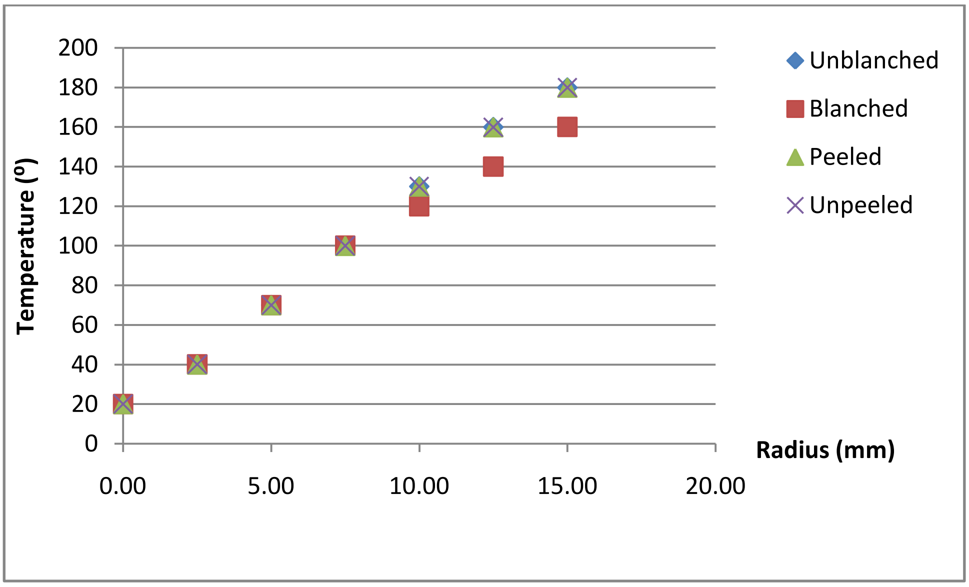


Figure 4.32: Simulated temperature distribution for variously treated ginger samples at 60^{0}C

From Fourier's law of heat conduction, it can be seen that the amount of heat flowing through a sample is given as

$$Q = kA\frac{\Delta T}{\Delta r} \tag{4.4}$$

From the plot of temperature variation against radius, the thermal conductivity, k, can be evaluated using the relationship:

$$k = \frac{Q}{slope \times A} \tag{4.5}$$

Table 4.36 presented the slopes of figures 4.27 through 4.32 for variously treated ginger samples. The values of table 4.36 were used to generate table 4.37 using equation 4.5. The average value for each treatment was evaluated and highlighted in table 4.37.

Table 4.36: Slope of temperature distribution against radius for various treatment

Temp (°C)	Unblanched	Blanched	Peeled	Unpeeled
10	3.785	4.000	3.785	4.000
20	3.785	4.714	3.785	4.000
30	9.571	9.428	7.571	8.000
40	12.280	12.280	12.280	12.280
50	12.240	12.280	12.280	11.140
60	11.140	9.571	11.140	11.140

Table 4.37: Thermal conductivity values from the simulated solution

Temp (°C)	Unblanched	Blanched	Peeled	Unpeeled
10	0.74749	0.70731	0.74749	0.70731
20	0.74749	0.60018	0.74749	0.70731
30	0.29561	0.30009	0.37370	0.35366
40	0.23040	0.23040	0.23040	0.23040
50	0.23115	0.23040	0.23040	0.25397
60	0.25397	0.29561	0.25397	0.25397
Average	**0.41768**	**0.39400**	**0.43057**	**0.41777**

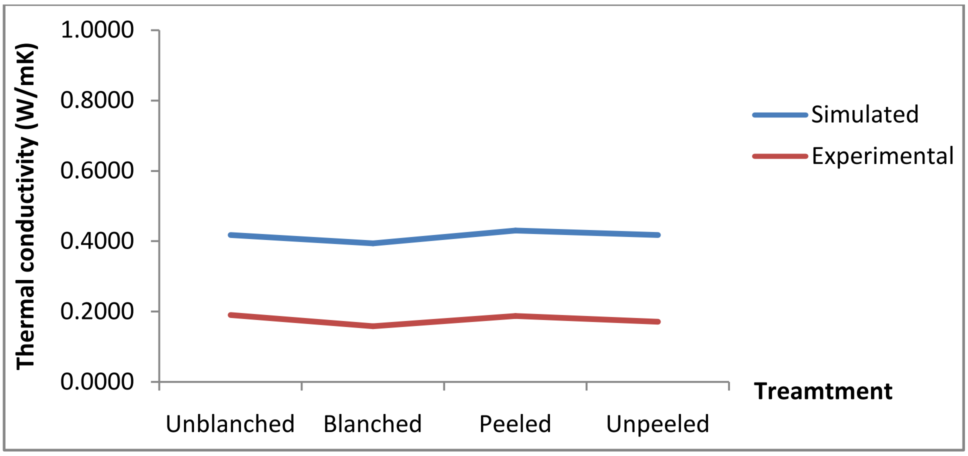


Figure 4.33: Comparsion of experimental and simulated thermal conductivity

Figure 4.33 compared the experimental and simulated thermal conductivity. The average values of thermal conductivities of table 4.19 and that of table 4.37 were used in the comparison. It could be seen that the plots followed the same trend for various treatment, although the plot for the simulated thermal conductivity was slightly higher that of the experimental.

Comparing the thermal conductivities for the unblanched at different temperature shows that at 10^0C, the result obtained by simulation is about 45.63% larger than that obtained from the experiment; at 20°C, the result obtained by simulation is about 45.63% larger than that obtained from the experiment; at 30°C, the result obtained by simulation is about 63.67% larger than that obtained from the experiment; at 40°C, the result obtained by simulation is about 67.19% larger than that obtained from the experiment; at 50°C, the result obtained by simulation is about 69.07% larger than that obtained from the experiment; at 60°C, the result obtained by simulation is about 70.00% larger than that obtained from the experiment. Similar results are obtained for other treatments. Comparing the average thermal conductivities for the variously treated ginger shows that simulation is about 54.37%, 59.86%, 56.41% and 59.12% larger than that obtained from the experiment for unblanched, blanched, peeled and unpeeled respectively. The large differences may have occurred from the values of the results from simulation.

Table 4.38 Table of Moisture Content (%) and Thermal Conductivity (W/m. K) for Unblanched, Blanched, Peeled and Unpeeled Ginger Rhizomes from $10℃$ to $60℃$ and drying time of 2 and 24 Hours

Temperature	10°C		20°C		30°C		40°C		50°C		60°C	
Time (Hour)	2	24	2	24	2	24	2	24	2	24	2	24
Final Moisture Content (%)												
Unblanched	88.84	49.55	86.55	47.81	87.34	39.55	79.32	30.12	71.65	17.95	74.16	6.63
Blanched	84.58	41.13	86.29	34.26	86.65	17.48	70.11	17.00	66.64	10.25	63.11	9.04
Peeled	88.74	55.91	87.85	37.49	87.95	27.76	75.93	23.92	65.50	13.21	70.75	8.56
Unpeeled	91.08	62.22	86.17	48.36	87.71	31.15	81.46	26.30	67.85	15.49	74.36	5.98
Thermal Conductivity (W/m. K)												
Unblanched	0.406	0.161	0.406	0.149	0.107	0.068	0.076	0.056	0.072	0.054	0.076	0.055
Blanched	0.329	0.140	0.292	0.131	0.1006	0.069	0.071	0.056	0.073	0.0556	0.084	0.052
Peeled	0.377	0.143	0.377	0.139	0.1459	0.065	0.072	0.052	0.076	0.0519	0.079	0.048
Unpeeled	0.340	0.171	0.345	0.171	0.1126	0.061	0.072	0.054	0.078	0.0460	0.078	0.046

4.8 Moisture Content Model by Dimensional Analysis

It is known that dimensionally, moisture content is a dimensionless quanitity hence we can establish a dimensionless group which relates moisture content with other variables. By dimensional analysis, we have

$$M = \left(\frac{W}{kTt}\right) \tag{4.6}$$

Where M is the moisture content, k is thermal conductivity (W/mK), t is time (sec), W is weight (N) and T is temperature (K).

Equation 4.4 can be transformed as

$$M = \alpha\left(\frac{W}{kTt}\right)^{\beta} \tag{4.7}$$

Taking the log of equation 4.7, will give

$$logM = log\alpha + \beta log\left(\frac{W}{kTt}\right) \tag{4.8}$$

Table 4.39 The log of the Moisture Model Dimensional Group

	log (W/kTt) @10^{o}C			
Ave Log M	Unblanched	Blanched	Peeled	Unpeeled
1.94561	-3.87294	-3.81678	-3.85375	-3.74269
1.91652	-4.11001	-4.01612	-4.03813	-4.07143
1.874186	-4.34303	-4.31376	-4.28523	-4.36118
1.832975	-4.42544	-4.38692	-4.43701	-4.38272
1.790579	-4.42508	-4.49953	-4.50961	-4.56
1.737729	-4.66195	-4.60153	-4.59503	-4.56176
1.712655	-4.81874	-4.72985	-4.70097	-4.71817
	log (W/kTt) @20^{o}C			
1.93783	-3.92823	-3.71319	-3.86489	-3.89176
1.894571	-4.218	-3.98889	-4.22008	-4.1171
1.858239	-4.42561	-4.3603	-4.39476	-4.38906
1.823883	-4.38089	-4.30641	-4.41282	-4.48539
1.716387	-4.57352	-4.58395	-4.57748	-4.60144
1.672099	-4.57041	-4.6587	-4.64994	-4.63646
1.618177	-4.69645	-4.97576	-4.80763	-4.778
	log (W/kTt) @30^{o}C			
1.941567	-3.40916	-3.26549	-3.42267	-3.38665
1.904854	-3.67558	-3.54191	-3.67179	-3.61616
1.860148	-3.92271	-3.92265	-3.82602	-3.95078
1.828361	-4.02608	-4.02077	-4.04384	-3.8336
1.626783	-4.21085	-4.38517	-4.53196	-4.14355
1.566035	-4.27701	-4.543	-4.35215	-4.1904
1.444141	-4.52368	-4.8189	-4.64174	-4.5819
	log (W/kTt) @40^{o}C			
1.88413	-3.21035	-3.27211	-3.26442	-3.17258
1.798401	-3.52399	-3.73028	-3.64309	-3.50228
1.699571	-3.91241	-4.07327	-3.94339	-3.83233
1.586498	-4.14319	-4.25618	-4.11658	-4.13754
1.50574	-4.15962	-4.49463	-4.24236	-4.22533
1.446703	-4.26655	-4.54754	-4.39777	-4.37871
1.377005	-4.49252	-4.74608	-4.5767	-4.60232
	log (W/kTt) @50^{o}C			
1.831686	-3.31652	-3.31857	-3.32618	-3.37205
1.75292	-3.6608	-3.5728	-3.55933	-3.71359
1.6233	-4.06594	-4.06987	-4.02851	-4.15794
1.531239	-4.19168	-4.21974	-4.27659	-4.09318
1.348032	-4.64601	-4.36685	-4.57157	-4.31995
1.276584	-4.81949	-4.45796	-4.55495	-4.39029
1.143936	-4.95954	-4.7511	-4.84913	-4.72592
	log (W/kTt) @60^{o}C			
1.847833	-3.22204	-3.37724	-3.25528	-3.22221
1.710043	-3.67073	-3.74112	-3.75901	-3.59135

1.54788	-4.06423	-4.24832	-4.14115	-3.91944
1.411877	-4.21562	-4.40348	-4.28764	-4.18106
1.224368	-4.62582	-4.61314	-4.64872	-4.42401
1.096223	-4.74034	-4.8217	-4.79082	-4.66634
0.871714	-5.17679	-5.04321	-5.02729	-5.11312

Table 4.39 was used to plot the graph of log(W/kTt) against log(M) at various temperature levels for the ginger samples. The graphs are presented in figures 4.34 – 4.39.

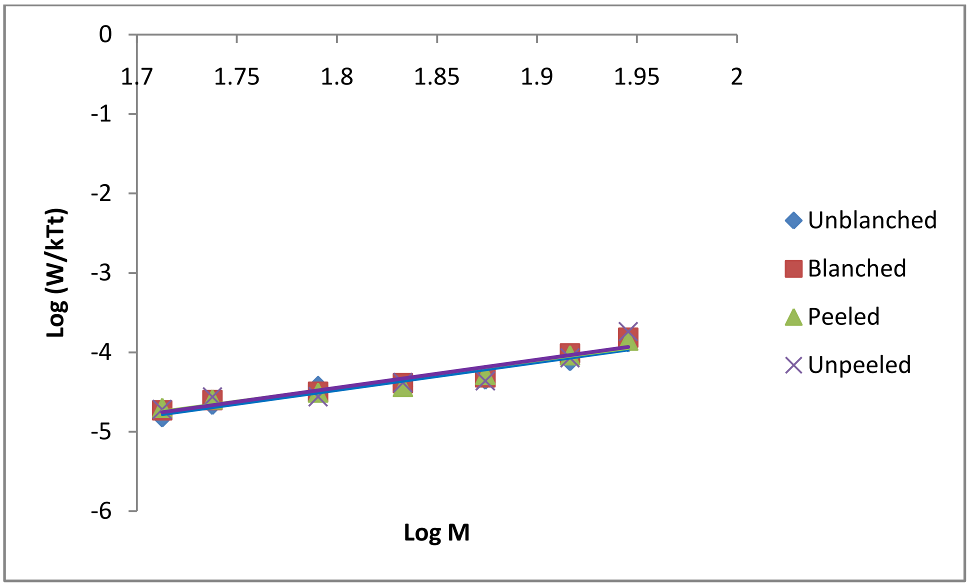


Figure 4.34: Moisture dimensional plot at 10^{o}C

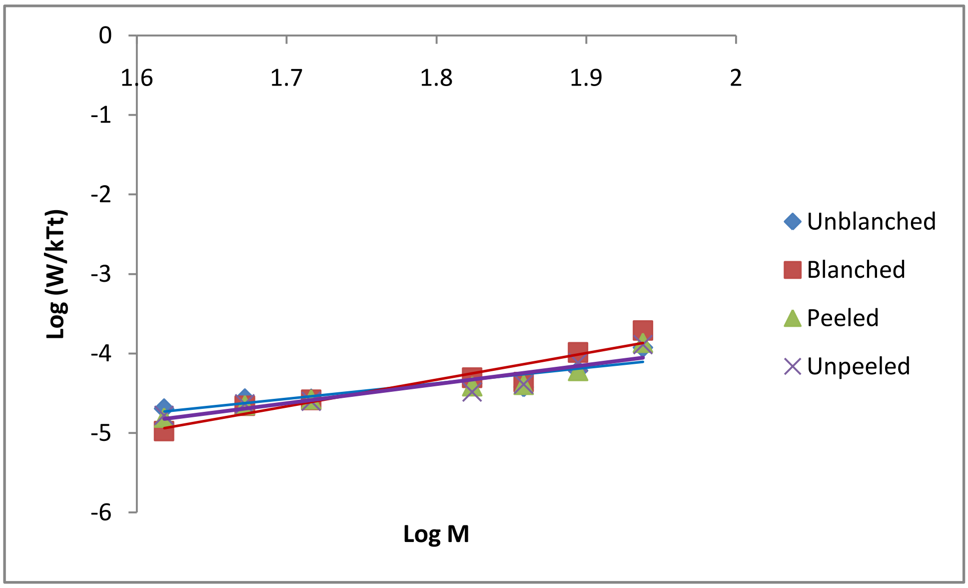


Figure 4.35: Moisture dimensional plot at 20^{o}C

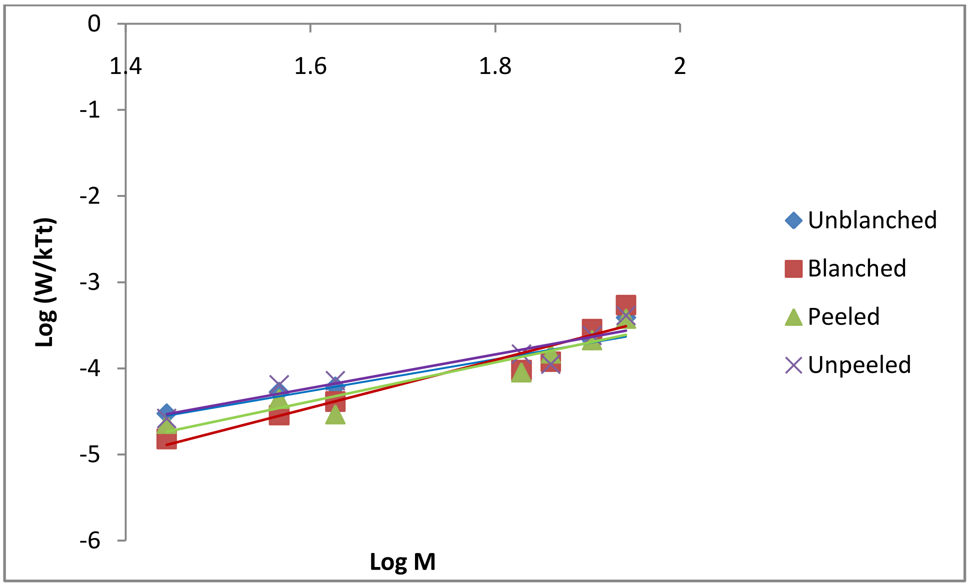


Figure 4.36: Moisture dimensional plot at 30°C

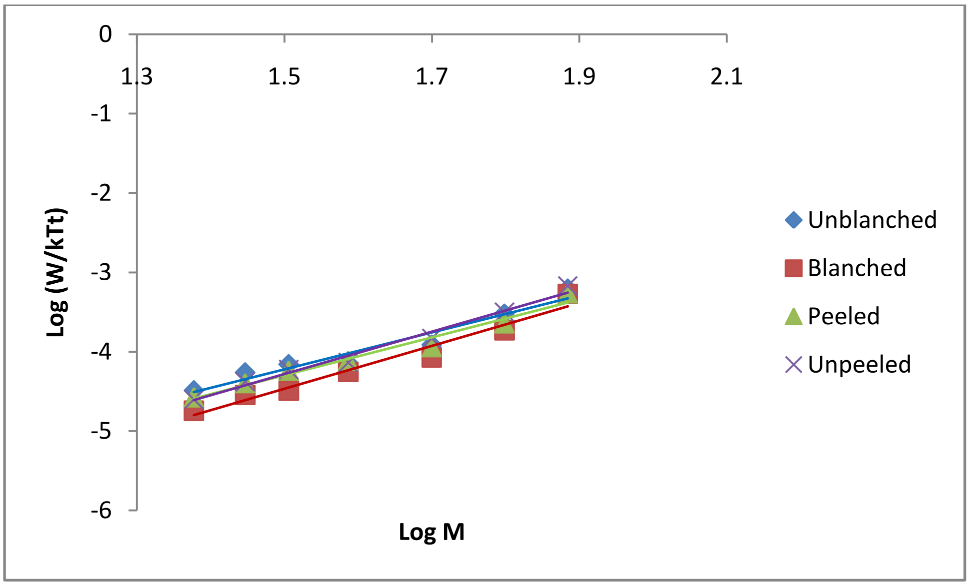


Figure 4.37: Moisture dimensional plot at 40°C

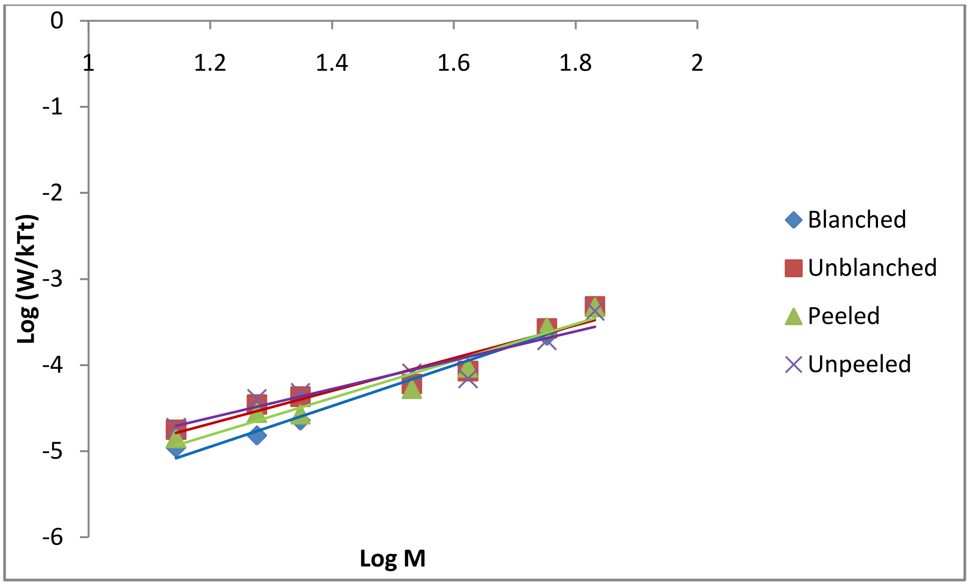


Figure 4.38: Moisture dimensional plot at 50^{o}C

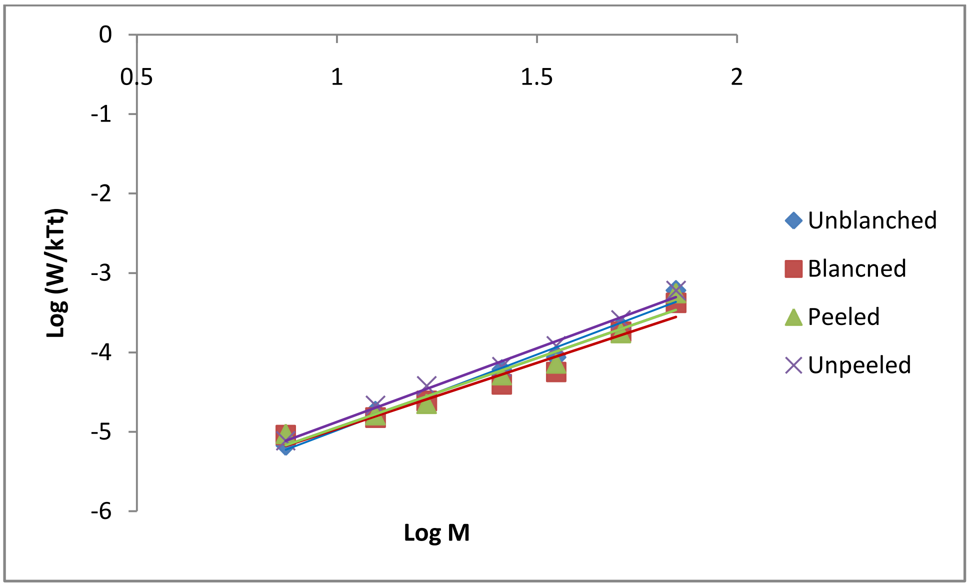


Figure 4.39: Moisture dimensional plot at 60^{o}C

Table 4.40: α and β values for the developed moisture content model

	Blanched		Unblanched		Peeled		Unpeeled	
Temperature	α	β	α	β	α	β	α	β
10^{o}C	1121.61	0.282	1215.8	0.287	1316.53	0.297	1138.67	0.283
20^{o}C	1225.03	0.298	10769.92	0.510	4224.55	0.416	4221.15	0.416
30^{o}C	1620.09	0.361	8197.49	0.543	3473.31	0.443	5920.44	0.514
40^{o}C	1431.1	0.371	2062.69	0.430	2020.51	0.420	1266.21	0.374
50^{o}C	1954.73	0.422	3124.38	0.524	2764.05	0.466	9032.77	0.597
60^{o}C	9673.15	0.601	4102.09	0.524	6843.84	0.573	4262.36	0.539
Average	**2837.62**	**0.39**	**4912.06**	**0.47**	**3440.47**	**0.44**	**4306.93**	**0.45**

From eqn 4.7, the empirical equations relating moisture content to properties of ginger were determined by dimensionless analysis. These equations for the variously treatment ginger rhizomes are presented in eqns (4.9) to (4.12). The coefficients and indices are the average values of α and β as contained in Table 4.40 respectively. These equations might be used to predict the moisture content of the variously treated ginger rhizomes.

$$M = 2837.62\left(\frac{W}{kTt}\right)^{0.39} \tag{4.9}$$

$$M = 4912.06\left(\frac{W}{kTt}\right)^{0.47} \tag{4.10}$$

$$M = 3440.47\left(\frac{W}{kTt}\right)^{0.44} \tag{4.11}$$

$$M = 4306.93\left(\frac{W}{kTt}\right)^{0.45} \tag{4.12}$$

Equations 4.9 to 4.12 were used in predicting moisture content for variously treated ginger samples. The results are presented in table 4.41, the predicted values are close to actual experimental values. This indicates that the models can be used to predict moisture content for the variously treated ginger. The results of table 4.41 were plotted in figures 4.40 to 4.43, to the deviations of the prediction models of moisture content from the experimental values.

Table 4.41: Actual and predicted values of moisture content

Temperature (^oC)	Blanched		Unblanched		Peeled		Unpeeled	
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
10	41.13	40.58	49.55	26.70	55.91	29.39	62.22	32.43
20	34.26	32.54	47.81	30.47	37.49	26.38	48.36	30.48
30	17.48	37.46	39.55	36.74	27.76	31.21	31.15	37.35
40	17.00	39.99	30.12	38.00	23.92	33.33	26.30	36.57
50	10.25	33.02	17.95	28.72	13.21	25.29	15.49	32.17
60	9.04	30.63	6.63	18.12	8.56	21.12	5.98	21.54

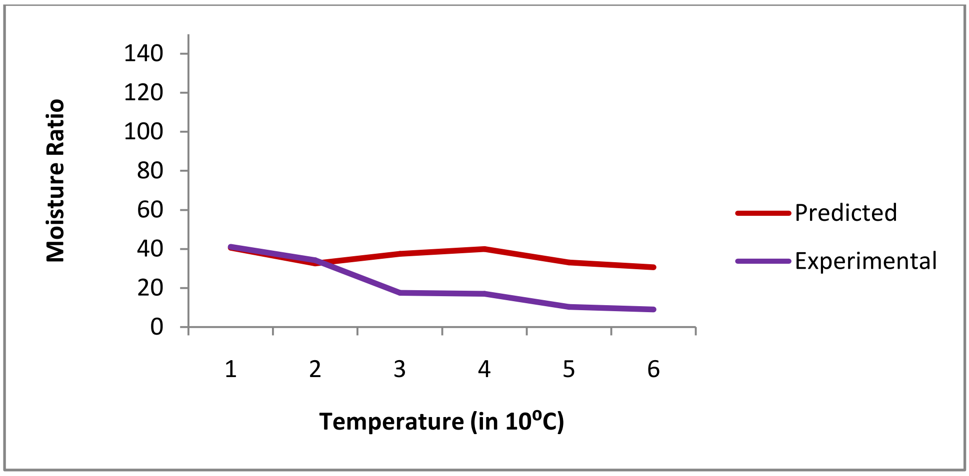


Figure 4.40: Experimental and predicted moisture content for blanched ginger

Figure 4.40 presents the comparison between the experimental values and predicted values of moisture ratio for blanched treated ginger sample. From the plot, it could be seen that both experimental values and predicted values are same at lower temperature of 10°C to 24°C. Moreover, the moisture ratio trends for both scenarios are same and close.

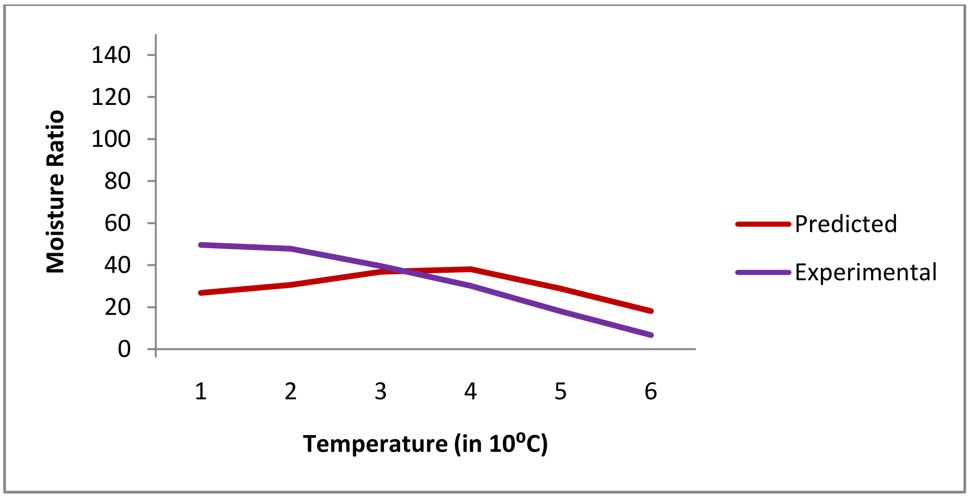


Figure 4.41: Experimental and predicted moisture content for unblanched ginger

Figure 4.41 presents the comparison between the experimental values and predicted values of moisture ratio for unblanched treated ginger sample. From the plot, it could be seen that the experimental values decrease progressively as the temperature increases while the predicted values increased with temperature upto 40°C and then decrease with increase in temperature. Both predicted and experimental moisture ratio had the same value at temperature of 32°C. From the plot, it could be deduced that the prediction model can be used to predict the behavior of the moisture ratio at temperature above 39^{o}C.

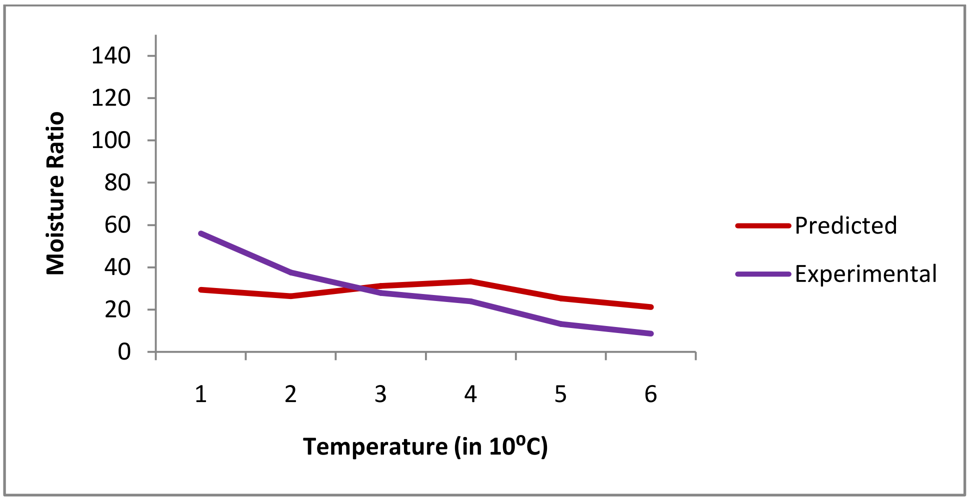


Figure 4.42: Experimental and predicted moisture content for peeled ginger

Figure 4.42 presents the comparison between the experimental values and predicted values of moisture ratio for peeled ginger sample. From the plot, it could also be seen that the experimental values decrease progressively as the temperature increases while the predicted values increased with temperature upto 40^{o}C and then decrease with increase in temperature. Both predicted and experimental moisture ratio had the same value at temperature of 27^{o}C. Also, the prediction model can be used to predict the behavior of the moisture ratio at temperature above 39^{o}C.

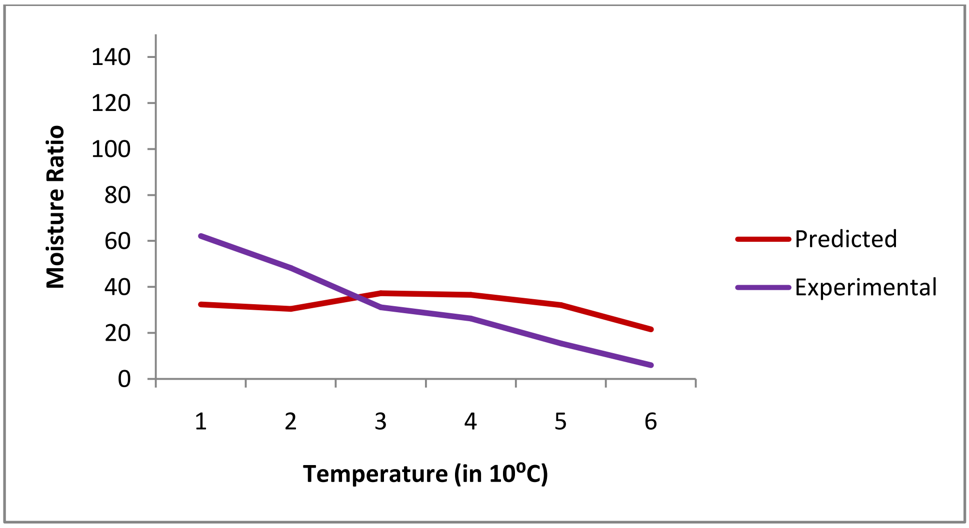


Figure 4.43: Actual and predicted moisture content for unpeeled ginger

Figure 4.43 presents the comparison between the experimental values and predicted values of moisture ratio for unpeeled ginger sample. From the plot, it could also be seen that the experimental trend decreases as temperature increases. Both predicted and experimental moisture ratio had the same value at temperature of 27°C. The predicted moisture ratio trend follows the same trend as the experimental values from 30°C upwards; hence, the prediction model could be use to predict behavior of the moisture ratio at 30°C and above.

4.9: Statistical Validation of the Drying Model

Both theoretical considerations and experimental investigations of drying processes are focused on the drying kinetics. The drying kinetics includes changes in moisture content and changes in mean temperature with respect to drying time. Drying studies provide the basis for understanding the unique drying characteristics of any particular food material. In the study of drying process, the moisture content of bio material exposed to a stream of drying air is monitored over a period of time.

Drying models are used for the investigation of the drying kinetics (Ceylan et al., 2007). A number of mathematical models have been developed to simulate moisture movement and mass transfer during the drying of many agricultural products. In this work, the experimental moisture ratio data of the various ginger treatments were fitted to twelve drying models. These models were presented in section 2.3.2 (Equations 2.18, 2.19, 2.21, 2.24-2.31) and the summary is given in Table 4.42.

The drying data of the ginger samples were fitted to the twelve thin layer drying models and the data subsets were fitted by multiple non linear regression technique. Regression analysis were performed using the R Project for Statistical Computing (R version 3.5.2).The determination coefficient (R^2) (2.33), is the primary basis for selecting the best equation to describes the drying curve. The models with the highest values of R^2 are the most suitable models for describing the thin layer drying characteristics of the ginger samples. Besides R^2, the standard error of estimate (SEE) and root mean square error (RMSE), (2.34) and (2.35) respectively, were used to determine the goodness of fit. The values of SEE and RMSE should be low for good fit. Tables 4.43-4.46 presented the results of the curve fitting computations with the drying time for the twelve models with statistical analysis.

Table 4.42: Drying Models for Agricultural Products

S/N	Model Name	Drying Model
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page	$MR = \exp -(kt)^n$
4	Henderson and Pabis	$MR = a.\exp(-kt)$
5	Logarithmic	$MR = a.\exp(-kt) + c$
6	Two term	$MR = a.\exp(-k_o t) + b.\exp(-k_1 t)$
7	Two term exponential	$MR = a.\exp(-kt) + (1-a)\exp(-kat)$
8	Wang and Singh	$MR = 1 + \mathrm{at} + \mathrm{bt}^2$
9	Diffusion approach	$MR = a.\exp(-kt) + (1-a)\exp(-kbt)$
10	Modified Henderson and Pabis	$MR = a.\exp(-kt) + b.\exp(-gt) + c.\exp(-ht)$
11	Verma et al.	$MR = a.\exp(-kt) + (1-a)\exp(-gt)$
12	Midilli et al.	$MR = a.\exp(-kt^n) + bt$
13	Austin Approach	$MR = \alpha\left(\frac{W}{ktT}\right) exp\beta$

Table 4.43: Coefficient of models and goodness of fit for Unblanched ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1738	0.4557	64.3219	0.0437
		20	k= -0.1723	0.4562	59.8300	0.0422
		30	k= -0.1663	0.4405	60.7943	0.0494
		40	k= -0.1564	0.4307	48.3551	0.0496
		50	k= -0.1399	0.4035	40.8199	0.0616
		60	k= -0.1171	0.3624	39.1357	0.1006
2	Page	10	k= -4.7054, n= -0.0491	0.7746	6.6736	0.1182
		20	k= -4.6631, n= -0.0525	0.8475	5.1806	0.0975
		30	k= -4.7522, n= -0.0649	0.7382	8.8685	0.1657
		40	k= -4.6913, n= -0.0889	0.9559	3.3324	0.0763
		50	k= -4.7001, n= -0.1220	0.9412	4.1183	0.1139
		60	k= -4.8946, n= -0.1692	0.8743	7.4558	0.2314
3	Modified Page	10	k= -2110000, n= 0.0832	0.2677	30.7637	39900000
		20	k= -2141000, n=	0.2628	28.5385	40790000

			0.0822			
		30	k= -4409000, n= 0.0784	0.2132	31.6093	104800000
		40	k= k= -3496000, n=0.0763	0.1725	26.3335	90820000
		50	k= -6722000, n= 0.0993	0.1199	24.6464	243400000
		60	k= -0.00008, n= -0.1693	0.8743	7.4558	0.0313
4	Henderson and Pabis	10	k= 0.0299, a= 95.8216	0.9345	3.7042	3.8099
		20	k= 0.0303, a= 89.9556	0.9310	3.6031	3.7144
		30	k= 0.0409, a= 97.2675	0.9139	5.2717	5.7999
		40	k= 0.0506, a= 83.5059	0.9588	3.4020	3.9632
		50	k= 0.0722, a= 79.7556	0.9867	2.0894	2.7490
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	5.0421
5	Logarithmic	10	k= 0.0297, a= 96.2870, c= -0.4886	0.9345	3.7041	171.5739
		20	k= 0.0566, a= 63.6015, c= 29.1920	0.9380	3.3824	44.7031
		30	k= 0.0374, a= 102.5839, c= -5.7667	0.9144	5.2667	155.2513
		40	k= 0.1155, a= 66.0792, c= 26.4788	0.9911	1.5304	6.6286
		50	k= 0.1121, a= 72.1372 c= 13.3545	0.9990	0.5569	2.4776
		60	k= 0.0997, a= 90.9417, c= -2.6588	0.9800	3.1412	15.9152
6	Two Term	10	K1= 0.0328, k2= 0.4860, a= 100.12 , b= -14.18	0.9408	3.5478	67.3540
		20	k1= -0.1975, k2= 0.0359, a= 0.0652, b= 92.50	0.9494	3.0662	8.6839
		30	k1= 0.0484, k2= 0.4031, a= 108.48, b= -27.04	0.9281	4.8917	84.5508
		40	k1= 0.0172, k2= 0.1602 , a= 44.07 , b= 50.50	0.9916	1.4888	68.4724
		50	k1= 0.0386, k2= 0.1812, a= 43.44, b= 44.82	0.9994	0.4129	25.9763
		60	k1= 0.0101, k2= 4.353, a= 83.38, b= 36130	0.9824	2.9025	394605484
7	Two Term Exponential	10	k= 0.0300, a= 95.93	0.9349	3.6865	3.6564
		20	k= 0.0306, a= 90.2740	0.9307	3.6283	3.5850
		30	k= 0.0409, a= 97.2743	0.9138	5.2696	5.7670
		40	k= 0.0505, a= 83.53	0.9588	3.4048	3.9541

		50	k= 0.07221, a= 79.75	0.9867	2.0896	2.7486
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	5.0421
8	Wang and Singh	10	a= 12.4486, b= -0.4665	0.3867	32.7700	3.85
		20	a= 11.4252, b= -0.4242	0.3676	31.5500	3.71
		30	a=11.6757, b= -0.4523	0.3623	33.4244	3.9258
		40	a= 8.8782, b= -0.3432	0.3113	29.5096	3.4660
		50	a= 7.3172, b= -0.2974	0.2963	27.0252	3.1742
		60	a= 6.6709, b= -0.2924	0.2939	28.3493	3.3297
9	Diffusion Approach	10	k= 0.1600, a= 195300, b= 1.001	0.6767	16.2880	11510000000
		20	k= 0.1612, a= 191300, b= 1.001	0.6397	16.6644	4285000000
		30	k= 0.1806, a= 72100, b= 1.004	0.7638	14.0258	2017000000
		40	k= 0.200, a= 6468, b= 1.032	0.7066	14.6413	12530070
		50	k= 0.2402, a= 221300, b= 1.001	0.8086	10.8549	10980000000
		60	k= 0.2869, a= 471100, b= 1.00	0.8913	8.4190	4267000000
10	Modified Henderson and Pabis	10	k= -0.5331, a= 0.00003, b= 298.4, g=0.0775, c= -213.5, h= 0.1197	0.9728	2.3789	64638.62
		20	k= -0.0319, a= 285.0, b= 164.1, g= -0.0835, c= -361.9, h= -0.0665	0.9717	2.2788	15457702
		30	k= 0.4411, a= -21.57, b= 301.1, g= 0.0603, c= -196.92, h= 0.0695	0.92665	4.9615	19006351
		40	k= 0.1252, a= 100.1, b= 250.9, g= 0.0415, c= -256.6 , h= 0.0557	0.9916	1.4863	22319738
		50	k= 0.1252, a= 100.1, b= 250.9, g= 0.0415, c= -256.6 , h= 0.0557	0.7720	10.4271	22319738
		60	k= 0.1252, a= 100.1, b= 250.9, g= 0.0415, c= -256.6 , h= 0.0557	0.6302	17.5589	22319738
11	Verma et al.	10	k= 0.0315, a= 97.9646, g= 1.6684	0.9387	3.5989	7.1512
		20	k= 0.0315, a= 97.9646, g= 1.6685	0.8576	6.0239	7.1512
		30	k= 0.0441, a= 101.52, g= 1.4019	0.9209	5.0911	11.1057
		40	k= 0.0441, a= 101.52, g= 1.4019	0.6988	14.4358	11.1057
		50	k= 0.0441, a= 101.52,	0.5952	24.2886	11.1057

			g= 1.4019			
		60	k= 0.0441, a= 101.52, g= 1.4019	0.5574	30.6585	11.1057
12	Midilli et at	10	k= -4.4492, a= -0.2297, b= 1.2110	0.6801	11.7124	1.1793
		20	k= -4.4356, a= -0.2418, b= 1.1722	0.7837	8.5460	0.87393
		30	k= -4.3899, a= -0.2158, b= 0.5625	0.8661	7.8576	0.7985
		40	k= -4.5787, a= -0.3113, b= 0.7594	0.8040	8.6490	0.9213
		50	k= -4.5178, a= -0.3290, b= 0.2430	0.89709	6.2558	0.7030
		60	k= -4.5607, a= -0.3298, b= -0.3387	0.9613	4.5454	0.5032

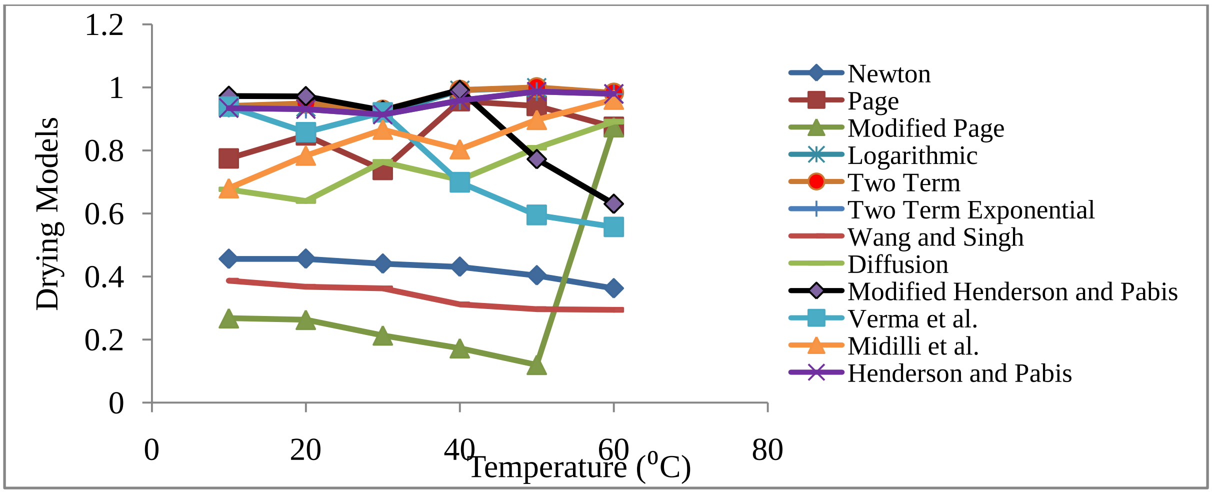


Figure 4.44 Drying models versus temperature for determination coefficient (Unblanched Treatment)

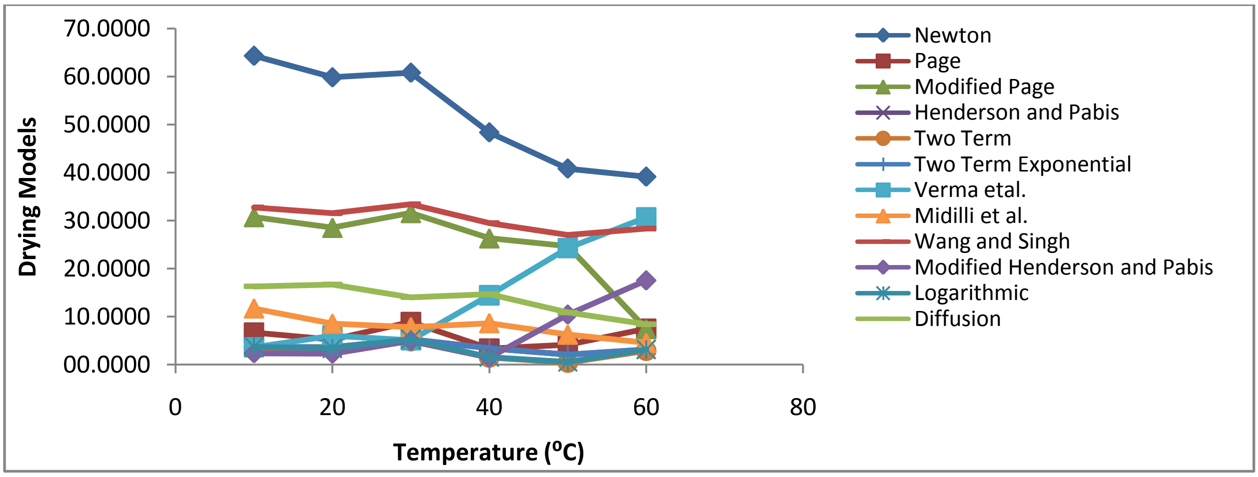


Figure 4.45 Drying models versus temperature for RMSE (Unblanched Treatment)

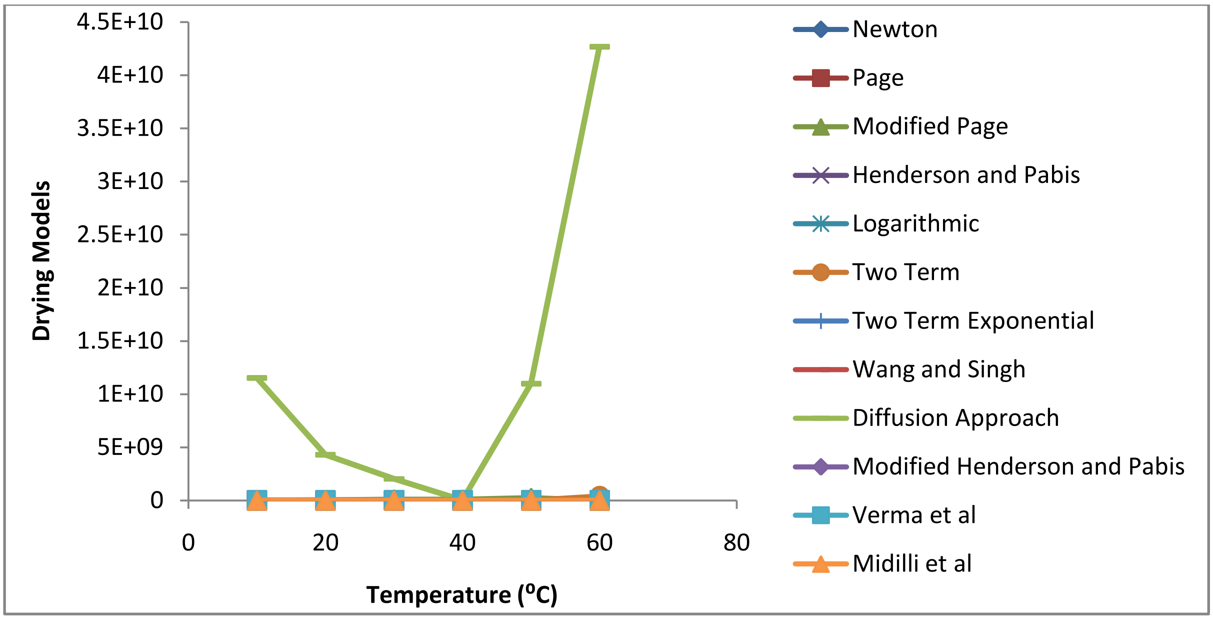


Figure 4.46 Drying models versus temperature for SEE (Unblanched Treatment)

Figures 4.44 to 4.46 were plotted using Table 4.43. Figure 4.44 showed that page model can be used to predict the drying characteristics of unblanched ginger treatment at temperature above 40⁰C and below 40⁰C, this model might not be suitable to simulate the drying characteristics of unblanched ginger. Figures 4.44 to 4.46 showed that Henderson and Pabis model, Logarithmic model, two term model and two term exponential model can be used to predict the drying characteristics of unblanched ginger treatment; but, two term exponential and Henderson and Pabis are most suitable for the prediction of the drying characteristics of the treatment.

Table 4.44: Coefficient of models and goodness of fit for Blanched ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1675	0.4487	56.9359	0.0449
		20	k= -0.1611	0.4320	56.9113	0.05228
		30	k= -0.1422	0.3983	55.2101	0.0790
		40	k= -0.1352	0.3850	37.7302	0.0636
		50	k= -0.1216	0.3659	36.9169	0.0854
		60	k= -0.1171	0.3624	39.1357	0.1006
2	Page	10	k= -4.6889, n= -0.0633	0.9176	4.1165	0.0808
		20	k= -4.7754, n= -0.0777	0.8124	7.8502	0.1553
		30	k= -4.9152, n= -0.1088	0.71565	12.8780	0.2713
		40	k= -4.7471, n= -0.1448	0.9388	4.4175	0.1342
		50	k= -4.7528, n= -0.1572	0.8127	8.3007	0.2700
		60	k= -4.8946, n= -0.1692	0.8743	7.4558	0.2313

3	Modified Page	10	k= -4226000, n= 0.0782	0.2309	28.0725	92440000
		20	k= -3125000, n= 0.0789	0.1842	31.2239	78310000
		30	k= -588800, n= 0.0738	0.1241	35.3529	220500000
		40	k= -18740000, n= 0.0643	0.0996	24.0806	874700000
		50	k= -9024000, n= 0.0651	0.0874	25.3152	483500000
		60	k= -0.00008, n= -0.1693	0.87432	7.4558	0.0313
4	Henderson and Pabis	10	k= 0.0364, a= 89.3923	0.9745	2.3897	2.5594
		20	k= 95.8828, a= 89.9556	0.9503	4.2258	4.8620
		30	k= 0.0738, a= 105.85	0.9270	6.7505	8.9577
		40	k= 0.0881, a= 80.21	0.9633	3.7128	5.3178
		50	k= 0.0995, a= 81.56	0.9528	4.3866	6.6680
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	
5	Logarithmic	10	k= 0.0746, a= 64.2547, c= 29.8133	0.9890	1.5410	12.2574
		20	k= 0.0571, a= 88.52, c= 8.5958	0.9507	4.1861	54.2203
		30	k= 0.0462, a= 131.86, c= -30.57	0.9401	6.2679	122.0081
		40	k= 0.1498, a= 75.83, c= 13.78	0.9874	2.0737	7.9296
		50	k= 0.0941, a= 82.68, c= -1.8811	0.9536	4.3728	23.9501
		60	k= 0.0997, a= 90.94, c= -2.6588	0.9800	3.1412	15.9152
6	Two Term	10	k1= -0.1352, k2= 0.0441, a= 0.3545, b= 92.0785	0.9902	1.4544	6.3997
		20	k1= 0.0516, k2= 0.4456, a= 100.32, b= -11.46	0.9526	4.1547	79.6655
		30	k1= 0.1260, k2= 0.2279, a= 255.99, b= -179.65	0.9623	5.0445	2635.26
		40	k1= -0.0904, k2= 0.1121, a= 1.2774, b= 84.96	0.9891	1.9295	10.3514
		50	k1= -0.0904, k2= 0.1121, a= 1.2774, b= 84.96	0.9105	5.8401	10.3514
		60	k1= 0.1007, k2= 4.353, a= 83.38, b= 36130	0.9824	2.9025	394605484
7	Two Term Exponential	10	k= 0.0365, a= 89.51	0.9743	2.4011	2.5274

		20	k= 0.0484, a= 95.88	0.9503	4.2256	4.8540
		30	k= 0.0738, a= 105.85	0.9270	6.7505	8.9576
		40	k= 0.0881, a= 80.21	0.9633	3.7128	5.3177
		50	k= 0.0995, a= 81.56	0.9528	4.3866	6.6679
		60	k= 0.1077, a= 89.5462	0.9792	3.1820	5.0421
8	Wang and Singh	10	a= 10.7915, b= -0.4071	0.3520	31.3122	3.6776
		20	a= 10.74, b= -0.4217	0.3406	33.1157	3.8895
		30	a= 10.29, b= -0.4353	0.3428	35.0269	4.1139
		40	a= 6.3126, b= -0.2574	0.2548	27.2138	3.1963
		50	a= 6.2735, b= -0.2702	0.2823	26.7532	3.1422
		60	a= 6.6709, b= -0.2924	0.2939	28.3493	3.3297
9	Diffusion Approach	10	k= 0.2738, a= 286200, b= 1.001	0.6627	16.2673	9949000000
		20	k= 0.1949, a= 75260, b= 1.003	0.7796	3.5730	9504000000
		30	k= 0.0231, a= 101600, b= 1.002	0.9083	9.1213	3442000000
		40	k= 0. 2720, a= 276900, b= 1.001	0.8364	10.1288	4205000000
		50	k= 0.2402, a= 221300, b= 1.001	0.9038	7.2400	4776000000
		60	k= 0.2869, a= 471100, b= 1.00	0.8913	8.4190	4267000000
10	Modified Henderson and Pabis	10	k= -0.1252, a= 100.1, b= 250.9, g=0.0415, c= -256.6, h= 0.0557	0.7502	11.2536	22319738
		20	k= -0.5382, a= 0.00003, b= 297.7, g= 0.1028, c= -214.6, h= 0.1537	0.9818	2.5323	48486.55
		30	k= -0.5382, a= 0.00003, b= 297.7, g= 0.1028, c= -214.6, h= 0.1537	0.7861	10.3395	48486.55
		40	k= -0.5382, a= 0.00003, b= 297.7, g= 0.1028, c= -214.6, h= 0.1537	0.6085	23.7125	48486.55
		50	k= -0.4659, a= 0.00007, b= 171.4, g= 0.1499, c= -105.1, h= 0.2611	0.9671	3.6323	13977.55
		60	k= 0.1367, a= 127.6, b= 4432, g= 1.670, c= -1221 , h= 0.9579	0.9971	1.1897	2665399
11	Verma et al.	10	k= 0.0440, a= 101.52, g= 1.4019	0.9293	4.8420	11.1057
		20	k= 0.0495, a= 97.19, g= 1.98	0.9510	4.2036	10.6059

		30	k= 0.0885, a= 126.07, g= 0.8917	0.9468	5.8809	24.0566
		40	k= 0.0885, a= 126.07, g= 0.8917	0.7114	18.8661	24.0567
		50	k= 0.1004, a= 82.35, g= 2.3186	0.9530	4.3842	19.6168
		60	k= -0.0491, a= 1.00, g= -1.00	0.5001	45221.66	2299.48
12	Midilli et al.	10	k= -4.5065, a= -0.2643, b= 1.0657	0.7582	9.5627	0.9778
		20	k= - 4.4475, a= - 0.2372, b= 0.4568	0.8890	7.2390	0.7340
		30	k= -4.4283, a= -0.2211, b= -0.4783	0.9475	6.2365	0.6280
		40	k= -4.6171, a -0.3675, b= 0.1731	0.9011	6.2294	0.7263
		50	k= - -4.36909, a= -0.3080, b= -0.3485	0.9502	4.6823	0.5370
		60	k= -4.5607, a= -0.3298, b= -0.3387	0.9613	4.5454	0.5032

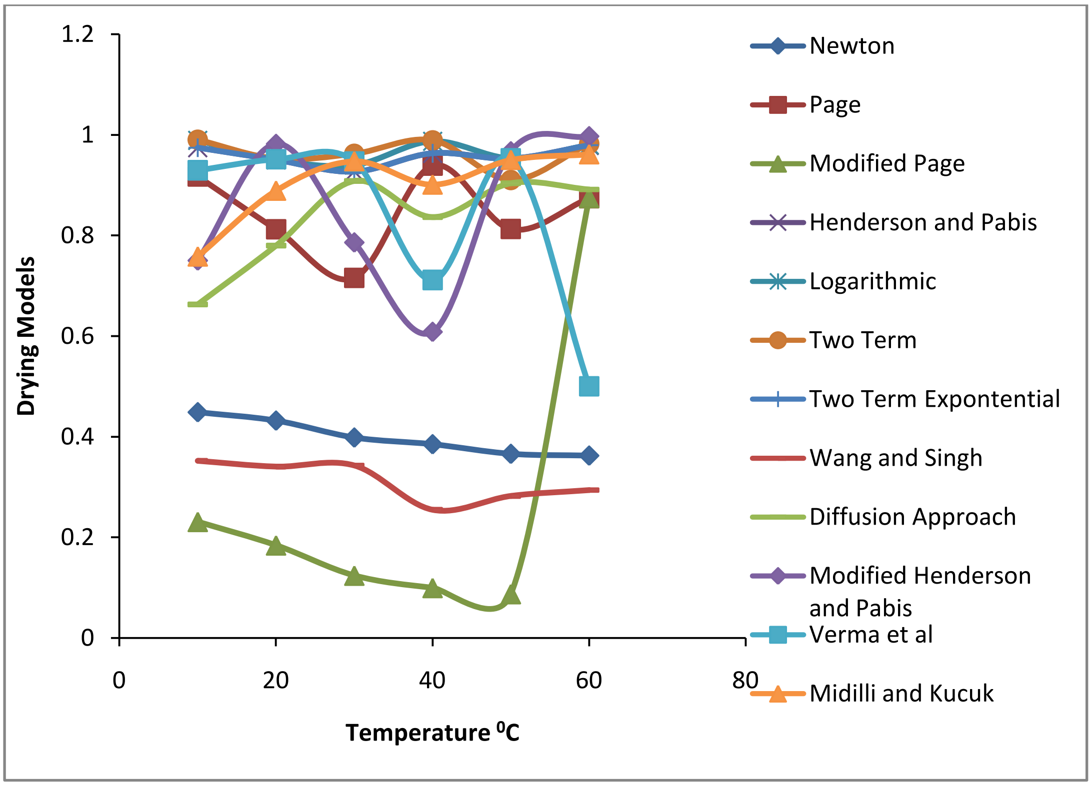


Figure 4.47 Drying models versus temperature for determination coefficient (Blanched Treatment)

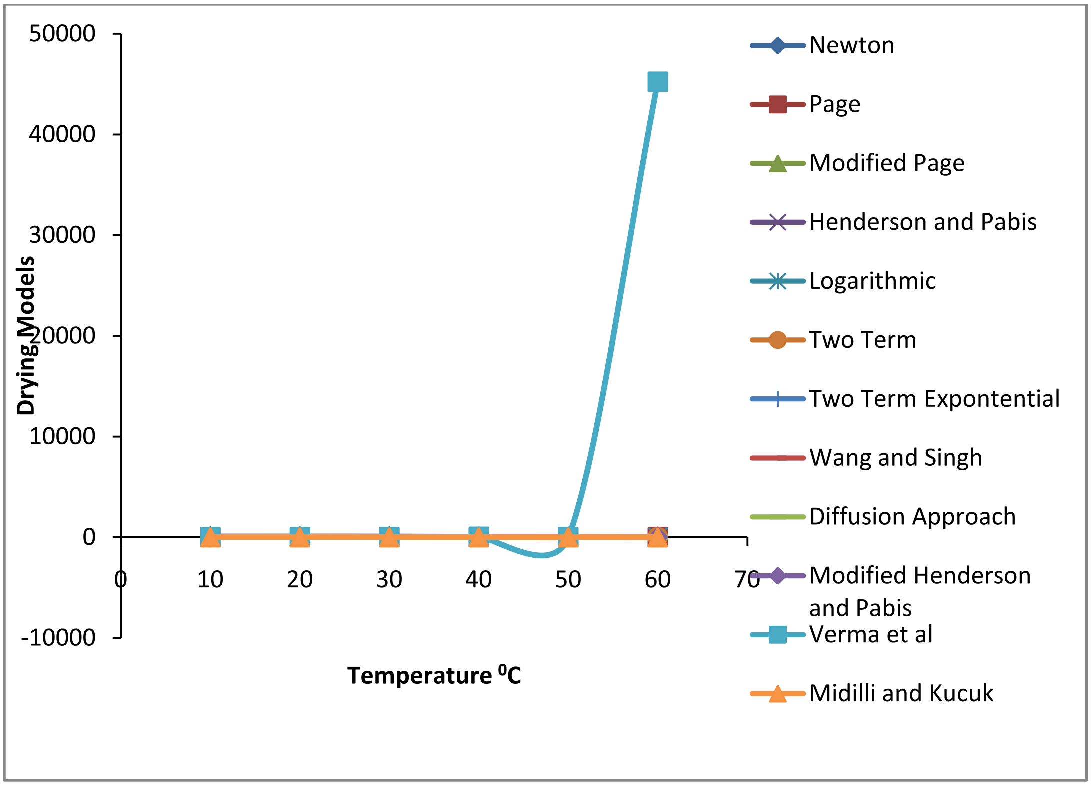


Figure 4.48 Drying models versus temperature for RMSE (Blanched Treatment)

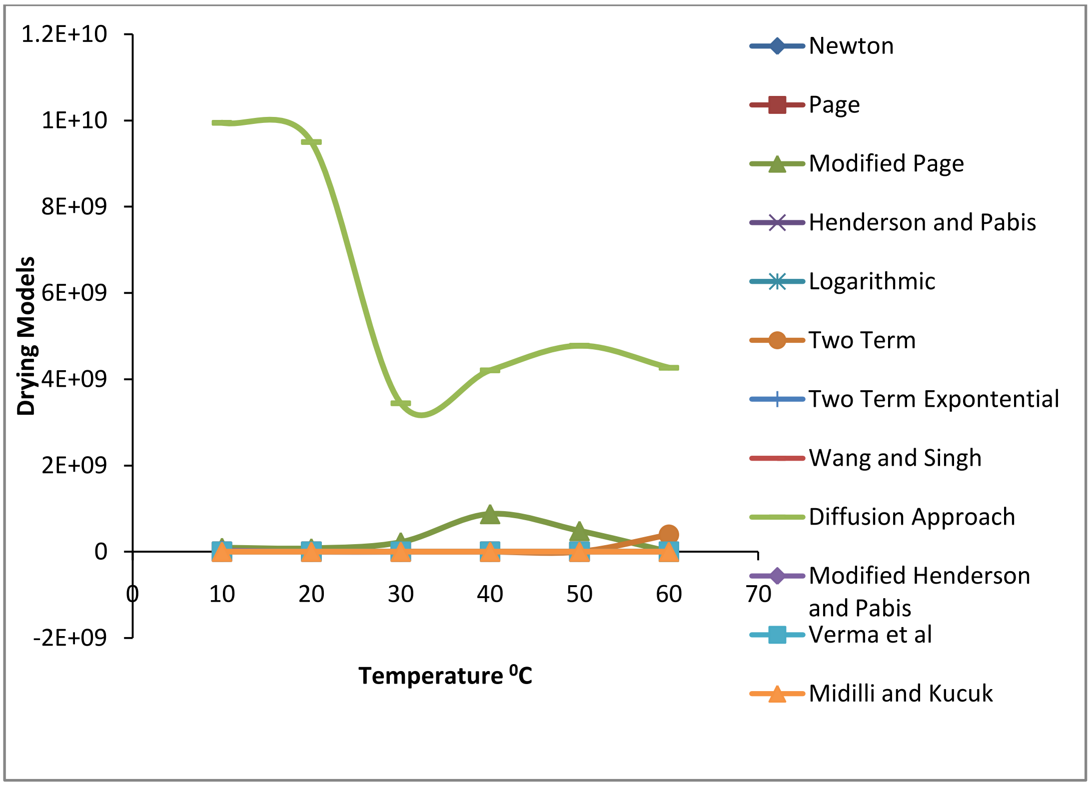


Figure 4.49 Drying models versus temperature for SEE (Blanched Treatment)

Figures 4.47 to 4.49 were plotted using Table 4.44. Page, Henderson and Pabis, Logarthmic, two term and two term exponential models can be used to predict the drying characteristics of blanched ginger treatment. Figure 4.49 showed that Page and logarithmic models have relatively high standard error for estimate. Also, two term model has a very high standard error for estimate at temperature of 60°C. From figures 4.47 to 4.49, it can be seen that two term exponential and Henderson and Pabis models are suitable models for predicting the drying characteristics of blanched ginger treatment

Table 4.45: Coefficient of models and goodness of fit for peeled ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1776	0.4653	62.1822	0.0386
		20	k= -0.1652	0.4423	59.2895	0.0494
		30	k= -0.1565	0.4256	59.4701	0.0608
		40	k= -0.1478	0.4138	44.4870	0.0559
		50	k= -0.1281	0.3740	37.1697	0.0739
		60	k= -0.1153	0.3418	34.2501	0.0916
2	Page	10	k= -4.6685, n= -0.0462	0.8983	3.8610	0.0695
		20	k= -4.7402, n= -0.0662	0.8325	6.6486	0.1266
		30	k= -4.8213, n= -0.0801	0.7351	10.4099	0.2003
		40	k= -4.7045, n= -0.1067	0.9098	5.1406	0.1294
		50	k= -4.7316, n= -0.1493	0.8551	7.0034	0.2214
		60	k= -4.9415, n= -0.2037	0.9565	4.1659	0.1535
3	Modified Page	10	k= -2706000, n= 0.0821	0.2864	28.3455	47990000
		20	k= -4392000, n=0.0782	0.2172	30.3384	102600000
		30	k= -3333000, n= 0.0787	0.1725	33.7539	89940000
		40	k= -5086000, n=0.0727	0.1386	25.9576	161300000
		50	k= - -2536000, n= 0.0704	0.1029	25.1014	113900000
		60	k= -0.0003, n= -0.2037	0.9565	4.1659	0.0227
4	Henderson and Pabis	10	k= 0.0253, a= 90.74	0.8869	4.2218	4.2175
		20	k= 0.0402, a= 94.65	0.9694	2.9409	3.2225
		30	k= 0.0523, a= 101.5	0.9468	4.8076	5.6582
		40	k= 0.0629, a= 82.49	0.9614	3.5608	4.4518
		50	k= 0.0961, a=81.64	0.3801	2.9839	4.4559
		60	k= 0.1314, a= 87.42	0.9809	2.9870	5.3356
5	Logarithmic	10	k= 0.1029, a= 49.12, c= 49.95	0.9447	2.8856	14.0887

		20	k= 0.0399, a= 95.00, c= -0.3819	0.9694	2.9409	76.1108
		30	k= 0.0258, a= 157.49, c= -59.85	0.9580	4.3489	266.6928
		40	k= 0.0995, a= 72.18, c= 15.47	0.9722	2.9522	15.0035
		50	k= 0.1177, a= 78.70, c= 6.0698	0.9808	2.6938	11.4802
		60	k= 0.1803, a= 88.28, c= 7.4852	0.9917	1.8916	7.3957
6	Two Term	10	k1= -0.2257, k2= 0.0347, a= 0.0638, b= 95.48	0.9603	2.4432	6.0690
		20	k1= 0.04268, k2= 0.2811, a= 98.37, b= -6.6067	0.9705	2.8971	65.5043
		30	k1= 0.0729, k2= 0.2668, a= 139.52, b= -58.19	0.9736	3.4759	186.4536
		40	k1= -0.3571, k2= 0.0696, a= 0.0014, b= 85.20	0.9791	2.5559	7.4420
		50	k1= -0.4324, k2= 0.1014, a= 0.0001, b= 83.45	0.9874	2.1677	8.3306
		60	k1= 0.1036, k2= 0.9256, a= 66.82, b= 104.58	0.9953	1.4380	170.3199
7	Two Term Exponential	10	k= 0.0260, a= 91.49	0.8864	4.2939	3.9553
		20	k= 0.0402, a= 94.68	0.9694	2.9421	3.2016
		30	k= 0.0523, a= 101.5	0.9468	4.8074	5.6552
		40	k= 0.0629, a= 82.50	0.9614	3.5611	4.4497
		50	k= 0.0961, a= 81.64	0.9774	2.9839	4.4559
		60	k= 0.1314, a= 87.42	0.9809	2.9870	5.3357
8	Wang and Singh	10	a= 11.64, b= -0.4186	0.3573	33.0116	3.8773
		20	a= 11.4299, b= -0.4242	0.3691	32.1510	3.7762
		30	a= 11.5435, b=-0.4670	0.3755	33.5090	3.9357
		40	a= 8.0601, b= 0.3215	0.3003	28.6259	3.3622
		50	a= 6.2309, b= -0.2617	0.2653	27.0580	3.1780
		60	a= 5.2180, b= -0.2252	0.2339	27.0332	
9	Diffusion Approach	10	k= 0.1540, a= 196900, b= 1.001	0.5672	19.3964	16890000000
		20	k= 0. 1780, a= 80140, b= 1.003	0.7295	14.7209	6117000000
		30	k= 0. 1905, a= 3371, b= 1.078	0.8462	11.3862	767920
		40	k= 0.2222, a= 206600,	0.7790	12.0862	6389000000

			b= 1.001			
		50	k= 0.2798, a= 295400, b= 1.001	0.9171	6.9287	2891000000
		60	k= 0.3393, a= 453400, b= 1.00	0.8876	8.4264	10250000000
10	Modified Henderson and Pabis	10	k= -0.0819, a= 4.693, b= 211.1, g= 0.0845, c= -1.240, h= 0.1319	0.9628	2.3659	157971.5
		20	k= 1.204, a= 17.06, b= 295.9, g= 0.0583, c= -204.4, h= 0.0701	0.9705	2.9043	1812176
		30	k= 0.2993, a= -31.57, b= 303.0, g= 0.0896, c= -188.5, h= 0.1165	0.9728	3.5402	2462192
		40	k= -0.2428, a= 0.0523, b= 290.8, g= 0.0251, c= -208.7 , h= 0.0557	0.9803	2.4858	4416167
		50	k= 1.028, a= 591.8, b= 0.00005, g= -1.00, c= -526.5, h= 0.489	0.4999	531789.3	1931900290
		60	k= 0.1146, a= 74.34, b= 0.0001, g= -0.4172, c= 1092, h= 2.284	0.9992	0.5609	70478.76
11	Verma et al.	10	k= -0.2756, a= 1.0003, g= 1.6684	0.4319	55.4450	10.7223
		20	k= -0.4515, a= 1, g= -0.9696	0.4991	6098.755	393.06
		30	k= -0.4442, a= 1.0001, g= -0.9619	0.5005	10439.87	311.3278
		40	k= -0.0911, a= 1.00, g=- 1.00	0.5000	50541.75	718.58
		50	k= -0.0480, a= 1.00, g=- 1.00	0.5000	53762.02	2705.80
		60	k= -0.0241, a= 1.00, g=-1.00	0.5000	51625.9	3292.332
12	Midilli et al.	10	k= - -4.5451, a= -0.2620, b= 1.6243	0.6759	10.5410	1.0607
		20	k= -4.4589, a= -0.2390, b= 0.7725	0.8044	9.3216	0.9431
		30	k= -4.4238, a= -0.2195, b= 0.1672	0.8455	9.6972	0.9770
		40	k= -4.4730, a= -0.2977, b= 0.3120	0.9317	5.0630	0.5488
		50	k= - 4.4461, a= -0.3287, b= -0.1340	0.9023	6.4256	0.7419
		60	k= -4.7967, a= -0.4207, b= -0.1312	0.9731	3.5040	0.4295

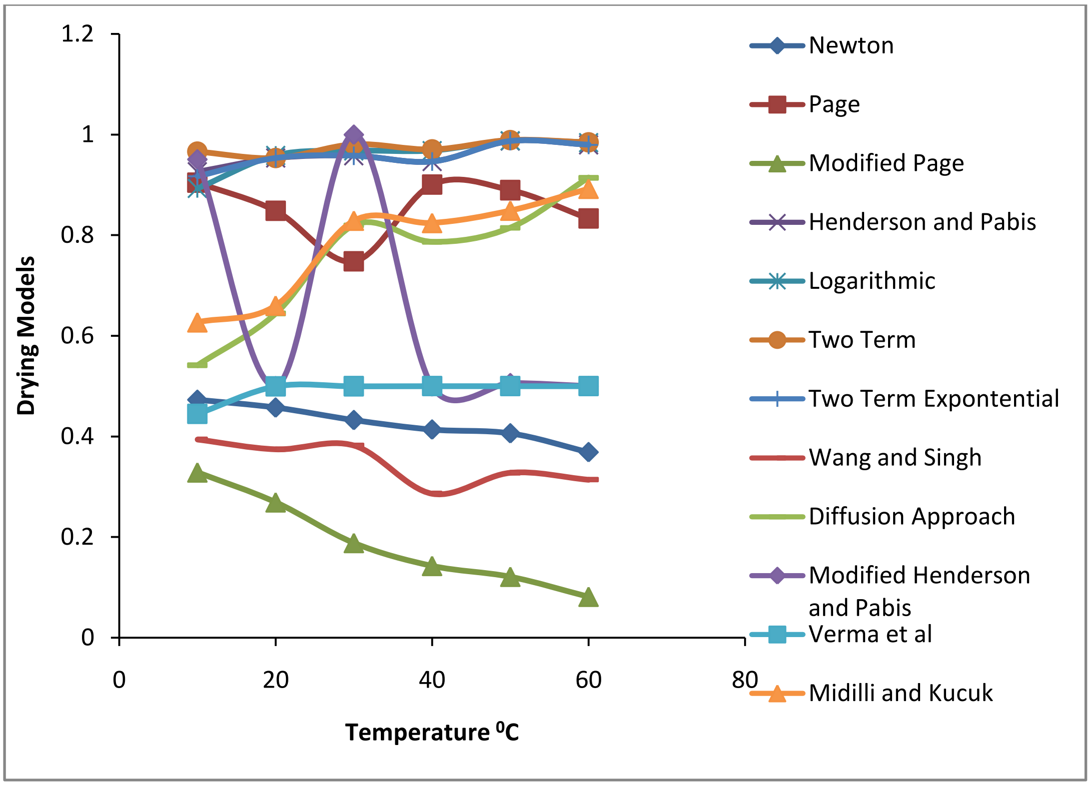


Figure 4.50 Drying models versus temperature for determination coefficient (Peeled Treatment)

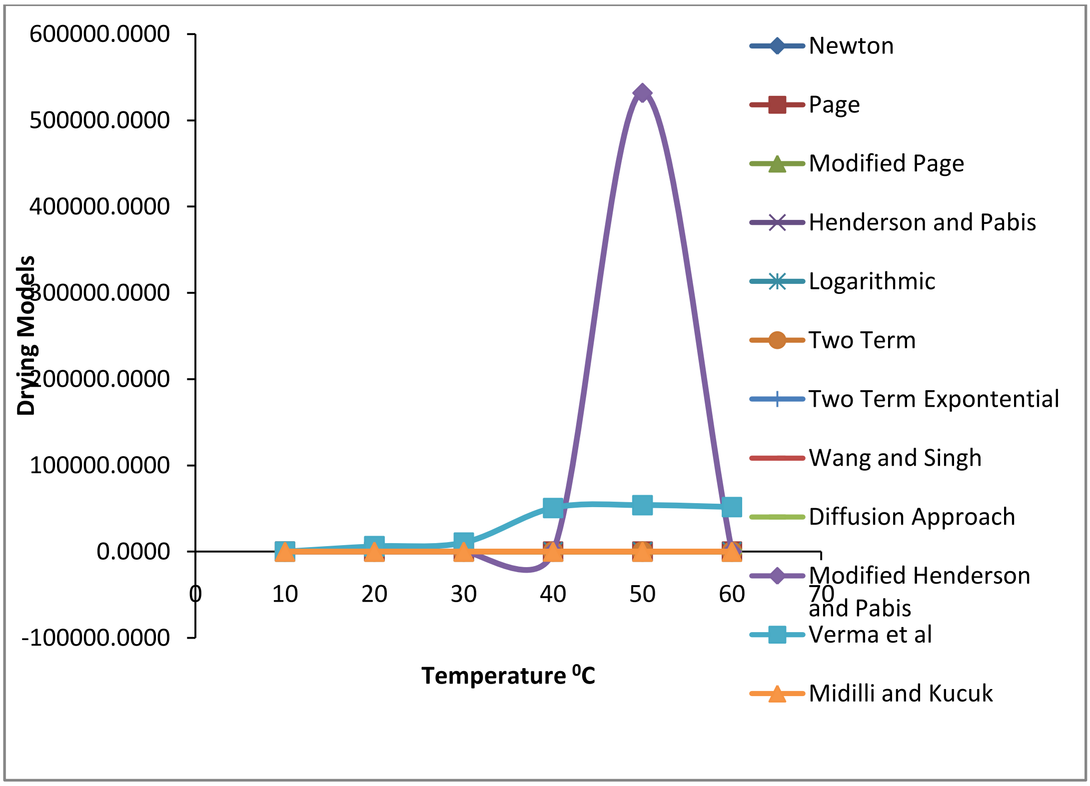


Figure 4.51 Drying models versus temperature for RMSE (Peeled Treatment)

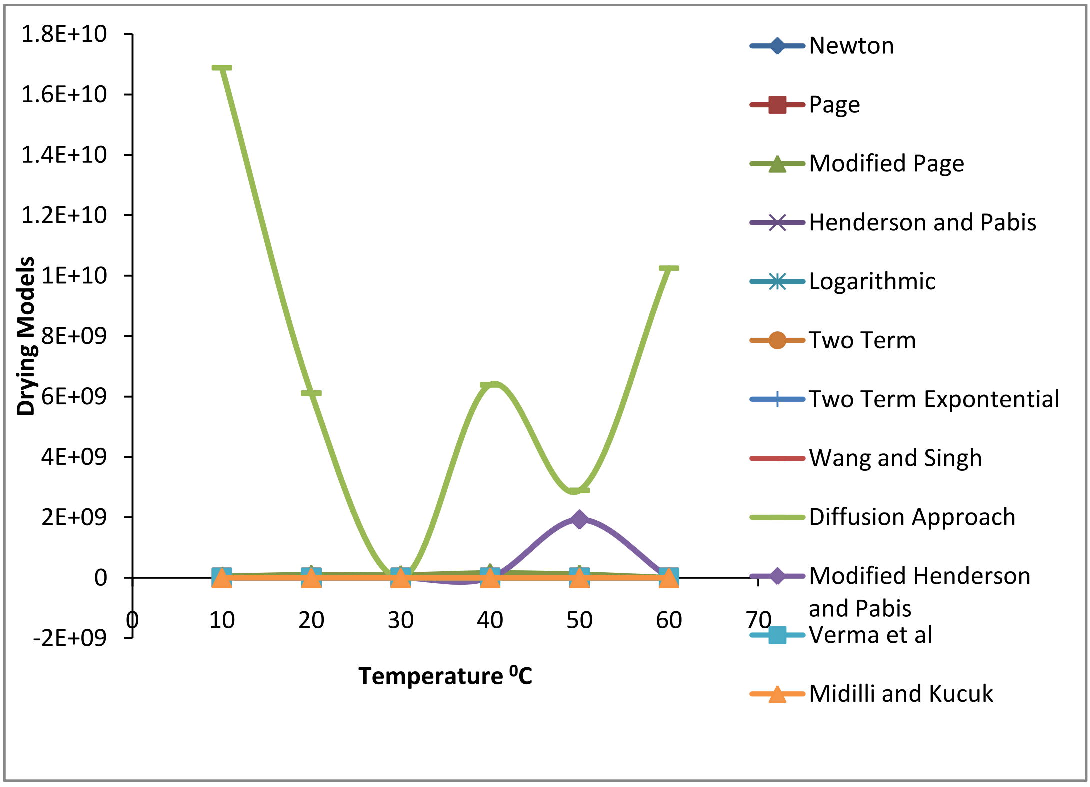


Figure 4.52 Drying models versus temperature for SEE (Peeled Treatment)

Figures 4.50 to 4.52 were plotted using Table 4.45. Also, it can be seen that Page, Henderson and Pabis, Logarithmic, two term and two term exponential models can be used to predict the drying characteristics of peeled ginger treatment. Figure 4.52 showed that two term and logarithmic models had relatively high standard error for estimate. Figure 4.52 showed that Page model has best standard error for estimate out of the five models; nevertheless, figure 4.50 showed that the coefficient of determination for Page model is 0.74 at temperature of 30^{o}C. Also, Henderson and Pabis' model has coefficient of determination of 0.38 at temperature of 50^{o}C. From figures 4.50 to 4.52, it can be seen that two terms exponential is the best suitable model for predicting the drying characteristics of peeled ginger treatment.

Table 4.46: Coefficient of models and goodness of fit for unpeeled ginger

S/N	Model	Temp	Parameter	R-Square	RMSE	SEE
1	Newton	10	k= -0.1819	0.4729	66.3958	0.0372
		20	k= -0.1732	0.4574	61.3710	0.0423
		30	k= -0.1602	0.4325	60.4977	0.0568
		40	k= -0.1515	0.4136	48.5415	0.0558
		50	k= -0.1373	0.4061	40.2028	0.0646
		60	k= -0.1182	0.3686	41.2707	0.1035
2	Page	10	k= -4.6460, n= -0.0348	0.9046	3.0463	0.0521
		20	k= -4.6713, n= -0.0502	0.8485	5.0895	0.0937
		30	k= -4.7943, n= -0.0729	0.7482	9.4711	0.1788
		40	k= -4.7957, n= -0.1056	0.9008	5.9562	0.1370
		50	k= -4.6344, n= -0.1159	0.8898	5.3958	0.1527
		60	k= -4.8811, n= -0.1573	0.8332	8.7907	0.2566
3	Modified Page	10	k= -2235000, n= 0.0842	0.3285	28.3148	34790000
		20	k= -2132000, n= 0.0826	0.2691	29.0093	39870000
		30	k= -3156000, n= -0.0796	0.1883	33.0412	78360000
		40	k= k= -3496000, n=0.0763	0.1428	28.8198	134000000
		50	k=-6932000, n= 696.5	0.1212	23.8724	247400000
		60	k= -18690000, n= 0.0642	0.0815	28.5251	1043000000
4	Henderson and Pabis	10	k= 0.0190, a= 92.15	0.9259	2.7535	2.6411
		20	k= 0.0294, a= 91.56	0.9533	2.9244	2.9981
		30	k= 0.0 471, a= 100.1	0.9581	3.9791	.5429
		40	k= 0.0223, a= 163.55	0.9464	4.6920	5.9165
		50	k= 0.0683, a= 76.56	0.9873	1.9206	2.4748
		60	k= 0.1021, a= 91.81	0.9799	3.1848	4.9043
5	Logarithmic	10	k= 0.0010, a= -1326, c= 1416	0.8932	3.2536	130450
		20	k= 0.0521, a= 65.88, c= 28.11	0.9587	2.7249	2.1523
		30	k= 0.0223, a= 163.55, c= -66.825	0.9676	3.5566	291.06
		40	k= 0.1185, a= 78.57, c= 20.70	0.9681	3.4930	14.8009
		50	k= 0.0768, a= 89.5462, c= 4.1163	0.9879	1.8705	14.1307
		60	k= 0.0824, a= 97.25, c= -8.5818	0.9843	2.8703	19.2747
6	Two Term	10	k1= -0.1702, k2= 0.0254, a= 0.1746, b= 95.07	0.9662	1.8321	5.7762
		20	k1= 0.0205, k2= 93.901, a= 0.0652, b=	0.9534	2.9232	2.4529

			92.50			
		30	k1= 0.0617, k2= 0.2966, a= 124.99, b= -42.92	0.9806	2.7704	84.1033
		40	k1= -0.1034, k2= 0.0824, a= 1.1100, b= 95.31	0.9705	3.3548	18.1470
		50	k1= 0.0634, k2= 0.5221, a= 71.81, b= 13.36	0.9892	1.7637	2.3807
		60	k1= 0.1543, k2= 0.1727, a= 533.0, b=-449.6	0.9845	2.8378	221004.2
7	Two Term Exponential	10	k= 0.0205, a= 93.90	0.9170	3.0476	2.4529
		20	k= 0.0296, a= 91.80	0.9534	2.9233	2.8602
		30	k= 0.0471, a= 100.1	0.9581	3.9781	4.5349
		40	k= 0.0645, a= 90.63	0.9464	4.6920	5.9155
		50	k= 0.0683, a= 76.56	0.9873	1.9208	2.4737
		60	k= 0.1021, a= 91.81	0.9799	3.1848	4.9043
8	Wang and Singh	10	a= 12.6298, b= 0.4488	0.3941	32.5889	3.8276
		20	a= 11.7577, b -0.4363	0.3746	31.8720	3.7434
		30	a= 11.8001, b= -0.4708	0.3821	33.0778	3.8851
		40	a= 8.6262, b= -0.3417	0.2864	31.8283	3.7383
		50	a= 7.4729, b= -0.3074	0.3280	25.4157	2.9852
		60	a= 7.2436, b= -0.3183	0.3141	29.0227	3.4088
9	Diffusion Approach	10	k= 0.1387, a= 63350, b= 1.001	0.5413	19.7390	5516000000
		20	k= 0.1600, a= 198000, b= 1.001	0.6444	16.7848	6701000000
		30	k= 0.1890, a= 89570, b= 1.003	0.8199	12.2230	7052000000
		40	k= 0.2311, a= 195500, b= 1.001	0.7867	13.3911	8539000000
		50	k= 0.2402, a= 221300, b= 1.001	0.8148	9.9827	165201.2
		60	k= 0.2780, a= 296000, b= 1.001	0.9144	7.6163	5180000000
10	Modified Henderson and Pabis	10	k= 0.0616, a= -5.523, b= 0.0000002, g= -0.6402, c= 99.04, h= 2.590	0.9508	2.2749	62837.38
		20	k= - 0.3036, a= -71.76, b= 0.00, g= -1.00, c= 153.1, h= 0.2477	0.5000	59898.73	2419747970
		30	k= 0.3613, a= 32.16, b= 0.000001, g=-0.9950, c= 23.88, h= -0.1593	0.9999	9969.08	201187.2

		40	k= 0.0857, a= -13.87, b= 0.000001, g= -0.9774, c= 95.01, h= 0.1903	0.4993	7007.75	11602604
		50	k= 1.287, a= -977.0, b= -0.000002, g= -0.8501, c= 1064, h= 0.6661	0.5061	810.10	24903272
		60	k= 0.1005, a= 97.59, b= -0.000003, g= -1.00, c= -13.32, h= 0.1150	0.5001	40037.12	20466604565
11	Verma et al.	10	k= -0.3170, a= 1.2163, g= -0.3879	0.4448	57.7136	62.264
		20	k= -0.4472, a= 1, g= -0.9167	0.4996	10714.09	979.63
		30	k= -0.4885, a= 1.00, g= -0.9167	0.4998	30930.09	1406.83
		40	k= -0.1035, a= 1.00, g= -1.00	0.5001	40996.2	1319.494
		50	k= -0.0713, a= 1.00, g= -1.00	0.5001	43038.15	1798.76
		60	k= -0.06755, a= 1.00, g= -1.00	0.5001	76978.86	3077.04
12	Midilli et al.	10	k= -4.5123, a= -0.2479, b= 1.9045	0.6269	11.0497	1.1074
		20	k= -4.4743, a= -0.2479, b= 1.3156	0.6602	11.4929	1.1669
		30	k= -4.4185, a= -0.2189, b= 0.3547	0.8289	9.7878	0.9874
		40	k= -4.6278, a= -0.3100, b= 0.4769	0.8243	9.2670	0.9678
		50	k=-4.4047, a= -0.3123, b= 0.1740	0.8489	7.4782	0.8520
		60	k= -4.5442, a -0.3158, b= -0.3465	0.8923	8.0241	0.8722

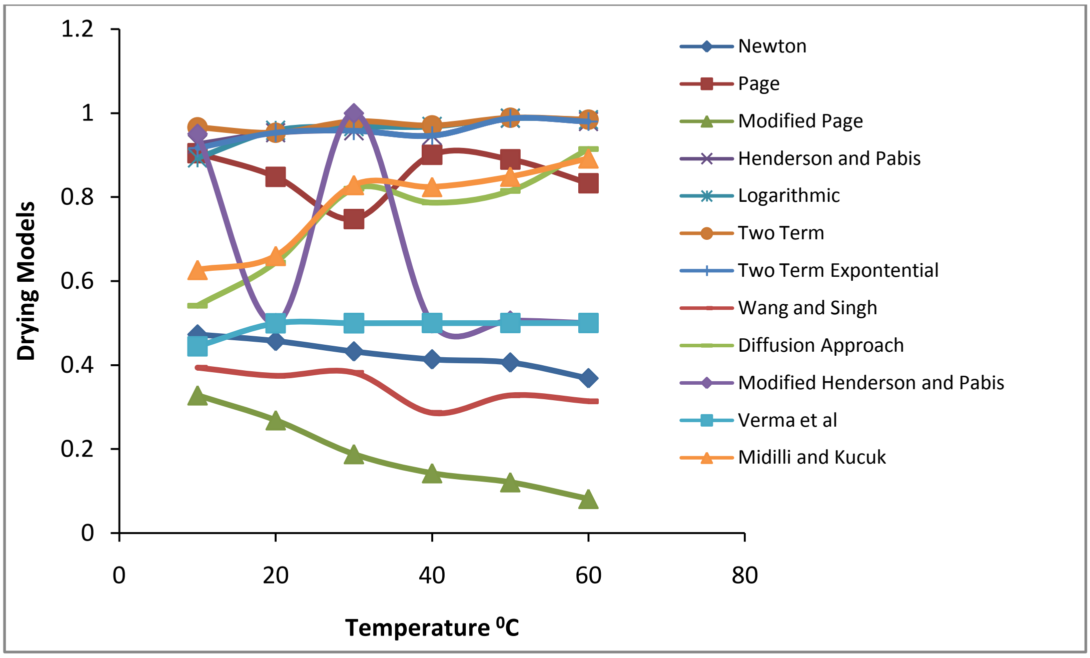


Figure 4.53 Drying models versus temperature for determination coefficient (Unpeeled Treatment)

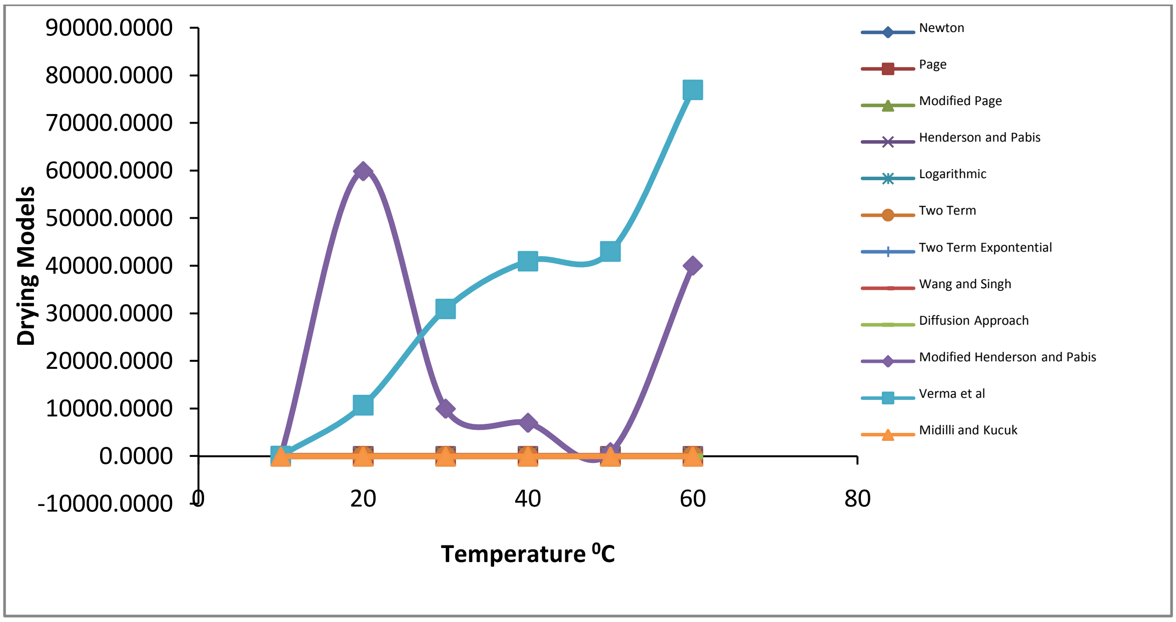


Figure 4.54 Drying models versus temperature for RMSE (Unpeeled Treatment)

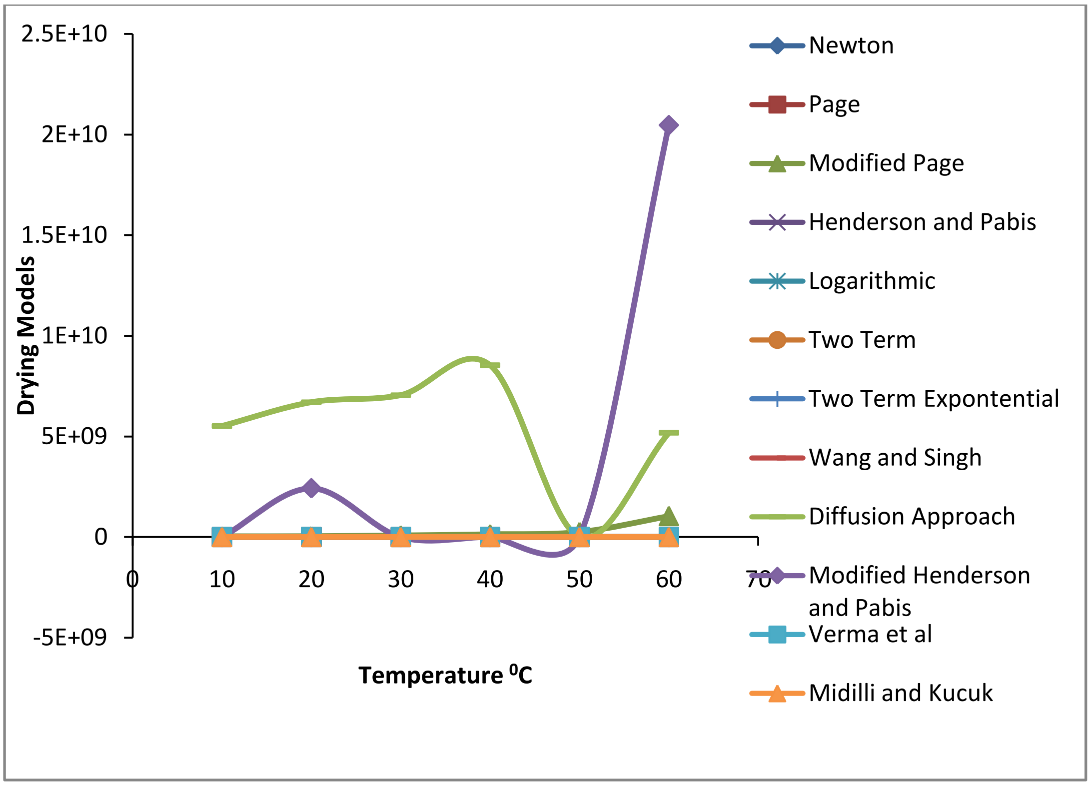


Figure 4.55 Drying models versus temperature for SEE (Unpeeled Treatment)

Figures 4.53 to 4.55 were plotted using Table 4.46. The plots showed that Page, Henderson and Pabis, Logarithmic, two term and two term exponential models can be used to predict the drying characteristics of unpeeled ginger treatment. Also, figure 4.55 showed that two term and logarithmic models had relatively high standard error for estimate. Figure 4.55 showed that Page model has best standard error for estimate when compared with the other four models; but, figure 4.53 showed that the determination coefficient is 0.75 at the temperature of 30°C. From figures 4.53 to 4.55, it can be seen that two terms exponential and Henderson and Pabis models are suitable models for predicting the drying characteristics of unpeeled ginger treatment.

This study revealed that five drying models can be used to predict the drying characteristics of the various ginger treatments. There are Page, Henderson and Pabis, Logarithmic, two term and two term exponential models. Nevertheless, two terms exponential proved to be the model most suitable for predicting the drying characteristics of ginger rhizome. The two terms exponential model, the prediction model (Austin Approach) and the experimental data were plotted in figures 4.56 to 4.59 for the four ginger treatments.

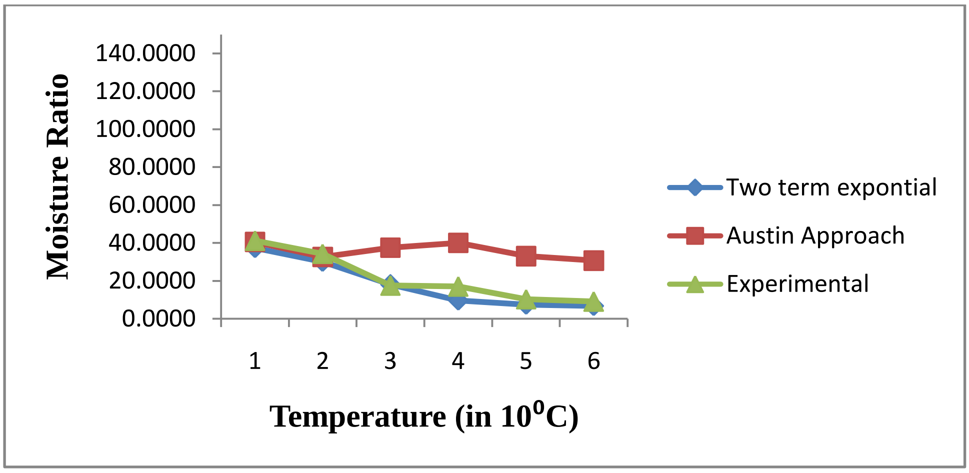


Figure 4.56: Comparison of drying models for blanched ginger

Figure 5.56 presents the comparison among two terms exponential model, the prediction model (Austin Approach) and the experimental data for blanched ginger treatment. It could be seen that two terms exponential model and experimental data agreed satisfactorily while Austin approach diverts somewhat from the two trends. The Austin approach predicted higher moisture ratio value.

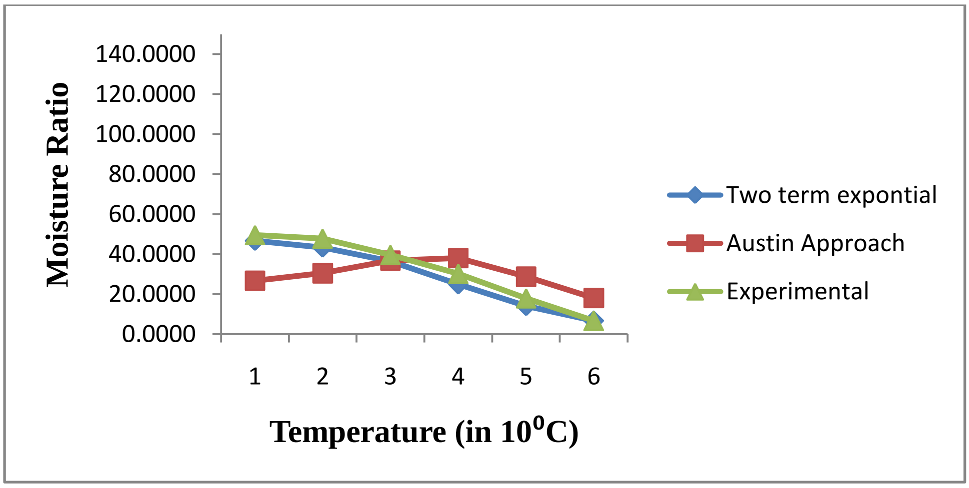


Figure 4.57: Comparison of drying models for unblanched ginger.

Figure 5.57 presents the comparison among two terms exponential model, the prediction model (Austin Approach) and the experimental data for unblanched ginger treatment. It could be seen that two terms exponential model and experimental data agreed satisfactorily while Austin approach diverts somewhat from the two trends. At temperature below 33°C, the Austin approach fall below the other trends and beyond 33°C, it has higher values than the other trends.

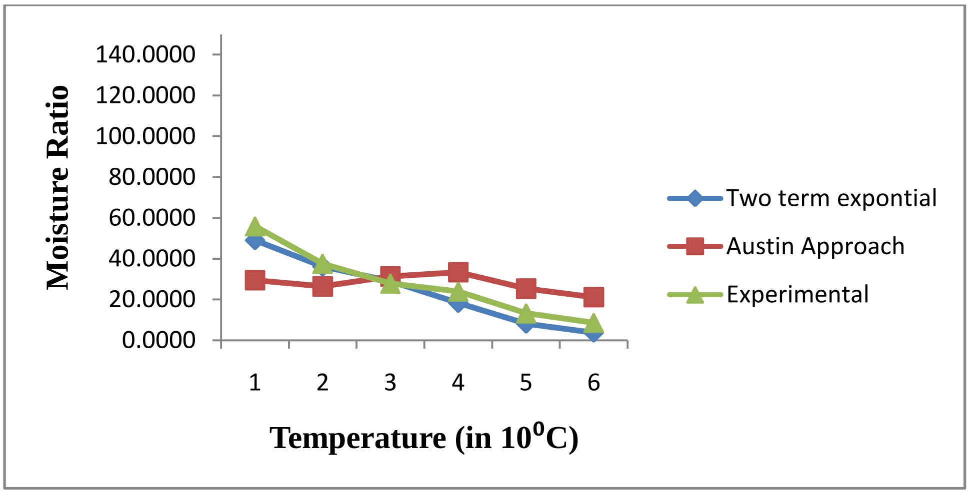


Figure 4.58: Comparison of drying models for peeled ginger

The comparison among two terms exponential model, the prediction model (Austin Approach) and the experimental data for peeled ginger is presented in figure 4.58. From the plot, it could be seen that two terms exponential model and experimental data agreed satisfactorily while Austin approach diverts somewhat from the two trends. All the trends had same value at temperature of 28°C; below this temperature, Austin approach had lower values and above the temperature, it had higher values.

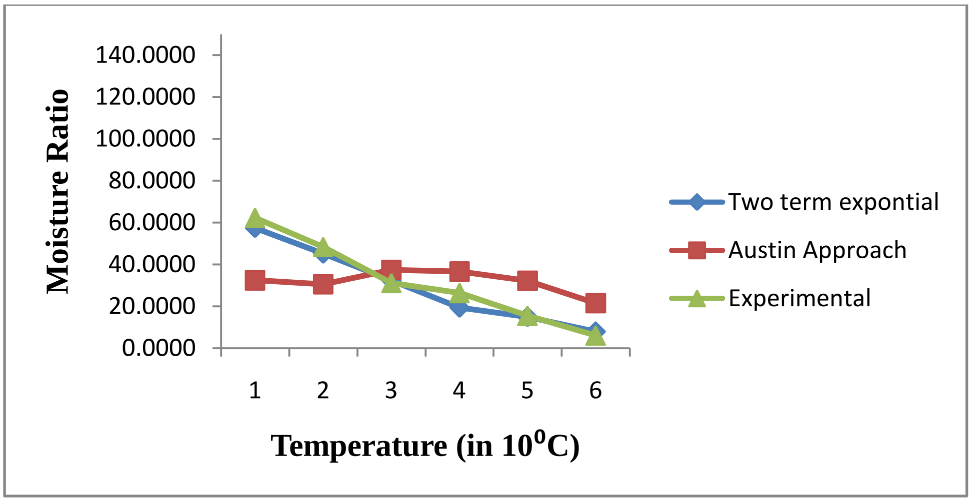


Figure 4.59: Comparison of drying models for unpeeled ginger

The comparison among two terms exponential model, the prediction model (Austin Approach) and the experimental data for unpeeled ginger is presented in figure 4.59. From the plot, it could be seen that two terms exponential model and experimental data agreed satisfactorily while Austin approach diverts somewhat from the two trends.Also, the three trends had same value at temperature of 28°C; below this temperature, Austin approach had lower values and above the temperature, it had higher values.

As stated earlier, the two terms expontial model is the most suitable model for predicting the drying characteristics of the sliced ginger rhizome. As could be seen from figures 4.56 to 4.59, two terms expontial model agreed satisfactorily with the experimental results. The Austin approach derived by dimensionless analysis predicted the moisture ratio fairly well but not as accurate as the two terms expontial model.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Preliminary scientific examinations were conducted to ascertain the proximate and phytochemical composition of the test sample. The sample recorded approximately 49% carbohydrate, 30.33% moisture content, 7.88% protein, 6.16% ash, 3.36% fibre and 3.3% fat. The photochemical composition of the sample were 33.5% of Trypsin inhibitor, 13.5% of Tannin, 11.11% of Steroids, 6.6% of Cardiac glycoside, 6.1% of Saponin, 4.58% of Cyanogenic glycoside, 4.08% of Alkaloid, 3.52% of Flavonoid, 3.19% of Phytate and 3.04% of Heamaglutinin.

The prediction of thin layer drying characteristics of ginger rhizomes slices in convective environment has been studied. The ginger rhizomes were given different treatments: blanched, unbanched, peeled and unpeeled. The following conclusions were drawn from this study:

- The results obtained for moisture content of ginger rhizomes clearly indicates that drying at significantly short time say two hours will not reduce the moisture sufficiently to reduce the effect of pest and bacterial infections.
- The drying rate at higher drying times (24 hours) was 0.889/°C and 0.4437/°C for 2 hours drying, giving 50% by moisture reduction rate. The interception which theoretically gives the initial moisture content of 0°C is lower at 24 hours drying (59.33%) compared to 95.12%on dry basis at 2 hours drying, as expected. The average drying time for the variously treated ginger sample is 2.4hours.
- The result of this study shows that the lowest moisture content (5.98%) is obtained for unpeeled ginger while the highest is the blanched (9.04%) all for 24 hours drying and at 60°C
- The average moisture content for 2 hours drying at 60°C was 70.6% while for 24 hours drying; it was an average of 7.55% which is close to the range of 4-

7% desired for this research. This is better than the result of 22.54% obtained at 50°C under blanched condition drying for 32 hours (Hoque et at , 2013) Eze and Agbo (2011) reported that the principal processing of ginger rhizomes involved sorting, washing, soaking, splitting or peeling and drying to moisture content 7-12%.

- The significance of drying ginger for a long time at even lower temperature around 60°C has been shown in this work. At higher temperatures ginger shrinkage and surface decoloration may occur. As can be seen, good results are achievable at temperature between 50°C to 60°C to sustain the quality of the products.
- The thermal conductivity for 24 hours –dried ginger at 60°C approximates to the thermal conductivity of dried ginger and it is 0.05 W/mk
- The results showed the superiority of the use of thin layer drying method in convective environment over all other methods.
- The average effective moisture diffusivity and the average activation energy for the variously treated ginger rhizome samples are $5.49\text{x}10^{-10}\text{m}^2/\text{s}$ and 22.63kJ/mol respectively.
- Dimensionless analysis was used to deduce empirical equations relating moisture content to properties of the variously treated ginger rhizomes.
- From the study, two terms exponential is the most suitable model for predicting the drying characteristics of the sliced ginger rhizome; although, Page, Henderson and Pabis, Logarithmic, and two term models could be used to predict the drying characteristics of ginger rhizomes with some restrictions.

5.2 Recommendations for Future Research

The Nigerian ginger rhizomes have the advantage of being in the tropical region. It makes them accessible in the off-season market. But it is attacked by pests, bacteria and fungi. It appears that these attacks are the major problems associated with the agricultural products; and their effects limit their advantages. As a result, efforts must be geared towards identifying the storage capacity of dried ginger rhizomes with respect to their ability to inhibit pest, bacterial and fungal rot. It will be recommended to test for both fresh ginger (about 90% moisture content) and dried ginger rhizomes (with average moisture content of 15% (wet basis)).

As the incidence of these diseases are limited by the drying processes employed, efforts must also be taken in conducting experiments using larger samples $(\geq 18 \times 30mm)$ and $(\geq 20g)$. This is important because using a smaller sample often has its own disadvantages in terms of being economical for farmers in making profit. Larger ginger drying would prove economical in saving time, and cost and it is profitable. The smaller versions used in the experiments could be utilized in the production of low volume in powdered form but for importation and commercial sales, larger ginger would be required to be dried. The pest, bacterial and fungal rot appear to be the most severe problems with post-harvest processing of Nigerian ginger rhizomes. And this particular area requires further research. As a result of this research, a single sample used for all the experimental samples because of loss of shapes and sizes; the author advises that in future investigations, an average moisture content for unblanched ginger dried at 10°C for 2 hours, 4 samples could be dried at this conditions and the averages of the four samples taken. These are as a result of loss of shapes, sizes and weight which influences the product's quality.

Shrinkages is a common physical phenomenon observed during the whole research under different dehydration processes. It affects the quality of this product in the reduction of microbiological activities which minimizes physical and chemical changes during storage of ginger. It is advisable that modelling shrinkages during the convective drying of ginger be another area of research. As shrinkages are rarely negligible in most agricultural products, it is advisable to take into account when predicting moisture content profile in ginger rhizomes or other materials undergoing dehydration processes. The physical modelling should be looked into to explain the shrinkage phenomenon of ginger rhizomes. Several authors have reported shrinkage analysis of soybean, corn, pasta, apple, carrot, potato, squid fish and gel.

5.3 Contribution to Knowledge

- From existing literature, no author had developed any computer programme to predict and analyze the drying process of ginger rhizomes. In this study, a computer programme was developed to address this challenge.
- This work provided the range of activation energy required to dry the variously treated ginger rhizomes samples.
- Dimensional analysis was used to deduce the relations between moisture content and other physical quantity in the drying process.
- This work will establish the best drying model for variously treated ginger rhizomes samples; hitherto there is no established drying model for ginger rhizomes.

REFERENCES

Abadio, F., Domingues, A., Borges, S., & Oliveira, V. (2004). Physical properties of powdered pineapple (Ananas comosus) juice—effect of malt dextrin concentration and atomization speed. *Journal of Food Engineering, 64*(3), 285-287. Retrieved June 30, 2015.

Adeyemi, S., & Onu, L. (1997). Development of ginger processing machines-ginger peeler. *Annual Research Report*.

Afolayan, M. O., Adama, K., Oberafo, A., Omojola, M., & Thomas, S. (2014). Isolation and Characterization Studies of Ginger (Zingiber officinale) Root Starch as a Potential Industrial Biomaterial. *American Journal of Materials Science*, *4*(2), 97-102. Retrieved March 12, 2015, from http://article.sapub.org/10.5923.j.materials. 20140402.06.html

AgricInfo. (2011). *About Us: My Agriculture Information Bank*. Retrieved March 12, 2015, from My Agriculture Information Bank Website: http://agriinfo.in/ default.aspx? page=topic&superid=2&topicid=1369

Ahmed, J. (2004). Effect of temperature on rheological characteristics of ginger paste. *Journal of Food and Agriculture*, *16*(1), 43-49. Retrieved January 20, 2015

Ajav, E., & Ogunlade, C. (2014). Physical Properties of Ginger (Zingiber Officinale). *Global Journal of Science Frontier Research: Agriculture and Veterinary, 14*(8), 1-8. Retrieved April 26, 2015

Akomas, G., & Oti, E. (1988). Developing a technology for the processing of Nigerian ginger (Zingiber Officinale Roscoe). *Proceedings of the First National Ginger Workshop*.

Akpinar, E. K. (2006) 'Mathematical modelling of thin layer drying process under open sun of some aromatic plants', *Journal of Food Engineering*, 77(4):864–870.

Akpinar, E. K. (2006). Determinatiuon of suitable thin layer drying curve model for some vegetable and fruits. *Journal of Food Engineering, 73*(1), 75-84. Retrieved January 20, 2015.

Akpinar, E. K. and Toraman, S. (2016) 'Determination of drying kinetics and convective heat transfer coefficients of ginger slices', *Heat Mass Transfer*, Springer-Verlag Berlin Heidelberg, 52(10), pp. 2271–2281. doi: 10.1007/s00231-015-1729-6.

Akpinar, E. K., Midilli, A. and Bicer, Y. (2003) 'Single layer drying behavior of potato slices in convective cyclone dryer and mathematical modeling, *Energy Convers Manag*, 44:1689-1705.

Akpinar, E., Bicer, Y., & Yildiz, C. (2003). Thin layer drying of red pepper. *Journal of Food Engineering, 59*(1), 99-104.

Alam, M. M., Zakaria Hossain, M., Aktar, M., Islam, S. and Hasan, Z. (2014) 'Drying and Dehydration Kinetics of Ginger', *International Journal of Innovation and Applied Studies ISSN*, 9(2), pp. 2028–9324. Available at: http://www.ijias.issr-journals.org/.

Ali, S., Ramaswamy, H., & Awuah, G. (2002). Thermo-Physical Properties Of Selected Vegetables As Influenced By Temperature And Moisture Content. *Journal of Food Process Engineering, 25*(5), 417-433.

Anne, P. (2002,). GINGER: Post-Production Management for Improved Market Access. (F. Mazaud, A. Röttger, & K. Steffel, Eds.) *Food and Agriculture Organization of the United Nations (FAO), AGST*, 2-20.

Arabhosseini, A., Huisman, W., van Boxtel, A., & Muller, J. (2006). Long-term effects of drying conditions on the essential oil and color of tarragon leaves during storage. *Journal of Food Engineering*(79), 561-566. Retrieved January 16, 2015.

Aregbesola, O. A., Ogunsina, B. ., Sofolahan, A. E. and Chime, N. N. (2015) ‘Mathematical modeling of thin layer drying characteristics of dika (Irvingia gabonensis) nuts and kernels’, *Nigerian Food Journal*, 33(1), pp. 83–89. doi: 10.1016/j.nifoj.2015.04.012.

Attanasio, G., Cinquanta, L., Albanese, D., & Di Matteo, M. (2004). Effects of drying temperatures on physico-chemical properties. *Journal of Food Chemistry, 88*, 583-590. Retrieved May 28, 2015

Aviara, N., & Haque, M. (2000). Moisture dependence of thermal properties of sheanut kernel. *Journal of Food Engineering, 47*, 109-113.

Aviara, N., Haque, M., & Ogunjimi, L. (2008). Thermal properties of guna seed. *International Agrophysics, 22*, 291-297.

Babettoa, C., Freirea, F., Barrozob, M., & Freirea, J. (2011). Drying of garlic slices: Kinetics and nonlinearity measures for selecting the best equilibrium moisture content equation. *Journal of Food Engineering, 107*(3-4), 347-352.

Bala, B. (1999). Drying and Storage of Cereal Grains. (S. P. Sokhansanj, Ed.) *Drying Technology: An International Journal, 17*(3), 639-640. Retrieved June 29, 2015

Bart-Plange, A., Addo, A., Amponsah, S., & Ampah, J. (2012). Effect of Moisture, Bulk Density and Temperature on Thermal Conductivity of Ground Cocoa Beans and Ground Sheanut Kernels. *Global Journal of Science Frontier Research Agriculture and Veterinary Sciences, 12*(7), 1-5.

Bart-Plnge, A., Addo, A., Kumi, F., & Piegu, A. (2009). Thermal conductivity of maize and cowpea. *Journal of Engineering and Technology, 2*(3), 6-11.

Bernard, A. (2008). *Diseases, pest and other factors limiting ginger(Zingiberofficinale Rose) production in River State*. Retrieved March 12, 2015, from http://uptonvilleoginstu.org/ginger.litm.

Bhardwaj, R., Sikka, B., Singh, A., Sharma, M., & Singh, N. (2011). Challenges and Constraints of Marketing and Export of Indian Spices in India. *International Conference on Technology and Business Management*, 739-749.

Bohm, M., Bade, M., & Kunz, B. (2002). Quality stabilization of fresh herbs using a combined vacuum-microwave drying process. *Advances in Food Science, 24*(2), 55-61. Retrieved January 16, 2014

Bonazzi, C., & Dumoulin, E. (2011). Quality Changes in Food Materials as Influenced by Drying Processes. (E. Tsotsas, & A. Mujumdar, Eds.) *Modern Drying Technology, 3*. Retrieved June 18, 2015

Ceylan I., Aktas M. and Dogan H. (2007) Mathematical model of drying characteristics of tropical fruits, *Applied Thermal Engineering*, 27:1931-1936.

Chandra, P. K. and Singh, R. P. (1995) *Applied numerical methods for food and agricultural engineers | Clc*. Boca Raton: CRC. Available at: http://library.wur.nl/ WebQuery/clc/909248.

Chegini, G., & Ghobadian, B. (2007). Spray Dryer Parameters for Fruit Juice Drying. *World Journal of Agricultural Sciences, 3*(2), 230-236. Retrieved June 30, 2015

Chinenye, N. M. (2009) ‘Effect of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean’, *Agricultural Engineering*, XI.

Cletus, A. B. (2007) *Drying characteristics of New Zealand chestnuts*. The University of Waikato. Materials and Process Engineering. Waikato, Available at: http://researchcommons. waikato.ac.nz/bitstream/handle/10289/2268/thesis.pdf?sequence=1&isAllowed=y (Accessed: 16 September 2016).

Convection Oven (no date) *ASAE*. Available at: https://engineering.purdue.edu/~abe305/moisture/html/page22.htm (Accessed: 20 September 2016).

Crank, J. (1975) ‘The Mathematics of Diffusion’. Oxford University Press, London.

C-Tech Unique Resources. (2015). *About Us: A. C-Tech Unique Resources*. Retrieved January 25, 2015, from A. C-Tech Unique Resources Website: http://www.c-techuniqueresources.net/dried-split-ginger.htm

Demir, V., Gunhan, T. and Yagcioglu, A. K. (2007) ‘Mathematical modelling of convection drying of green table olives’, *Biosystems Engineering*, 98(1), pp. 47–53. doi: 10.1016/j.biosystemseng.2007.06.011.

Depiver Joshua (2015). Experimental Investigations of Convective Drying of Ginger Rhizomes. *Dissertation/Project report*. Greenwich Universty, Medway, Kent, UK.

Deshmukh, A. W., Varma, M. N., Yoo, C. K. and Wasewar, K. L. (2014) ‘Investigation of Solar Drying of Ginger (Zingiber officinale): Emprical Modelling, Drying Characteristics, and Quality Study’, *Chinese Journal of Engineering*, pp. 1–7. doi: 10.1155/2014/305823.

Deshpande, S., Bal, S., & Ojha, T. (1996). Bulk thermal conductivity and diffusity of soybean. *Journal of Processing and Preservation, 30*(3), 177-189.

Desrosier, N., & Desrosier, J. (2006). The Technology of Food Preservation. *Molecular Nutrition - Food Research, 23*(1), 99. Retrieved June 18, 2015

Diamante, L. M. and Munro, P. A. (1993) ‘Mathematical modelling of the thin layer solar drying of sweet potato slices’, *Solar Energy*. Pergamon, 51(4), pp. 271–276. doi: 10.1016/0038-092X(93)90122-5.

Diamante, L., & Munro, P. (1991). Mathematical modelling of hot air drying of sweet potato slices. *International Journal of Food Science and Technology, 26*(1), 99-109. Retrieved January 27, 2015

Diamante, L., Ihns, R., Savage, G., & Vanhane, L. (2010). Short communications: A new mathematical model for thin drying of fruits. *International Journal of Food Science & Technology, 45*(9), 1956-1962.

docstoc. (2015). *About Us: A. Docstoc Corp*. Retrieved March 11, 2015, from A Docstoc Website: http://www.docstoc.com/docs/80154154/lab-5

Doymaz, I., & Pala, M. (2002). Hot-air drying characteristics of red pepper. *Journal of Food Engineering, 55*(4), 331-335.

Edwards David, (1975). Market for Dried, Preserved and Fresh Ginger. Publisher: Natural Resource Institute U. K.

Egbuchua, C., & Enujeke, E. (2013). Growth and yield responses of ginger (Zingiber officinale) to three sources of organic manures in a typical rainforest zone, Nigeria. *Journal of Horticulture and Forestry, 5*(7), 109-114.

Ekechukwu, O. V. (1999) 'Review of Solar-Energy drying systems I: an overview of drying principles and theory.', *Energy Conversion & Management*, 40, pp. 593–613. Retrieved June 17, 2015.

Ekundayo, O., Laakso, I., & Hiltumen, R. (2006). Composition of ginger (Zingiber officinale roscoe) volatile oils from Nigeria. *Flavour and Fragrance Journal, 3*(2), 85-90. Retrieved February 19, 2015.

Erbay, Z. and Icier, F. (2010) 'A review of thin layer drying of foods: theory, modeling, and experimental results.', *Critical reviews in food science and nutrition*, 50(5):441–464.

Ertekin, C., & Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering, 63*(3), 349-359.

ESPEC. (2015). *An Espec Corporation* . Retrieved March 11, 2015, from Espec Corp: http://www.espec.co.jp/english/inquiry/pdf/AR_e.pdf.

Eze, J. and Agbo, K. (2011) 'Comparative studies of sun and solar drying of peeled and unpeeled ginger', *American Journal of Scientific and Industrial Research*, 2(2), pp. 136–143. doi: 10.5251/ajsir.2011.2.2.136.143.

FAOSTAT. (2012). *Food and Agricultural Organisation of the United Nation*. (FAOSTAT, Producer) Retrieved March 8, 2015, from A FAOSTAT Website: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

Fernandesa, F. A., Rodrigues, S., Gaspareto, O. C., & Oliveira, E. L. (2006). Optimization of osmotic dehydration of papaya followed by air-drying. *Food Research International, 39*(4), 492-498. Retrieved January 20, 2015

Fontana, A., Varith, J., Ikediala, J., Reyes, J., & Wacker, B. (1999). Thermal properties of selected foods using a dual needle heat-pulse sensor. *ASAE Meeting Presentation.996063*. WA, USA: ASAE/CSAE-SCGR Annual International Meeting.

Food and Agricultural Organisation of the United Nation. (FAO) (2008). Country notes for the FAOSTAT domain on Production and prices. Accessed on October, 2008. www.faostat.org.

Fortes, M., Okos, M. R. and Member Asae, A. (1980) 'Non-Equilibrium Thermodynamics Approach to Heat and Mass Transfer in Corn Kernels. Hemisphere Publishing Corporation, New York.

FrançoisMazaud, AlexandraRöttger, K. S. (2002) 'Post-harvest Operations -', *Food and Agricultural Organization of the United Nations (FAO)*, p. 24. Available at: http://www.fao.org/3/a-av003e.pdf.

Ganesapillai, M., Murugan, P. And Singh, A. (2012) 'Experimental Analysis of Microwave Drying Kinetics and Characterization of Ginger Rhizomes', *Journal of Food Processing and Preservation*. Blackwell Publishing Inc, 36(5), pp. 401–411. Retrieved January 18, 2014. doi: 10.1111/j.1745-4549.2011.00577.x.

Ganguly, N., Singh, P., Kant, L., Shah, B., Muthuswamy, V., & Saxena, N. (2003). Ginger: Its Role in Xenobiotic Metabolism. (N. Medappa, & V. Srivastava, Eds.) *ICMR Bullemtin, 33*(6), 57-63. Retrieved January 15, 2014, from http://icmr.nic.in/ BUJUNE03new.pdf

Gbasouzor, Austin I., Omenyi S. N. (2019). Convective Drying of Ginger Rhizomes. Transaction in Engineering Technologies published by Springer Nature Singapore Pte Ltd., The Netherlands pp 83 -98.

Gbasouzor, Austin I., Omenyi S. N., & Sabuj Mallik (2020). Simulation of discretized element of ginger on Thin Layer Drying using Matlab PDES foroptimal programming. Journal of Engineering and Applied Sciences, Volume 16, number 1, pp64 – 80.

Geta, E., & Kifle, A. (2011). Production, processing and marketing of ginger in Southern Ethiopia. *Journal of Horticulture and Forestry, 3*(7), 207-213.

Gharibzahedi, S. M., Ghahderijani, M., & Lajevardi, Z. S. (2013). Specific heat, thermal conductivity and thermal diffusivity of red lentil seed as a function of moisture content. *Journal of Food Processing and Preservation*, 1-5. Retrieved April 10, 2015

Ghazanfari, A., Emami, S., Tabil, L. G. and Panigrahi, S. (2006) 'Thin-Layer Drying of Flax Fiber: III. Influence of Layer Thickness on Drying Parameters', *Drying Technology*, (24), pp. 1637–1642. doi: 10.1080/07373930601031471.

Gigler, J., Van Loon, W., Seres, I., Meerdink, G., & Coumans, W. (2000). PH - Postharvest Technology: Drying Characteristics of Willow Chips and Stems. *Journal of Agricultural Engineering Research, 77*(4), 391-400. Retrieved June 16, 2015

Gingerplant Network. (2013). *Gingerplant Network*. Retrieved January 10, 2014, from Gingerplant Network Website: http://gingerplant.net/wholesale-plants/

Glenn, T. L. (1978) *Dynamic Analyses of Grain Drying Systems Dissertation Presented in Partial Fulfillment of the Requirements for the Degree Doctor of* Philosophy in the Graduate. The Ohio State University.

Goula, A., Adamopoulos, K., & Kazakis, N. (2004). Influence of Spray Drying Conditions on Tomato Powder Properties. *Drying Technology: An International Journal, 22*(5), 1129-1151. Retrieved June 30, 2015.

Grabowski, J., Truong, V., & Daubert, C. (2006). Spray-Drying of Amylase Hydrolyzed Sweetpotato Puree and Physicochemical Properties of Powder. *Journal of Food Science, 71*(5), E209–E217. doi:DOI: 10.1111/j.1750-3841.2006.00036.x

Green, M., & Schwarz, D. (2001). Solar Drying Technology for Food Preservation. *gate Information Service / gtz,* 1-8. Retrieved July 2, 2015.

GRIN. (2003). *Agricultural Research Service*. (Trans. Linn. Soc. London 8:348. 1807) Retrieved October 22, 2014, from Zingiber officinale Roscoe: http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?42254

Guiné, R., Pinho, S., & Barroca, J. M. (2011). Study of the convective drying of pumpkin(Cucurbita maxima). *Food and Bioproducts Processing, 89,* 422-428. Retrieved January 19, 2015

Gunhan, T., Demir, V., Hancioglu, E., and Hepbasli, A. (2005). Mathematical modelling of drying of bay leaves. Energy Conversion and Management.46:1667–1679.

Gwak, H., & Eun, J. (2010). Changes in the Chemical Characteristics of Gulbi, Salted and Dried Yellow Corvenia, During Drying at Different Temperatures. *Journal of Aquatic Food Product Technology, 19,* 274-283. Retrieved January 19, 2015

Hankins, M. (1995). *Solar Electric Systems for Africa.* Commonwealth Science Council and. Retrieved July 1, 2015.

Henderson, S. . and Pabis, S. (1961) ‘Grain drying theory I:Temperature effect on drying coefficient’, *Journal of Agricultural Engineering Research*, 6, pp. 169–174.

Henderson, S. M. (1974) ‘Progress in Developing the Thin Layer Drying Equation’, in *Transactions of the ASAE*, pp. 1167–1172.

Hislop, D. (1992). *Energy Options – Chapter 3: Heat from Solar Energy*. Intermediate Technology Development Group. Retrieved July 2, 2015

Hoque, M., Bala, B., Hossain, M. and Uddin, M. B. (2013) ‘Drying Kinetics Of Ginger Rhizome (Zingiber officinale)’, *Bangladesh Journal of Agricultural Research*, 38(2), pp. 301–319. doi: 10.3329/bjar.v38i2.15892.

Hosain, D., & Mohammad, Z. (2012). Thermal Conductivity of Sunflower Seed as a Function of Moisture Content and Bulk Density. *World Applied Sciences Journal , 18*(9), 1321-1325.

Hossain, M., & Bala, B. (2002). Thin-Layer Drying Characteristics for Green Chilli. *Drying Technology: An International Journal, 20*(2), 489-505.

Hossain, M., & Bala, B. (2007). Drying of hot chilli using solar tunnel drier. (I. Farkas, Ed.) *Elsevier, 81*(1), 85-92. Retrieved June 28, 2015.

Ibrahim, D. (2004). Convective air drying characteristics of thin layer carrots. *Journal of Food Engineering, 61*(3), 359-364.

Isa, J., Oladele, S., & Akinlade, E. (2014). The Effect of Moisture Content on Thermal Properties of Some Selected Species of Egusi Melon (Colocynthis citrillus L.). *International Journal of Emerging Technology and Advanced Engineering, 4*(4), 580-586.

ITC. (2013). *International Trade Centre*. Retrieved January 16, 2015, from International Trade Centre Website: http://www.trademap.org/ Country_SelProduct.aspx? nvpm=1||||091010||| 6|1|1|2|1|1|2|1|1

ITDG. (2014). Ginger. *Journal of Food Processing & Technology*, 1-3. Retrieved January 16, 2015.

Janjaia, S., Bala, B., & Srisittipokakun, N. (2008). Experimental and modelling performances of a roof-integrated solar drying system for drying herbs and spices. *Energy, 33*(1), 91-103. Retrieved January 17, 2014.

Jayas, D. S., & Sokhansanj, J. (1989). Thin layer drying of barley at low temperatures. *Canadian Agricultural Engineering, 31*, 21-23. Retrieved June 15, 2015

Jayashree, E., Visvanathan, R., & John, Z. (2012). Quality of dry ginger (Zingiber officinale) by different drying methods. (A. o. (India), Ed.) *Journal of Food Science and Technology*.

Jiřičková, M., Pavlík, Z., & Černý, R. (2006). Thermal Properties of Biological Agricultural Materials. *Thermophysics 2006* (pp. 68-71). Prague, Czech Republic,: Czech Technical University in Prague. Retrieved June 29, 2015

John, I., Olugbenga, S., & Kayode, Q. (2014). Determination of Thermal Conductivity and Thermal Diffusivity of Three Varieties of Melon. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 5*(2), 123-128.

Joseph, G., & Kochi. (2006). *Ginger prices fall on cheap China, Nigeria arrivals.* Retrieved October 22, 2014, from Business Standard: http://www.business-standard.com/article/markets/ginger-prices-fall-on-cheap-china-nigeria-arrivals-106020701067_1.html

KADP. (2000). Production of ginger: an extension guide. *Kaduna State Agriculture Development Project*. Retrieved March 12, 2015

KADP. (2004). *Annual Report.* Ministry of Agricultural Development, Kaduna State Agricultural Development. Kaduna, Nigeria: Kaduna State Agricultural Development Project. Retrieved March 12, 2015

Kamo Ltd. (2015). *About Us: A. Kamo Garden Ltd Company*. Retrieved January 25, 2015, from A. Kamo Garden Ltd Company Website: http://www.kamoltd.co.jp/ kakegawa/english/ syokuji.htm

Karathanos, V. T. (1999) ‘Determination of water content of dried fruits by drying kinetics’, *Journal of Food Engineering*, 39(4), pp. 337–344. doi: 10.1016/S0260-8774(98)00132-0.

Karel, M. (1991). Physical structure and quality of dehydrated foods. *In the proceedings of Drying 91, (A.S.Mujundar ed.)*, 26-35. Retrieved January 16, 2015.

Karuppiyan, R., Rahman, H., Avasthe, R., Kalita, H., Singh, M., Ramesh, K., . . . Kumar, A. T. (2014). Pest and Disease Management in Ginger. *ICAR Research complex for NEH Region, 732*(102).

Kaymak-Ertekin, F. (2002). Drying and rehydrating kinetics of green and red peppers. *Journal of Food Science*. **67**:168–175.

Kew. (2014). *A. Royal Botanic Gardens*. Retrieved January 14, 2014, from A. Royal Botanic Gardens Website: http://www.kew.org/science-conservation/plants-fungi/zingiber-officinale-ginger.

Koyuncu, T., Pinar, Y., & Lule, F. (2006). Convective drying characteristics of azarole red (Crataegus monogyna Jacq.) and yellow (Crataegus aronia Bosc.) fruits. *Journal of Food Engineering, 78*, 1471–1475. Retrieved January 19, 2015.

Koyuncua, T., Serdar, U., & Tosun, I. (2004). Drying characteristics and energy requirement for dehydration of chestnuts (Castanea sativa Mill.). *Journal of Food Engineering, 62*(2), 165-168. Retrieved May 27, 2015

Kucuk H, Midilli A, Kilic A, Dincer I. (2014). A review on thin-layer drying-curve equations. Drying Technol 32(7):757–73.

Kurozawa, L., Park, K., & Azonbel, P. (2008). Thermal conductivity and thermal diffusivity of Papaya (Carica papaya,L) and Cashew Apple (Anacardium occidental, L). *Braz. Journal of Food Technology, 11*, 78-85.

Lahsasni, S., Kouhila, M., Mahrouz, M., & Jaouhari, J. (2004). Drying kinetics of prickly pear fruit (Opuntia ficus indica). *Journal of Food Engineering, 61*(2), 173-179. Retrieved June 15, 2015

Lee, B. (2013). *A. Lifehack Organisation*. Retrieved January 22, 2015, from A. Lifestyle Organisation website: http://www.lifehack.org/articles/lifestyle/10-benefits-of-ginger-that-you-didnt-know-about.html

Lewis, W. K. (1921) 'The Rate of Drying of Solid Materials.', *Journal of Industrial & Engineering Chemistry*. American Chemical Society, 13(5), pp. 427–432. doi: 10.1021/ie50137a021.

Loha, C., Das, R., Choudhury, B., & Chatterjee, P. (2012). Evaluation of Air Drying Characteristics of Sliced Ginger (Zingiber officinale) in a Forced Convective Cabinet Dryer and Thermal Conductivity Measurement. *Journal of Food Processing & Technology, 3*(160), 1-5.

Luangmalawata, P., Prachayawarakornb, S., Nathakaranakule, A., & Soponronnarita, S. (2008). Effect of temperature on drying characteristics and quality of cooked rice. *LWT - Food Science and Technology, 41*(4), 716-723. Retrieved June 5, 2015

Mahapatra, A., Melton, S., & Isang, E. (2013). Effect of moisture content on thermal properties of cowpea flours. *Agric Eng Int: CIGR Journal, 15*(2), 251-255.

Marinos-Kouris, D. and Maroulis, Z. (2006) 'Transport Properties in the Drying of Solids', in *Handbook of Industrial Drying, Third Edition*. CRC Press. doi: 10.1201/9781420017618.ch4.

Mayor, L., & Sereno, A. (2004). Modelling shrinkage during convective drying of food materials: a review. *Journal of Food Engineering, 61*, 373-386.

McMinn, W., & Magee, T. (1999, September). Principles, Methods and Applications of the Convective Drying of Foodstuffs. *Food and Bioproducts Processing, 77*(3), 175-193. Retrieved January 26, 2015

Mehta, P., & Chandel, R. (2014). *AINP Inc*. Retrieved January 25, 2015, from A. AINP Inc. Website: http://www.ainpwhitegrubs.com/palampur.htm

Mendi, S., Nain, C., Imélé, H., Ngoko, Z., & Mbofung, C. (2009). Microflora of fresh ginger rhizomes and ginger powder produced in the North-West Region of Cameroon. *Journal of Animal & Plant Sciences*, *4*(1), 251-260. Retrieved July 19, 2015

Midilli, A., Kucuk, H. and Yapar, Z. (2002) 'A New Model for Single-Layer Drying', *Drying Technology*. Taylor & Francis Group, 20(7), pp. 1503–1513. doi: 10.1081/DRT-120005864.

Muller, J. (2007). Convective drying of medicinal, aromatic and spice plants: a review. *Stewart Postharvest Review 2007*, 1-7. Retrieved January 16, 2014, from https://www.yumpu.com/en/document/view/6230170/convective-drying-of-medicinal-aromatic-and-spice-plants-a-review.

Muramatsu, Y., Tagawa, A., Kasai, T., Takeya, K., & Fukushima, M. (2007). Prediction of thermal conductivity of kernels and packed bed of brown rice. *Japan Journal of Food Engineering, 80*(1), 241-248.

NdaNmadu, J. (2014). Efficiency of Ginger Production in Selected Local Government Areas of Kaduna State, Nigeria. *International Journal of Food and Agricultural Economics, 1*(2), 39-52.

Ndukwu, M. C. (2009). Effect of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean. *Agricultural Engineering International: the CIGR Ejournal, X1*, 1-7. Retrieved June 16, 2015.

Netzsch. (2015). *About Us: A Netzsch Group Ltd*. Retrieved March 11, 2015, from A Netzsch Group Website: http://www.netzsch-thermal-analysis.com/en/landing-pages/thermal-conductivity-diffusivity/definition-thermal-conductivity.html.

Nigerian Export Promotion Council, NEPC (1999). Product Profile of Ginger. Nigerian Export Promotion Council b/k 312, Kumba St. Wuse, Zone II, Abuja, 1- 6.

Nishina, M., Sato, D., Nishijima, W., & Mau, R. (2013). Ginger Root Production in Hawaii. *Hawaii Cooperative Extension Service*, *6*(92).

Nwandikom, G., & Njoku, B. (1988). Design-related physical properties of Nigerian ginger. *Proceedings of First National Ginger Workshop*, 101-107.

Okafor, G., & Okafor, J. (2007). Effects of pricking, sun-drying and sieving on Ginger (Zingiber officinale Roscoe) colour and powder. *Nigerian Food Journal, 25*(1), 155-160.

Omeni, B. (2015). *About Us: Agronigeria Ltd*. (Agronigeria, Producer, & Agronigeria Ltd) Retrieved March 7, 2015, from An Agronigeria Ltd Website: http://agronigeria.com.ng/2014/01/09/steps-to-take-in-ginger-plantation/

Onu, L. (1997). Design and fabrication of manual ginger slicing machine. *Annual Research Report, 34*(1).

Onu, L. (1998). Testing and characterization of mechanical slicing of ginger. *Annual Research Report, 37*(3). Retrieved May 12, 2015

Onu, L. I. and Okafor, G. I. (2003) 'Effect of physical and chemical factor variations on the efficiency of mechanical slicing of Nigerian ginger (Zingiber Officinale Rose)', *Journal of Food Engineering*, 56(1), pp. 43–47. doi: 10.1016/S0260-8774(02)00146-2.

Onwude D. I., Norhashila H., Rimfiel B. J., Nazmi M. N., and Khalina A. (2016) Modeling the Thin-Layer Drying of Fruits and Vegetables: A Review. Comprehensive Reviews in Food Science and Food Safety, 15:599-618.

Organic Facts. (2012). *About Us: Organic Information Services Pvt Ltd*. Retrieved January 24, 2015, from An Organic Information Services Pvt Ltd.: https://www.organicfacts.net/ health-benefits/herbs-and-spices/ginger.html

Oti, E., Okwuowulu, P., Ohiori, V., & Chijioke, G. (1988). Biochemical changes in ginger (Zinginger officinale roscoe) rhizomes stored under river sand and under dry grasses in pits in the humid tropics. *Trorical Science, 28*, 87-94.

Overhults, D. G., White, G. M., Hamilton, H. E. and Ross, I. J. (1973) 'Drying Soybeans With Heated Air', in *Transactions of the ASAE*, pp. 112–113. Available at: http://elibrary.asabe.org/azdez.asp?AID=37459&T=2 (Accessed: 19 August 2016).

Özdemir, M. and Onur Devres, Y. (1999) 'The thin layer drying characteristics of hazelnuts during roasting', *Journal of Food Engineering*, 42(4), pp. 225–233. doi: 10.1016/S0260-8774(99)00126-0.

Özgüven, M., Bux, M., Koller, W., Sekeroglu, N., Kirpik, M., & Müller, J. (2007). Influence of fluctuating drying conditions during shade-, sun- and solar-drying on the quality of Lavandula officinalis L., Origanum syriacum L. und Thymbra spicata L. *Journal of Medicinal and Spice Plants, 12*(2), 80-87. Retrieved January 18, 2014

Özilgen, M. and Özdemir, M. (2001) 'A Review on Grain and Nut Deterioration and Design of the Dryers for Safe Storage with Special Reference to Turkish Hazelnuts', *Critical Reviews in Food Science and Nutrition*. Taylor & Francis, 41(2), pp. 95–132. doi: 10.1080/20014091091779.

Page, G.E. (1949). Factors influencing the maximum rate of air drying shelled corn in thin-layers. M.S.Thesis, Purdue University, West Lafayette, Indiana

Parti, M. (1993) 'Selection of Mathematical Models for Drying Grain in Thin-Layers', *Journal of Agricultural Engineering Research*. Academic Press, 54(4), pp. 339–352. doi: 10.1006/jaer.1993.1026.

Perera, C. (2005). Selected Quality Attributes of Dried Foods. *Drying Technology: An International Journal, 23*(4), 717-730. doi:10.1081/DRT-200054180

Perusulla, C., Viviana, C., & Mends, L. (2010). Development of a linear Heat Source Probe and Determination of Banana Thermal Conductivity. *Journal of Food Engineering, 6*(5).

Phoungchandang, S., & Sertwasana, A. (2010). Spray-drying of ginger juice and physicochemical. *ScienceAsia, 36*, 40-45. Retrieved June 29, 2015

Plotto, A. (2002). GINGER: Post-Production Management for Improved Market Access. (F. Mazaud, A. Röttger, & K. Steffel, Eds.) *INPhO - Post - harvest Compendium*, 2-20.

Puengphian, C., & Sirichote, A. (2008). gingerol content and bioactive properties of ginger (Zingiber officinale Roscoe) extracts from supercritical CO2 extraction. *Asian Journal of Food and Agro-Industry, 1*(01), 29-36. Retrieved May 24, 2015

Purnomo, H., Jaya, F., & Widjanarko, S. (2010). The effects of type and time of thermal processing on ginger (Zingiber officinale Roscoe) rhizome antioxidant compounds and its quality. *International Food Research Journal, 17*, 335-347. Retrieved June 24, 2015

Queenland Wetlands Program. (2013). *A. Wetlandinfo International*. Retrieved January 21, 2015, from A. Wetlandinfo International website: http://wetlandinfo.ehp.qld. gov.au/ resources/static/pdf/resources/reports/ farming-case-studies/cs-ginger-15-04-13.pdf

Rai, S. (2015). *Management of Ginger (Zingiber officinale Rosc.) Rhizome Rot in Darjeeling and Sikkim Himalayan Region.* Retrieved March 10, 2015, from DKVK: http://www.mtnforum.org/sites/default/files/publication/files/1679.pdf

Raina, V., Kumar, A., & Aggarwal, K. (2013). Essential Oil Composition of Ginger (Zingiber officinale Roscoe) Rhizomes from Different Place in India. *Journal of essential oil-bearing plants JEOP, 8*(2), 187-191.

Rao, M., Syed, S., Rizvi, A., & Datta, J. (2014). *Engineering Properties of Foods, Fourth Edition.* CRC Press Boca Raton, Florida, USA.

Ravindran P. N. & Babu K. N. (ed) 2005 Ginger. The Genus Zingiber. CRC Press Boca Raton, Florida, USA:, pp. 551, ISBN 0-415-32468-8

Read & Digest. (2014). *Read Digest*. Retrieved October 22, 2014, from readanddigest website: http://readanddigest.com/dry-ginger-uses-and-benefits/

Sah, P., Al-Tamimi, B., Al-Nassri, N., & Al-Mamari. (2012). Effect of Temperature on Antibiotic Properties of Garlic (Allium sativum L.) and Ginger (Zingiber officinale Rosc.). *African Journal of Biotechnology, 95*(11), 16192-16195.

Salathe, M., Hughes, D., Lindsay, M., & Lambert, B. (2014). *Abous Us: PlantVillage*. (H. I. Sciences, Producer) Retrieved March 8, 2015, from A PlantVillage Website: https://www.plantvillage.com/en/topics/ginger/infos/ diseases_and_ pests_description_uses_propagation.

Sasidharan, I., & Menon, A. (2010). Comparative Chemical Composition and Antimicrobial Activity Fresh & Dryginger Oils (Zingiber Officinale Roscoe). *International Journal of current pharmeceutical research, 2*(4), 40-43.

Shalini, R., Ranjan, A., & Kumar, N. (2008). Studies on the Drying Characteristics of Apple pomace on tray drier. *16th International Drying Symposium (IDS 2008),* 1636-1640.

Sharaf-Eldeen, Y. I., Blaisdell, J. L., Hamdy, M. Y., Member, A. and Asae, A. (1980) ‘A Model for Ear Corn Drying’, in *Transactions of the ASAE*, pp. 1261–1271.

Shi, Q.-L., Xue, C.-H., Zhao, Y., Li, Z.-J., & Wang, X.-Y. (2008). Drying characteristics of horse mackerel (Trachurus japonicus) dried in a heat pump dehumidifier. *Journal of Food Engineering, 84*(1), 12-20. Retrieved January 20, 2015

Shirin, A., & Prakash, J. (2011). Chemical composition and antioxidant properties of ginger root (Zingiber officinale). *Journal of Medicinal Plants Research, 4*.

Sigge, G. O., Hansmann, C. F. and Joubert, E. (1998) ‘Effect of Temperature and Relative Humidity on the Drying Rates and Drying Times of Green Bell Peppers (*Capsicum Annuum L*)’, *Drying Technology*, 16(8), pp. 1703–1714. doi: 10.1080/07373939808917487.

Singh, K., & Goswani, T. (2000). Thermal propeties of cumin seed. *Journal of Food Engineering, 45*(4), 181-187.

Soysal, Y., & Oztekin, S. (2001). Technical and economic performance of a tray dryer for medicinal and aromatic plants. *Journal of Agricultural Engineering Research, 79*(1), 73-79.

Subramanian, S., & Viswanathan, R. (2003). Thermal Properties of Minor Millet Grains and Flours. *Biosystems Engineering, 84*(3), 289-296.

Sukrasno, Waningsih, E. S., & Fidrianny, I. (2014). Heating effect of Ginger (Zingiber officinale Rosc) in a content of volatile oil and Oleoresin. *International Journal of Research in Pharmaceutical Sciences*, 132-136. Retrieved January 20, 2015

Sun Best. (2015). *About Us: A Sun Best Limited*. (M. Rajesh, Editor, & IndiaMART InterMESH Limited) Retrieved May 26, 2015, from Sun Best Limited Web site: http://www.indiamart.com/sun-best/small-solar-dryer.html

Tecquipment. (2015). *A. TecQuipment Ltd.* Retrieved March 11, 2015, from A. TecQuipment Ltd Website: http://www.tecquipment.com/prod/TD1002A.aspx

TES Global Limited. (2015). *About Us: A. SBI3UPlantsJan2012 Inc.* (T. G. Limited, Producer, & Tangient LLC) Retrieved May 26, 2015, from A. SBI3UPlants Jan2012 Website: https://sbi3uplantsjan2012.wikispaces.com/Asexual+Reproduction+In+Plants+Wiki

Thermal Conductivity Formula, Thermal Conductivity Equation | Formulas @TutorVista.com (no date). Available at: http://formulas.tutorvista.com/physics/thermal-conductivity-formula.html (Accessed: 19 September 2016).

Toˇgrul, Ý.T., and Pehlivan, D. (2003). Modelling of drying kinetics of single apricot. *Journal of Food Engineering*. 58(1):23–32.

Treybal, R. E. (1968) *Mass Transfer Operations*. 2nd Edition. New York: Mc Graw Hill.

Ugwoke, C., & Nzekwe, U. (2010). Phytochemistry and proximate composition of ginger (Zinginer offcinale). *Journal of Pharmacuetical and Allied Sciences, 7*(5).

UUMC. (2013). *A. UMMC research*. (U. o. Centre, Producer) Retrieved January 21, 2015, from A. UMMC website: http://umm.edu/health/medical/altmed/herb/ginger

Vargas, T., & Camacho, S. (1996). *Solar Drying of Fruits and Vegetables: Experiences in Bolivia.* Bolivia: FAKT, Energetica. Retrieved July 3, 2015

Vengatesan M. R., Varghese A. M. and Mittal V. (2018). *Thermosets: Structure, Properties, and Applications, Second Edition*. Elsevier Ltd. ISBN: 978-0-08-101021-1. pp.69.

Verma, L. ., Bucklin, R. ., Endan, J. . and Wratten, F. . (1985) 'Effects of Drying Air Parameters on Rice Drying Models', *Transactions of the ASAE*. American Society of Agricultural Engineers, 28(1), pp. 0296–0301. Available at: http://elibrary.asabe.org/azdez.asp?JID=3&AID=32245&CID=t1985&v=28&i=1&T=1&refer=7&access=&dabs=Y.

Vikaspedia. (2014). *Technologies from CIPHET*. Retrieved January 26, 2015, from A. Vikaspedia Website: http://vikaspedia.in/agriculture/post-harvest-technologies/technologies-for-agri-horti-crops/technologies-from-ciphet

Wang, Y., Zhang, M., & Mujumdar, A. (2011). Convective Drying Kinetics and Physical Properties of Silver Carp (Hypophthalmichthys molitrix) Fillets. *Journal of Aquatic Food Product Technology, 20,* 361-378. Retrieved January 19, 2015.

Weaver, C., Dwyer, J., Fulgoni III, V., King, J., Leveille, G., MacDonald, R., Schnakenberg, D. (2014). Processed foods: contributions to nutrition. *The American Journal of Clinical Nutrition (AJCN), 99*(6), 1525-1542. Retrieved January 18, 2014.

White, G. M., Loewer, O. J., Ross, I. J. and Egli, D. B. (1976) ‘Storage Characteristics of Soybeans Dried with Heated Air’, *Transactions of the ASAE*, pp. 306–310. Available at: http://elibrary.asabe.org/azdez.asp?AID=36017&T=2 (Accessed: 19 August 2016).

Xanthopoulosa, G., Yanniotisb, S., & Lambrinosa, S. (2009). Study of the drying behaviour in peeled and unpeeled whole figs. *Journal of Food Engineering, 97*(3), 419-424.

Yagcioglu, A Degirmencioglu, A Cagatay, F. (1999) ‘Drying characteristic of laurel leaves under different conditions.’, in *Proceedings of the 7th international congress on agricultural mechanization and energy*. Adana: Faculty of Agriculture, Çukurova University., pp. 565–569.

Yahaya, M., Othman, M., Sopian, K., Daud, W., & Yatim, B. (2004). Quality of pegaga leaf dried in a solar assisted Dehumidification drying system. *Drying 2004-Proceedings of the 14th International Drying Symposium (IDS 2004)*(B), 1049-1054.

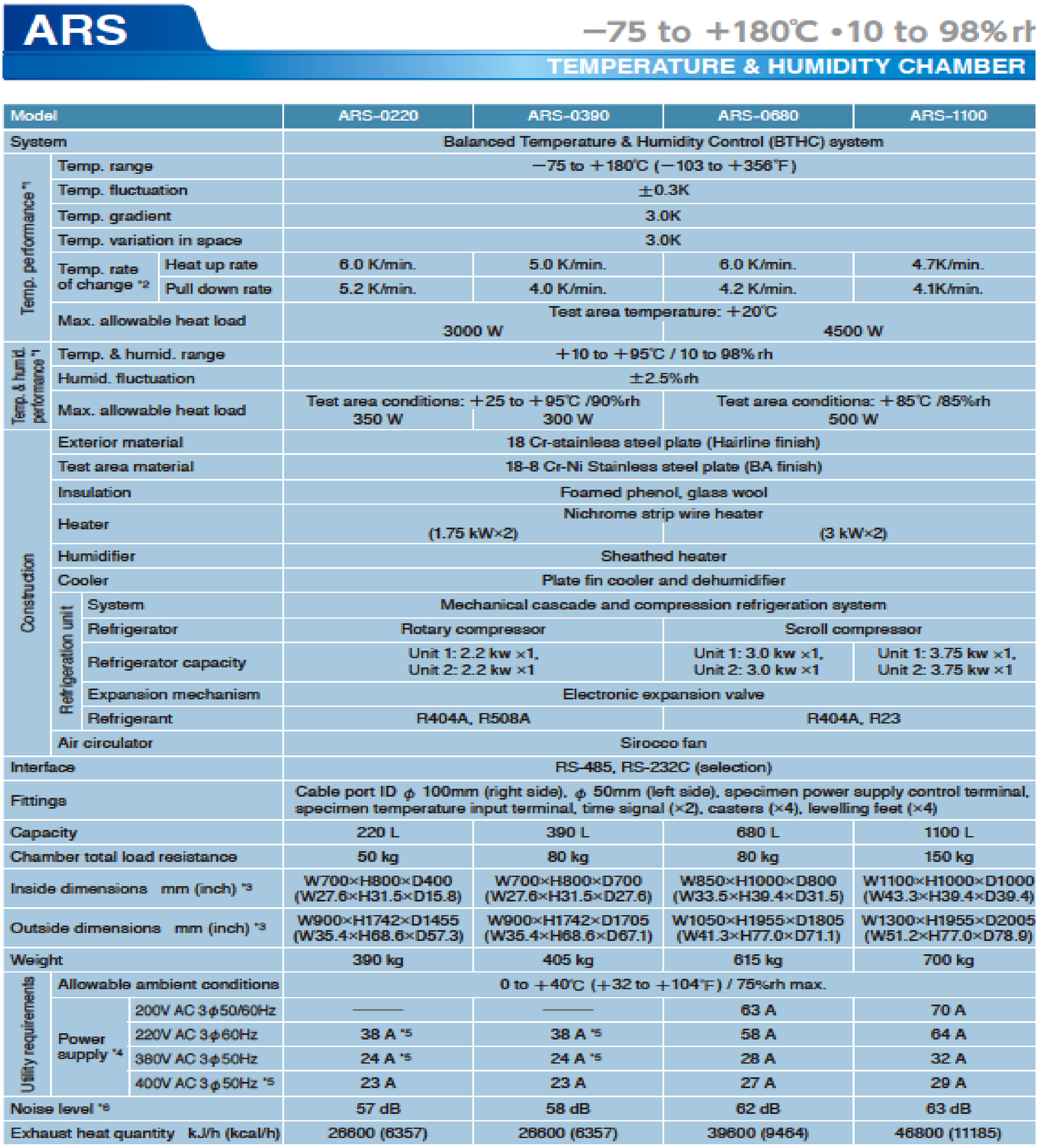
Yang, W., Siebenmorgen, T., Thielen, T., & Cnossen, A. (2003). Effect of Glass Transition on Thermal Conductivity of Rough Rice. *Biosystems Engineering, 84*(2), 193-200.

Yang, W., Sokhansanj, S., Tang, J., & Winter, P. (2002). PH—Postharvest Technology: Determination of Thermal Conductivity, Specific Heat and Thermal Diffusivity of Borage Seeds. *Biosystems Engineering, 82*(2), 169-176.

Zabalaga, R., & Carballo, S. (2014). Convective Drying and Water Adsorption Behaviour of unriped banana: Mathematical Modeling. *Journal of Food Processing and Preservation*, 1-8.

APPENDIX

A.1: ARS – 0680 TEMPERATURE AND HUMIDITY CHAMBER EQUIPMENT SPECIFICATION



ARS

−75 to +180℃ •10 to 98%rh

TEMPERATURE & HUMIDITY CHAMBER

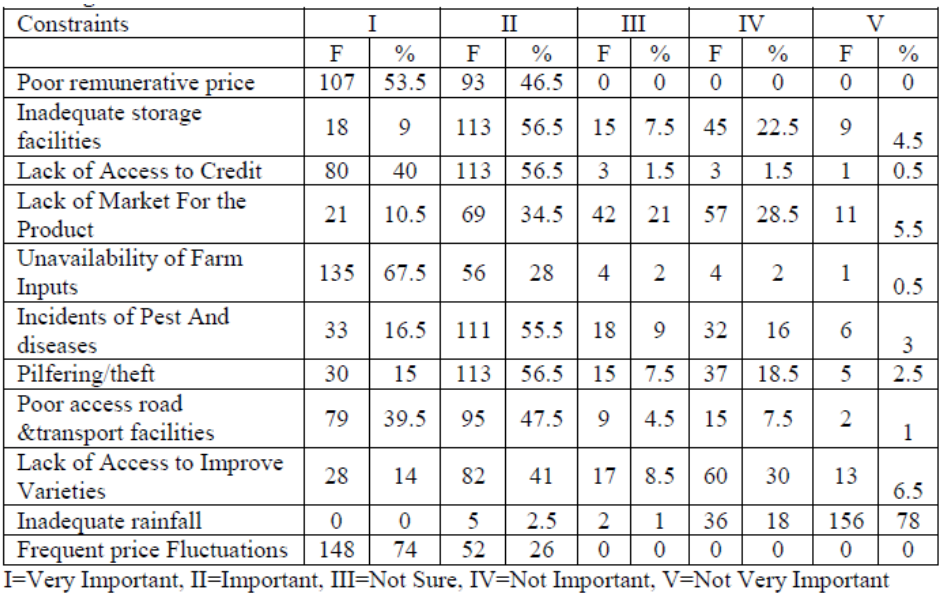
Model				ARS-0220	ARS-0390	ARS-0680	ARS-1100
System				Balanced Temperature & Humidity Control (BTHC) system			
Temp. performance [*1]	Temp. range			−75 to +180℃ (−103 to +356°F)			
	Temp. fluctuation			±0.3K			
	Temp. gradient			3.0K			
	Temp. variation in space			3.0K			
	Temp. rate of change [*2]	Heat up rate		6.0 K/min.	5.0 K/min.	6.0 K/min.	4.7K/min.
		Pull down rate		5.2 K/min.	4.0 K/min.	4.2 K/min.	4.1K/min.
	Max. allowable heat load			Test area temperature: +20℃ 3000 W		4500 W	
Temp. & humid. performance [*1]	Temp. & humid. range			+10 to +95℃ / 10 to 98% rh			
	Humid. fluctuation			±2.5%rh			
	Max. allowable heat load			Test area conditions: +25 to +95℃ /90%rh 350 W	300 W	Test area conditions: +85℃ /85%rh 500 W	
Construction	Exterior material			18 Cr-stainless steel plate (Hairline finish)			
	Test area material			18-8 Cr-Ni Stainless steel plate (BA finish)			
	Insulation			Foamed phenol, glass wool			
	Heater			Nichrome strip wire heater (1.75 kW×2)		(3 kW×2)	
	Humidifier			Sheathed heater			
	Cooler			Plate fin cooler and dehumidifier			
	Refrigeration unit	System		Mechanical cascade and compression refrigeration system			
		Refrigerator		Rotary compressor		Scroll compressor	
		Refrigerator capacity		Unit 1: 2.2 kw ×1, Unit 2: 2.2 kw ×1		Unit 1: 3.0 kw ×1, Unit 2: 3.0 kw ×1	Unit 1: 3.75 kw ×1, Unit 2: 3.75 kw ×1
		Expansion mechanism		Electronic expansion valve			
		Refrigerant		R404A, R508A		R404A, R23	
	Air circulator			Sirocco fan			
Interface				RS-485, RS-232C (selection)			
Fittings				Cable port ID ϕ 100mm (right side), ϕ 50mm (left side), specimen power supply control terminal, specimen temperature input terminal, time signal (×2), casters (×4), levelling feet (×4)			
Capacity				220 L	390 L	680 L	1100 L
Chamber total load resistance				50 kg	80 kg	80 kg	150 kg
Inside dimensions mm (inch) [*3]				W700×H800×D400 (W27.6×H31.5×D15.8)	W700×H800×D700 (W27.6×H31.5×D27.6)	W850×H1000×D800 (W33.5×H39.4×D31.5)	W1100×H1000×D1000 (W43.3×H39.4×D39.4)
Outside dimensions mm (inch) [*3]				W900×H1742×D1455 (W35.4×H68.6×D57.3)	W900×H1742×D1705 (W35.4×H68.6×D67.1)	W1050×H1955×D1805 (W41.3×H77.0×D71.1)	W1300×H1955×D2005 (W51.2×H77.0×D78.9)
Weight				390 kg	405 kg	615 kg	700 kg
Utility requirements	Allowable ambient conditions			0 to +40℃ (+32 to +104°F) / 75%rh max.			
	Power supply [*4]	200V AC 3ϕ50/60Hz		———	———	63 A	70 A
		220V AC 3ϕ60Hz		38 A [*5]	38 A [*5]	58 A	64 A
		380V AC 3ϕ50Hz		24 A [*5]	24 A [*5]	28 A	32 A
		400V AC 3ϕ50Hz [*5]		23 A	23 A	27 A	29 A
Noise level [*6]				57 dB	58 dB	62 dB	63 dB
Exhaust heat quantity kJ/h (kcal/h)				26600 (6357)	26600 (6357)	39600 (9464)	46800 (11185)

Figure A.1: ARS – 0680 Temperature and Humidity Chamber Equipment Specifications (ESPEC, 2015)

A.2: Ginger production in Kaduna State, Nigeria (Map)

Figure A.2: Map of Kaduna state, Nigeria showing the study area in grey shading (NdaNmadu, 2014)

A.3: Constraints Faced by Ginger Farmers in Nigeria based on Local area survey



Constraints	I		II		III		IV		V	
	F	%	F	%	F	%	F	%	F	%
Poor remunerative price	107	53.5	93	46.5	0	0	0	0	0	0
Inadequate storage facilities	18	9	113	56.5	15	7.5	45	22.5	9	4.5
Lack of Access to Credit	80	40	113	56.5	3	1.5	3	1.5	1	0.5
Lack of Market For the Product	21	10.5	69	34.5	42	21	57	28.5	11	5.5
Unavailability of Farm Inputs	135	67.5	56	28	4	2	4	2	1	0.5
Incidents of Pest And diseases	33	16.5	111	55.5	18	9	32	16	6	3
Pilfering/theft	30	15	113	56.5	15	7.5	37	18.5	5	2.5
Poor access road &transport facilities	79	39.5	95	47.5	9	4.5	15	7.5	2	1
Lack of Access to Improve Varieties	28	14	82	41	17	8.5	60	30	13	6.5
Inadequate rainfall	0	0	5	2.5	2	1	36	18	156	78
Frequent price Fluctuations	148	74	52	26	0	0	0	0	0	0

I=Very Important, II=Important, III=Not Sure, IV=Not Important, V=Not Very Important

Figure A.3: Distribution of the Respondents According to the Constraints Faced in Ginger Farming - Field Survey 2011**(NdaNmadu, 2014)**

A.4: Flow Chart for Dried, Preserved Ginger and Essential Ginger Oil Production

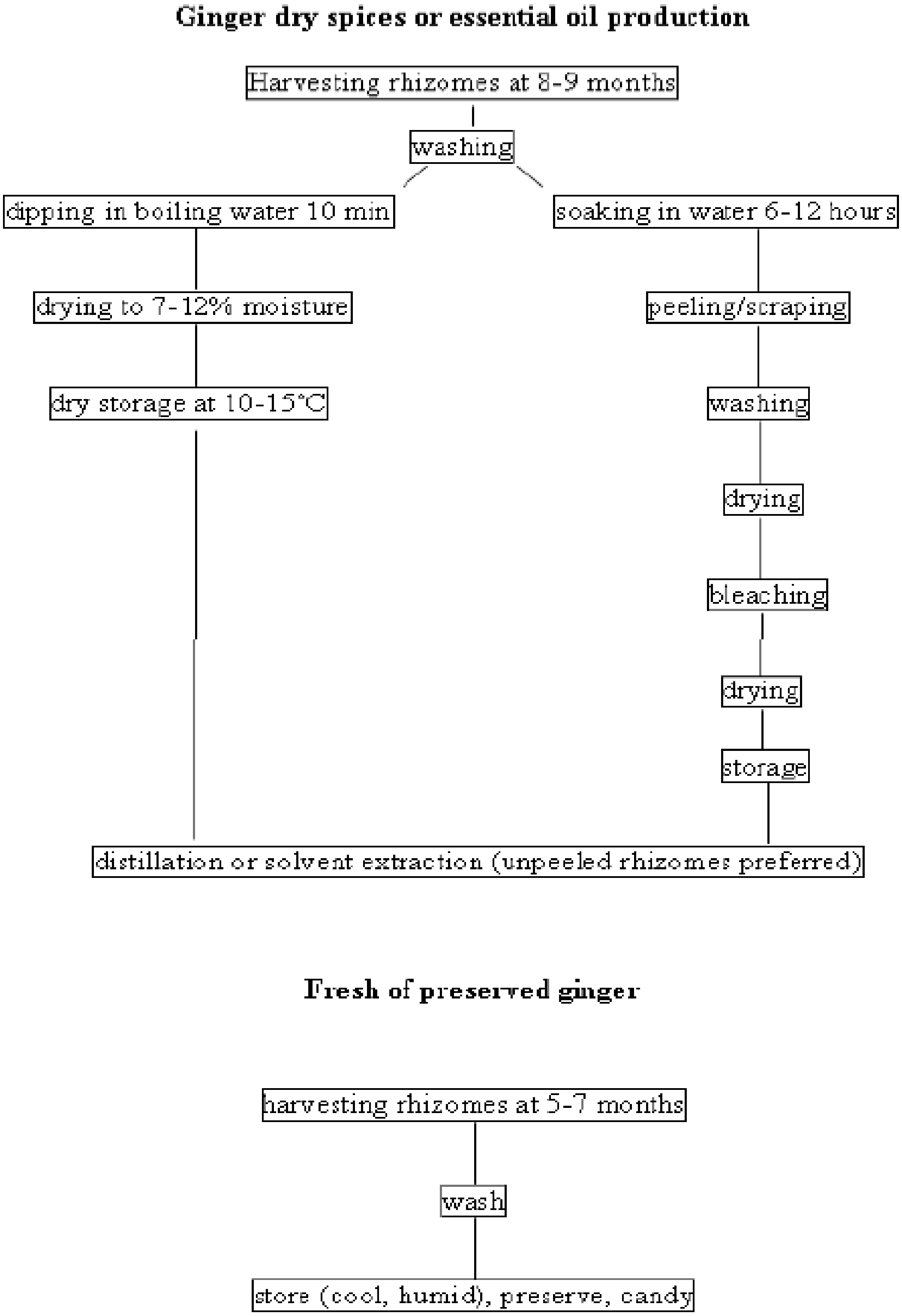


Figure A.4: Flow Chart for Dried, Preserved Ginger and Essential Ginger Oil Production(FrançoisMazaud and AlexandraRöttger, 2002)

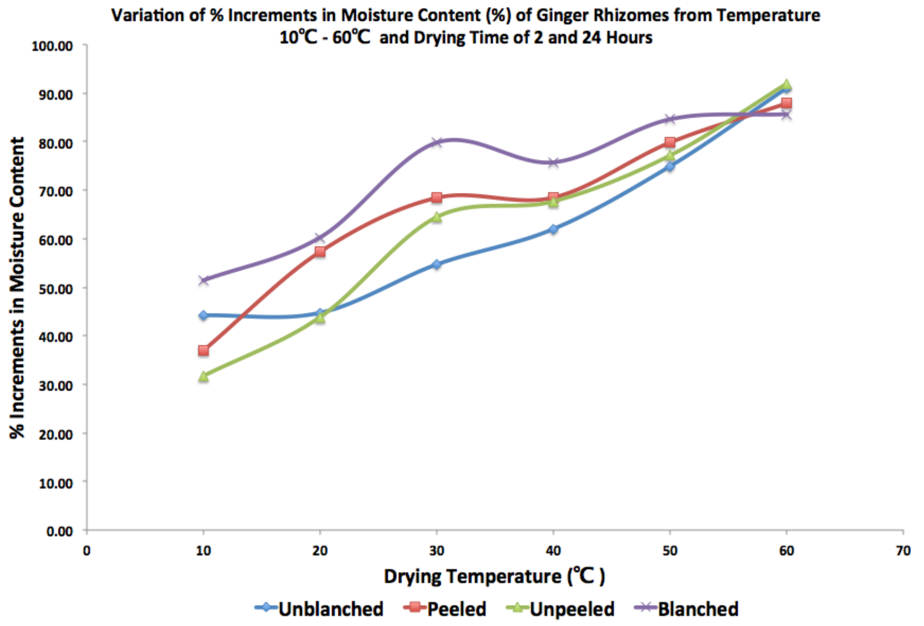


Figure A.5: Graph of variation of percentage increase in Moisture Content (%) of Ginger Rhizomes from Temperature 10℃ - 60℃and Drying Time of 2 and 24 Hours

Table A.1: Table of Percentage increase in Moisture Content (%) of Ginger Rhizomes for Temperature from 10℃ - 60℃ and Drying rates

Temperature (°C)	**10**℃		**20**℃		**30**℃		**40**℃		**50**℃		**60**℃	
Time (Hour)	2	24	2	24	2	24	2	24	2	24	2	24
Moisture Content (%)												
Unblanched	88.84	49.55	86.55	47.81	87.34	39.55	79.32	30.12	71.65	17.95	74.16	6.63
Blanched	84.58	41.13	86.29	34.26	86.65	17.48	70.11	17.00	66.64	10.25	63.11	9.04
Peeled	88.74	55.91	87.85	37.49	87.95	27.76	75.93	23.92	65.50	13.21	70.75	8.56
Unpeeled	91.08	62.22	86.17	48.36	87.71	31.15	81.46	26.30	67.85	15.49	74.36	5.98
	Average Drying rates											
Unblanched	0.298		0.029		0.036		0.037		0.041		0.051	
Blanched	0.033		0.039		0.052		0.040		0.043		0.041	
Peeled	0.025		0.038		0.046		0.039		0.040		0.047	
Unpeeled	0.022		0.029		0.043		0.042		0.040		0.052	

Table A.2: Table of Percentage increase in Thermal Conductivity (W/m. K) of Ginger Rhizomes for Temperature from 10℃ - 60℃ and Drying Time of 2 and 24 Hours

Temperature (℃)	**10**℃		**20**℃		**30**℃		**40**℃		**50**℃		**60**℃	
Time (Hour)	2	24	2	24	2	24	2	24	2	24	2	24
Thermal Conductivity (W/m. K)												
Unblanched	0.4064	0.1607	0.4064	0.1491	0.1074	0.0677	0.0756	0.0557	0.0715	0.0541	0.0762	0.0553
Blanched	0.3290	0.1400	0.2919	0.1312	0.1006	0.0689	0.0707	0.0562	0.0730	0.0556	0.0836	0.0516
Peeled	0.3768	0.1449	0.3768	0.1391	0.1459	0.0652	0.0717	0.0516	0.0759	0.0519	0.0791	0.0483
Unpeeled	0.3397	0.1713	0.3454	0.1713	0.1126	0.0611	0.0717	0.0543	0.0776	0.0460	0.0776	0.0460
	Percentage Increase in Thermal Conductivity											
Unblanched	60.46		63.31		36.96		26.32		24.34		27.43	
Blanched	57.45		55.05		31.51		20.51		23.84		38.28	
Peeled	61.54		63.08		55.31		28.03		31.62		38.94	
Unpeeled	49.57		50.41		45.74		24.27		40.72		40.72	

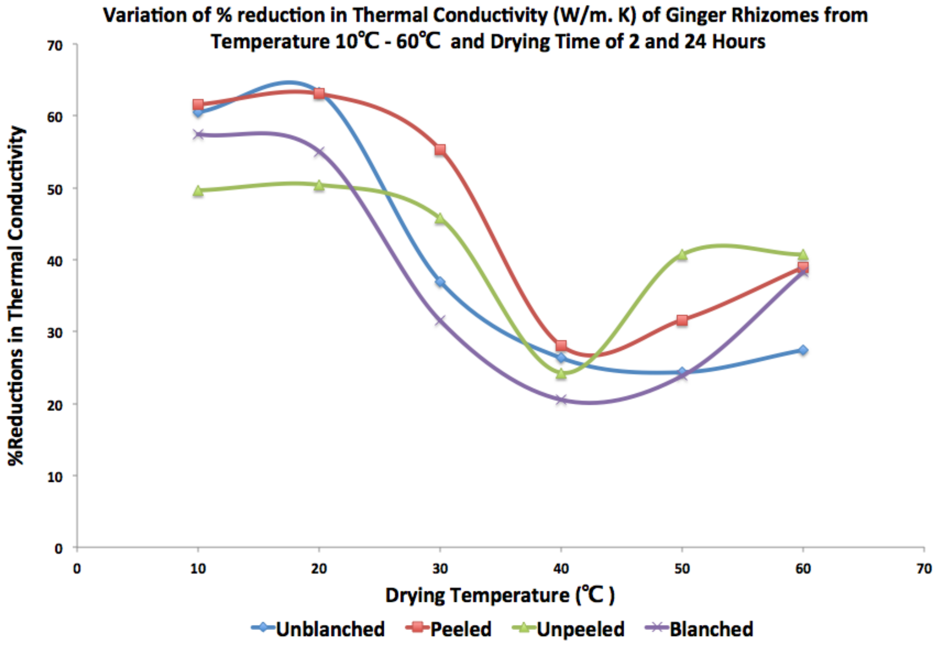


Figure A.6: Graph of variation of percentage reductions in Thermal Conductivity (W/m. K) of Ginger Rhizomes for Temperature from 10℃ - 60℃and Drying Time of 2 and 24 Hours

Table A.3: Food Driers Classifications(Green & Schwarz, 2001)

S/Nos.	Classification	Description
1	Open-Air	Food is exposed to the sun and wind by placing in trays, on racks, or on the ground. Food is rarely protected from predators and the weather.
2	Direct Sun	Food is enclosed in a container with a clear lid allowing sun to shine directly on the food. Vent holes allow for air circulation.
3	Indirect Sun	Fresh air is heated in a solar heat collector and then passed through food in the drier chamber. In this way the food is not exposed to direct sunlight.
4	Mixed Mode	Combines the direct and indirect types; a separate collector preheats air and direct sunlight ads heat to the food and air.
5	Hybrid	Combines solar heat with another source such as fossil fuel or biomass.
6	Fueled	Uses electricity or fossil fuel as a source of heat and ventilation.

Table A.4: Forced Air compared with solar dryer, open-air and fuel drying (Adapted from: (Hankins, 1995; Hislop, 1992; Vargas & Camacho, 1996).

Type of Drying	Benefits (+) & Demerits (-) of Forced air Convection
Forced air vs. Solar/Open-air	+ Can lead to better quality dried products, and better market prices + Reduces losses and contamination from insects, dust, and animals + Reduces land required (by roughly 1/3) + Some driers protect food from sunlight, better preserving nutrition & colour + May reduce labour required + Faster drying time reduces chances of spoilage + More complete drying allows longer storage + Allows more control (sheltered from rain, for example) - More expensive, may require importing some materials - In some cases, food quality is not significantly improved - In some cases, market value of food will not be increased
Forced air vs. Fuelled	+ Prevents fuel dependence + Often less expensive + Reduced environmental impact (consumption of non-renewables) +Requires less time - Greater difficulty controlling process, may result in lower quality product

APPENDIX B

B.1: Detailed Experimental Calculations for Moisture Content (%) and Thermal Conductivity (W/m. K)

Table B.1: Experimental Results @ Temperature of 10℃

Unblanched							Blanched						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture Content (%) $(W_i-W_j)/W_i$ X 100	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before (W_i)	After (W_j)	Difference (W_i-W_j)					Before	After	Difference		
1	2	12.76	11.31	1.45	11.36	0.4064	1	2	12.32	10.42	1.90	15.42	0.3290
2	4	12.13	10.28	1.85	15.25	0.3188	2	4	14.66	11.52	3.14	21.42	0.2878
3	8	12.80	10.02	2.78	21.72	0.2657	3	8	12.72	8.04	4.68	36.79	0.1993
4	10	12.19	8.98	3.21	26.33	0.2303	4	10	12.97	8.10	4.87	37.55	0.1901
5	14	15.64	10.20	5.44	34.78	0.1834	5	14	14.64	7.82	6.82	46.58	0.1699
6	16	12.23	6.25	5.98	48.90	0.1727	6	16	13.78	6.48	7.30	52.98	0.1558
7	24	12.27	6.08	6.19	50.45	0.1607	7	24	15.81	6.50	9.31	58.87	0.1400
Peeled							Unpeeled						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	12.35	10.96	1.39	11.26	0.3768	1	2	14.01	12.76	1.25	8.92	0.3397
2	4	13.78	11.43	2.35	17.05	0.3004	2	4	12.99	10.90	2.09	16.09	0.3093
3	8	14.62	11.30	3.32	22.71	0.2623	3	8	11.71	9.61	2.10	17.93	0.2657
4	10	12.63	8.03	4.60	36.42	0.2115	4	10	13.65	10.02	3.63	26.59	0.2329
5	14	14.23	8.63	5.60	39.35	0.1919	5	14	12.84	8.83	4.01	31.23	0.2205
6	16	12.18	7.00	5.18	42.53	0.1658	6	16	14.75	9.54	5.21	35.32	0.2093
7	24	12.86	7.19	5.67	44.09	0.1449	7	24	13.13	8.17	4.96	37.78	0.1713

Table B.2: Experimental Results @ Temperature of 20℃

Unblanched							**Blanched**						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	11.94	10.31	1.63	13.65	0.4064	1	2	14.08	12.15	1.93	13.71	0.2919
2	4	10.77	8.30	2.47	22.93	0.3188	2	4	14.33	11.15	3.18	22.19	0.2527
3	8	10.73	7.69	3.04	28.33	0.2382	3	8	12.34	8.36	3.98	32.25	0.2228
4	10	12.45	8.83	3.62	29.08	0.1974	4	10	14.19	9.25	4.94	34.81	0.1742
5	14	13.74	7.64	6.10	44.40	0.1901	5	14	14.23	6.16	8.07	56.71	0.1570
6	16	15.38	7.67	7.71	50.13	0.1658	6	16	14.18	5.47	8.71	61.42	0.1449
7	24	16.19	7.74	8.45	52.19	0.1491	7	24	10.45	3.58	6.87	65.74	0.1312
Peeled							Unpeeled						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	12.59	11.06	1.53	12.15	0.3768	1	2	11.06	9.53	1.53	13.83	0.3454
2	4	10.87	8.39	2.48	22.82	0.3238	2	4	13.42	10.98	2.44	18.18	0.3343
3	8	13.51	9.84	3.67	27.17	0.2839	3	8	13.01	9.97	3.04	23.37	0.2839
4	10	13.24	8.79	4.45	33.61	0.2115	4	10	12.73	8.19	4.54	35.66	0.2329
5	14	14.48	7.24	7.24	50.00	0.1818	5	14	13.63	8.31	5.32	39.03	0.2205
6	16	12.87	6.14	6.73	52.29	0.1594	6	16	13.47	7.16	6.31	46.84	0.1802
7	24	14.91	5.59	9.32	62.51	0.1391	7	24	15.24	7.37	7.87	51.64	0.1713

Table B.3: Experimental Results @ Temperature of 30℃

Unblanched							Blanched						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	10.66	9.31	1.35	12.66	0.1074	1	2	14.01	12.14	1.87	13.35	0.1006
2	4	11.57	9.35	2.22	19.19	0.0996	2	4	14.85	11.66	3.19	21.48	0.0913
3	8	13.77	10.49	3.28	23.82	0.0987	3	8	13.20	8.61	4.59	34.77	0.0810
4	10	13.86	10.00	3.86	27.85	0.0955	4	10	13.60	8.48	5.12	37.65	0.0800
5	14	16.28	7.75	8.53	52.40	0.0809	5	14	16.00	4.88	11.12	69.50	0.0761
6	16	16.38	7.38	9.00	54.95	0.0785	6	16	15.23	3.73	11.50	75.51	0.0732
7	24	13.68	5.41	8.27	60.45	0.0677	7	24	15.96	2.79	13.17	82.52	0.0689
Peeled							Unpeeled						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	13.94	12.26	1.68	12.05	0.1459	1	2	11.72	10.28	1.44	12.29	0.1126
2	4	13.38	10.72	2.66	19.88	0.1132	2	4	13.42	10.99	2.48	18.11	0.1021
3	8	16.13	12.07	4.06	25.17	0.0909	3	8	10.88	8.07	2.81	25.83	0.0810
4	10	11.76	7.80	3.96	33.67	0.0776	4	10	14.60	12.07	4.53	31.03	0.0740
5	14	13.71	3.27	10.44	54.27	0.0715	5	14	15.20	7.36	7.84	51.58	0.0658
6	16	14.29	5.48	8.81	61.65	0.0693	6	16	16.65	7.23	9.42	56.58	0.0630
7	24	14.30	3.97	10.33	72.24	0.0652	7	24	13.71	4.27	9.44	68.85	0.0611

Table B.4: Experimental Results @ Temperature of 40℃

Unblanched							Blanched						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	13.49	10.70	2.79	20.68	0.0756	1	2	12.38	8.68	3.70	29.89	0.0707
2	4	14.11	9.50	4.61	32.67	0.0691	2	4	10.41	5.66	4.75	45.63	0.0662
3	8	13.58	7.42	6.16	45.36	0.0660	3	8	12.40	5.03	7.37	59.40	0.0648
4	10	11.88	5.27	6.61	55.64	0.0638	4	10	14.55	4.05	10.50	72.16	0.0636
5	14	16.38	6.77	9.61	58.67	0.0608	5	14	13.19	3.12	10.07	76.35	0.0606
6	16	15.61	5.78	9.83	62.97	0.0581	6	16	15.88	2.99	12.89	81.17	0.0574
7	24	16.40	4.94	11.46	69.88	0.0557	7	24	16.35	2.78	13.57	83.00	0.0562
Peeled							Unpeeled						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	11.80	8.96	2.84	24.07	0.0717	1	2	13.59	11.07	2.52	18.54	0.0717
2	4	12.27	7.42	4.85	39.53	0.0710	2	4	13.48	9.51	3.97	29.45	0.0658
3	8	14.03	6.93	7.10	50.61	0.0662	3	8	14.40	8.26	6.14	42.64	0.0611
4	10	11.64	5.48	6.16	52.92	0.0624	4	10	12.45	4.75	7.70	61.85	0.0572
5	14	17.75	5,43	12.32	69.41	0.0590	5	14	15.20	5.36	9.84	64.74	0.0560
6	16	14.92	4.03	10.89	72.99	0.0548	6	16	13.17	4.28	8.89	67.50	0.0557
7	24	15.76	3.77	11.99	76.08	0.0516	7	24	14.22	3.74	10.48	73.70	0.0543

Table B.5: Experimental Results @ Temperature of 50℃

Unblanched							Blanched						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	11.36	8.14	3.22	28.35	0.0715	1	2	12.53	8.35	4.18	33.36	0.0730
2	4	15.16	8.85	6.31	41.62	0.0698	2	4	13.05	6.73	6.32	48.43	0.0650
3	8	12.82	5.45	7.37	57.49	0.0675	3	8	11.36	5.10	6.26	55.11	0.0626
4	10	12.41	4.66	7.75	62.45	0.0652	4	10	14.63	4.65	9.98	68.22	0.0610
5	14	14.59	4.15	10.44	71.56	0.0582	5	14	15.19	2.19	13.00	85.58	0.0584
6	16	14.57	3.72	10.85	74.47	0.0563	6	16	15.40	1.67	13.43	87.21	0.0581
7	24	15.21	2.73	12.48	82.05	0.0541	7	24	16.88	1.73	15.15	89.75	0.0556
Peeled							Unpeeled						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	14.27	8.49	5.78	34.50	0.0759	1	2	11.51	7.81	3.70	32.15	0.0776
2	4	15.43	9.09	6.34	41.09	0.0695	2	4	11.24	6.51	4.73	42.08	0.0710
3	8	14.15	5.63	8.52	60.21	0.0634	3	8	10.00	4.10	5.90	59.00	0.0622
4	10	12.79	3.58	9.21	72.01	0.0571	4	10	14.28	5.70	8.58	60.08	0.0596
5	14	13.22	2.47	10.75	81.32	0.0555	5	14	16.19	4.29	11.90	67.80	0.0540
6	16	15.52	2.87	12.65	83.50	0.0543	6	16	15.14	3.59	11.55	76.29	0.0465
7	24	15.82	2.09	13.73	86.79	0.0519	7	24	15.88	2.46	13.42	84.51	0.0460

Table B.6: Experimental Results @ Temperature of 60℃

Unblanched							Blanched						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	15.09	11.19	3.90	25.84	0.0762	1	2	13.58	8.57	5.01	36.89	0.0836
2	4	14.19	7.51	6.68	47.08	0.0720	2	4	14.30	6.76	7.54	52.73	0.0762
3	8	13.90	5.86	8.04	57.84	0.0695	3	8	15.25	4.04	11.21	73.51	0.0732
4	10	15.42	5.14	10.28	66.67	0.0691	4	10	15.70	2.78	12.92	82.29	0.0576
5	14	16.01	2.64	13.37	83.51	0.0652	5	14	16.68	2.36	14.32	85.85	0.0566
6	16	15.39	2.29	13.10	85.12	0.0644	6	16	15.31	1.58	13.73	89.68	0.0536
7	24	16.28	1.08	15.20	93.37	0.0553	7	24	15.15	1.37	13.78	90.96	0.0516
Peeled							Unpeeled						
Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$	Sample S/Nos.	Time (Hours)	Weight of Sample (g)			Moisture content (%)	Thermal Conductivity $\left(\frac{W}{m.K}\right)$
		Before	After	Difference					Before	After	Difference		
1	2	15.18	10.74	4.44	29.25	0.0791	1	2	15.29	11.37	3.92	25.64	0.0776
2	4	13.26	6.19	7.07	53.32	0.0727	2	4	14.56	8.63	5.93	40.73	0.0689
3	8	15.69	4.69	11.00	70.11	0.0664	3	8	15.72	7.32	8.40	53.44	0.0622
4	10	13.20	3.85	9.35	75.83	0.0611	4	10	15.42	4.80	10.62	68.87	0.0596
5	14	15.49	2.14	13.35	86.18	0.0557	5	14	14.21	3.48	10.73	75.51	0.0540
6	16	14.65	1.69	12.96	88.46	0.0534	6	16	14.32	1.96	12.36	86.31	0.0465
7	24	15.53	1.33	14.20	91.44	0.0483	7	24	17.40	1.04	16.36	94.02	0.0460

B.2: Thermal Conductivity Calculations

Table B.7: Thermal Conductivity Calculations at drying temperature 10℃**(Author, 2015)**

Unblanched							Blanched						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area= $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$(℃)	Area = $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	5.1	0.000707	0.4064	1	2	20	0.02	6.3	0.000707	0.3290
2	4	20	0.02	6.5	0.000707	0.3188	2	4	20	0.02	7.2	0.000707	0.2878
3	8	20	0.02	7.8	0.000707	0.2657	3	8	20	0.02	10.4	0.000707	0.1993
4	10	20	0.02	9.0	0.000707	0.2303	4	10	20	0.02	10.9	0.000707	0.1901
5	14	20	0.02	11.3	0.000707	0.1834	5	14	20	0.02	12.2	0.000707	0.1699
6	16	20	0.02	12.0	0.000707	0.1727	6	16	20	0.02	13.3	0.000707	0.1558
7	24	20	0.02	12.9	0.000707	0.1607	7	24	20	0.02	14.8	0.000707	0.1400
Peeled							Unpeeled						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area = $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$(℃)	Area = $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	5.5	0.000707	0.3768	1	2	20	0.02	6.1	0.000707	0.3397
2	4	20	0.02	6.9	0.000707	0.3004	2	4	20	0.02	7.4	0.000707	0.3093
3	8	20	0.02	7.9	0.000707	0.2623	3	8	20	0.02	7.8	0.000707	0.2657
4	10	20	0.02	9.8	0.000707	0.2115	4	10	20	0.02	8.9	0.000707	0.2329
5	14	20	0.02	10.8	0.000707	0.1919	5	14	20	0.02	9.4	0.000707	0.2205
6	16	20	0.02	12.5	0.000707	0.1658	6	16	20	0.02	9.9	0.000707	0.2093
7	24	20	0.02	14.3	0.000707	0.1449	7	24	20	0.02	12.1	0.000707	0.1713

Table B.8: Thermal Conductivity Calculations at drying temperature 20℃

Unblanched							Blanched						
S/ N	Drying Time (Hours)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	5.1	0.000707	0.4064	1	2	20	0.02	7.1	0.000707	0.2919
2	4	20	0.02	6.5	0.000707	0.3188	2	4	20	0.02	8.2	0.000707	0.2527
3	8	20	0.02	8.7	0.000707	0.2382	3	8	20	0.02	9.3	0.000707	0.2228
4	10	20	0.02	10.5	0.000707	0.1974	4	10	20	0.02	11.9	0.000707	0.1742
5	14	20	0.02	10.9	0.000707	0.1901	5	14	20	0.02	13.2	0.000707	0.1570
6	16	20	0.02	12.5	0.000707	0.1658	6	16	20	0.02	14.3	0.000707	0.1449
7	24	20	0.02	13.9	0.000707	0.1491	7	24	20	0.02	15.8	0.000707	0.1312
Peeled							Unpeeled						
S/	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	5.5	0.000707	0.3768	1	2	20	0.02	6.0	0.000707	0.3454
2	4	20	0.02	6.4	0.000707	0.3238	2	4	20	0.02	6.2	0.000707	0.3343
3	8	20	0.02	7.3	0.000707	0.2839	3	8	20	0.02	7.3	0.000707	0.2839
4	10	20	0.02	9.8	0.000707	0.2115	4	10	20	0.02	8.9	0.000707	0.2329
5	14	20	0.02	11.4	0.000707	0.1818	5	14	20	0.02	9.4	0.000707	0.2205
6	16	20	0.02	13.0	0.000707	0.1594	6	16	20	0.02	11.5	0.000707	0.1802
7	24	20	0.02	14.9	0.000707	0.1391	7	24	20	0.02	12.1	0.000707	0.1713

Table B.9: Thermal Conductivity Calculations at drying temperature 30℃ (Author, 2015)

Unblanched							Blanched						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A} \left(\frac{W}{m.K}\right)$	S/N.	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A} \left(\frac{W}{m.K}\right)$
1	2	20	0.02	19.3	0.000707	0.1074	1	2	20	0.02	20.6	0.000707	0.1006
2	4	20	0.02	20.8	0.000707	0.0996	2	4	20	0.02	22.7	0.000707	0.0913
3	8	20	0.02	21.0	0.000707	0.0987	3	8	20	0.02	24.1	0.000707	0.0810
4	10	20	0.02	21.7	0.000707	0.0955	4	10	20	0.02	25.9	0.000707	0.0800
5	14	20	0.02	22.8	0.000707	0.0809	5	14	20	0.02	26.2	0.000707	0.0761
6	16	20	0.02	26.4	0.000707	0.0785	6	16	20	0.02	28.3	0.000707	0.0732
7	24	20	0.02	30.6	0.000707	0.0677	7	24	20	0.02	30.1	0.000707	0.0689
Peeled							Unpeeled						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$(℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A} \left(\frac{W}{m.K}\right)$	Sample S/Nos.	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area$= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A} \left(\frac{W}{m.K}\right)$
1	2	20	0.02	14.2	0.000707	0.1459	1	2	20	0.02	18.4	0.000707	0.1126
2	4	20	0.02	18.3	0.000707	0.1132	2	4	20	0.02	20.3	0.000707	0.1021
3	8	20	0.02	22.8	0.000707	0.0909	3	8	20	0.02	25.6	0.000707	0.0810
4	10	20	0.02	26.7	0.000707	0.0776	4	10	20	0.02	28.0	0.000707	0.0740
5	14	20	0.02	29.0	0.000707	0.0715	5	14	20	0.02	31.5	0.000707	0.0658
6	16	20	0.02	29.9	0.000707	0.0693	6	16	20	0.02	32.9	0.000707	0.0630
7	24	20	0.02	31.8	0.000707	0.0652	7	24	20	0.02	33.9	0.000707	0.0611

Table B.10: Thermal Conductivity Calculations at drying temperature 40℃ (Author, 2015)

Unblanched							Blanched						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	27.4	0.000707	0.0756	1	2	20	0.02	29.3	0.000707	0.0707
2	4	20	0.02	30.0	0.000707	0.0691	2	4	20	0.02	31.3	0.000707	0.0662
3	8	20	0.02	31.4	0.000707	0.0660	3	8	20	0.02	32.0	0.000707	0.0648
4	10	20	0.02	32.5	0.000707	0.0638	4	10	20	0.02	32.6	0.000707	0.0636
5	14	20	0.02	34.1	0.000707	0.0608	5	14	20	0.02	34.2	0.000707	0.0606
6	16	20	0.02	35.7	0.000707	0.0581	6	16	20	0.02	36.1	0.000707	0.0574
7	24	20	0.02	37.2	0.000707	0.0557	7	24	20	0.02	36.9	0.000707	0.0562
Peeled							Unpeeled						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$(℃)	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	28.9	0.000707	0.0717	1	2	20	0.02	28.9	0.000707	0.0717
2	4	20	0.02	29.2	0.000707	0.071	2	4	20	0.02	31.5	0.000707	0.0658
3	8	20	0.02	31.3	0.000707	0.0662	3	8	20	0.02	33.9	0.000707	0.0611
4	10	20	0.02	33.2	0.000707	0.0624	4	10	20	0.02	36.2	0.000707	0.0572
5	14	20	0.02	35.1	0.000707	0.0590	5	14	20	0.02	37.0	0.000707	0.0560
6	16	20	0.02	37.8	0.000707	0.0548	6	16	20	0.02	37.2	0.000707	0.0557
7	24	20	0.02	40.2	0.000707	0.0516	7	24	20	0.02	38.2	0.000707	0.0543

Table B.11: Thermal Conductivity Calculations at drying temperature 50℃ (Author, 2015)

Unblanched							Blanched						
S/N	Drying Time (Hour)	Power (Watts)	Length $(\boldsymbol{L_4 - L_5}), \boldsymbol{L} = \boldsymbol{0.02m}$	$\boldsymbol{Temp.} = \Delta\boldsymbol{T}$ (℃)	Area = $\boldsymbol{0.000707m}$	$\boldsymbol{k} = \frac{\boldsymbol{Q * L}}{\boldsymbol{\Delta T * A}} \left(\frac{\boldsymbol{W}}{\boldsymbol{m.K}}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(\boldsymbol{L_4 - L_5}), \boldsymbol{L} = \boldsymbol{0.02m}$	$\boldsymbol{Temp.} = \Delta\boldsymbol{T}$ (℃)	Area $= \boldsymbol{0.000707m^2}$	$\boldsymbol{k} = \frac{\boldsymbol{Q * L}}{\boldsymbol{\Delta T * A}} \left(\frac{\boldsymbol{W}}{\boldsymbol{m.K}}\right)$
1	2	20	0.02	29.0	0.000707	0.0715	1	2	20	0.02	28.4	0.000707	0.0730
2	4	20	0.02	29.7	0.000707	0.0698	2	4	20	0.02	31.9	0.000707	0.0650
3	8	20	0.02	30.7	0.000707	0.0675	3	8	20	0.02	33.1	0.000707	0.0626
4	10	20	0.02	31.8	0.000707	0.0652	4	10	20	0.02	34.0	0.000707	0.0610
5	14	20	0.02	32.3	0.000707	0.0582	5	14	20	0.02	35.5	0.000707	0.0584
6	16	20	0.02	36.8	0.000707	0.0563	6	16	20	0.02	35.7	0.000707	0.0581
7	24	20	0.02	38.3	0.000707	0.0541	7	24	20	0.02	37.3	0.000707	0.0556
Peeled							Unpeeled						
S/N	Drying Time (Hour)	Power (Watts)	Length $(\boldsymbol{L_4 - L_5}), \boldsymbol{L} = \boldsymbol{0.02m}$	$\boldsymbol{Temp.} = \Delta\boldsymbol{T}$ (℃)	Area $= \boldsymbol{0.000707m^2}$	$\boldsymbol{k} = \frac{\boldsymbol{Q * L}}{\boldsymbol{\Delta T * A}} \left(\frac{\boldsymbol{W}}{\boldsymbol{m.K}}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(\boldsymbol{L_4 - L_5}), \boldsymbol{L} = \boldsymbol{0.02m}$	$\boldsymbol{Temp.} = \Delta\boldsymbol{T}$ (℃)	Area $= \boldsymbol{0.000707m^2}$	$\boldsymbol{k} = \frac{\boldsymbol{Q * L}}{\boldsymbol{\Delta T * A}} \left(\frac{\boldsymbol{W}}{\boldsymbol{m.K}}\right)$
1	2	20	0.02	27.3	0.000707	0.0759	1	2	20	0.02	29.1	0.000707	0.0776
2	4	20	0.02	29.8	0.000707	0.0695	2	4	20	0.02	31.4	0.000707	0.0710
3	8	20	0.02	32.7	0.000707	0.0634	3	8	20	0.02	33.7	0.000707	0.0622
4	10	20	0.02	36.3	0.000707	0.0571	4	10	20	0.02	34.9	0.000707	0.0596
5	14	20	0.02	38.0	0.000707	0.0555	5	14	20	0.02	38.2	0.000707	0.0540
6	16	20	0.02	39.1	0.000707	0.0543	6	16	20	0.02	41.0	0.000707	0.0465
7	24	20	0.02	39.9	0.000707	0.0519	7	24	20	0.02	42.5	0.000707	0.0460

Table B.12: Thermal Conductivity Calculations at drying temperature 60℃ (Author, 2015)

Unblanched							Blanched						
S/N	Drying Time (Hour)	Power (Watts)	Length $(\boldsymbol{L_4 - L_5}), \boldsymbol{L} = \boldsymbol{0.02m}$	$\boldsymbol{Temp.} = \Delta \boldsymbol{T}$(℃)	Area = $\mathbf{0.0007}07m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area = $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	27.2	0.000707	0.0762	1	2	20	0.02	24.8	0.000707	0.0836
2	4	20	0.02	28.8	0.000707	0.0720	2	4	20	0.02	27.2	0.000707	0.0762
3	8	20	0.02	29.8	0.000707	0.0695	3	8	20	0.02	28.3	0.000707	0.0732
4	10	20	0.02	30.0	0.000707	0.0691	4	10	20	0.02	35.6	0.000707	0.0576
5	14	20	0.02	31.8	0.000707	0.0652	5	14	20	0.02	36.0	0.000707	0.0566
6	16	20	0.02	32.2	0.000707	0.0644	6	16	20	0.02	38.7	0.000707	0.0536
7	24	20	0.02	37.5	0.000707	0.0553	7	24	20	0.02	40.2	0.000707	0.0516
Peeled							Unpeeled						
S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$(℃)	Area = $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$	S/N	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T$ (℃)	Area = $0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
1	2	20	0.02	26.2	0.000707	0.0791	1	2	20	0.02	26.7	0.000707	0.0776
2	4	20	0.02	28.5	0.000707	0.0727	2	4	20	0.02	30.1	0.000707	0.0689
3	8	20	0.02	31.2	0.000707	0.0664	3	8	20	0.02	33.3	0.000707	0.0622
4	10	20	0.02	33.9	0.000707	0.0611	4	10	20	0.02	34.8	0.000707	0.0596
5	14	20	0.02	37.2	0.000707	0.0557	5	14	20	0.02	38.4	0.000707	0.0540
6	16	20	0.02	38.8	0.000707	0.0534	6	16	20	0.02	44.6	0.000707	0.0465
7	24	20	0.02	42.9	0.000707	0.0483	7	24	20	0.02	45.1	0.000707	0.0460

APPENDIX C

C.1: Pictures of Experimental Samples and Equipment Setup

Figure C.1: Pictures of samples in environmental chambers (Author, 2015) (UoG Laboratory/Workshop, 2015)

C.2: Concept of Thermal Conductivity

$$\frac{dQ}{dt} = \dot{Q} = -\lambda A \frac{T_2 - T_1}{\Delta x} \quad ; \quad \dot{q} = -\lambda \frac{\Delta T}{\Delta x}$$

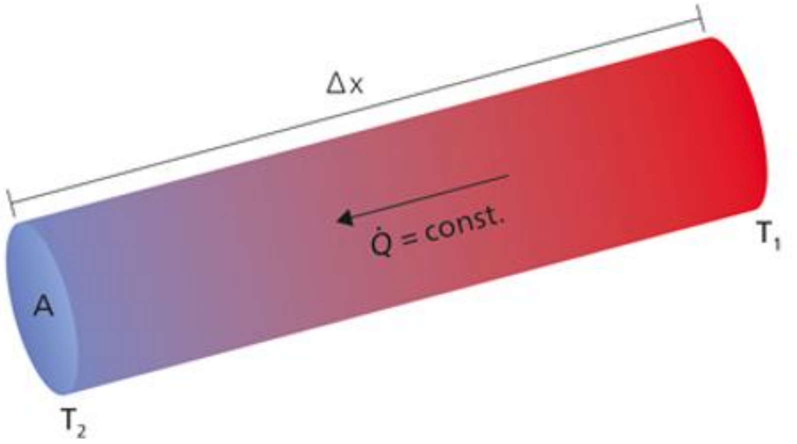


Figure C.2: Schematic describing the concept of thermal conductivity with $T_2 > T_1$ (NETZSCH, 2014)

C.3: Flow Diagram of Process Selection and Relationship of Drying Materials and Environment

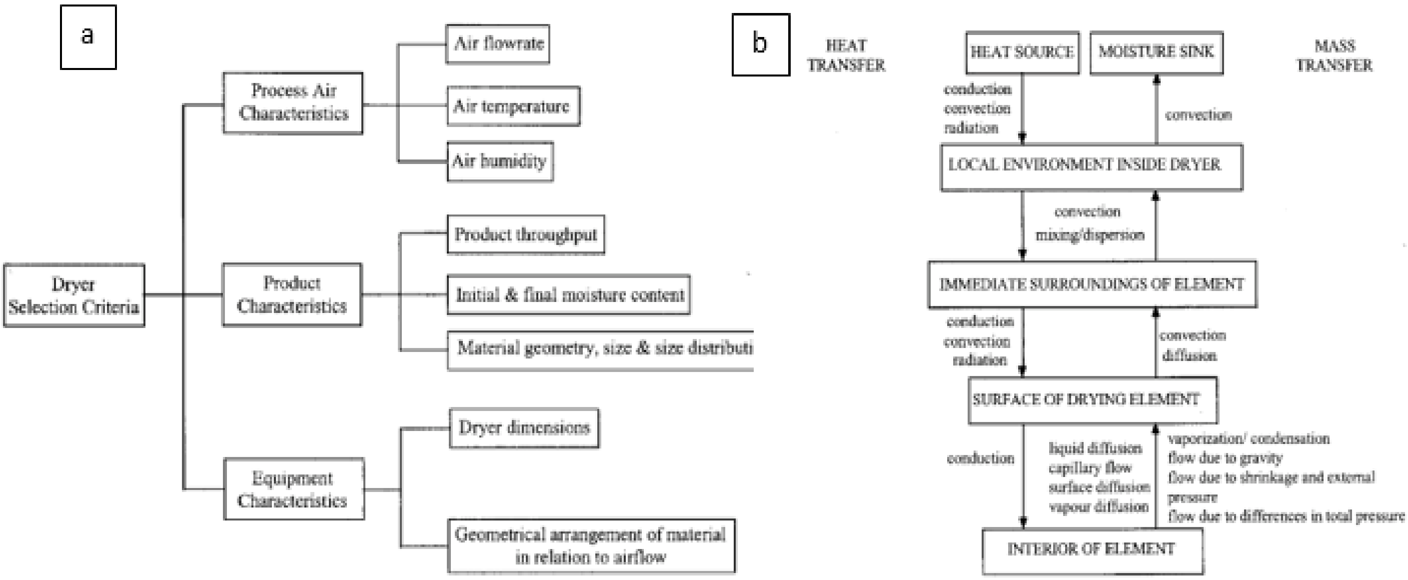


Figure C.3: a) Flow diagram representing dryer selection criteria b) Schematic of relationship between drying material and surround environment (McMinn & Magee, 1999)

Table C.1: Thermal Conductivity of powdered unblanched ginger rhizomes at temperature of 60℃ and drying time of 24 hours

Powdered Unblanched Ginger						
Parameters	Drying Time (Hour)	Power (Watts)	Length $(L_4 - L_5), L = 0.02m$	$Temp. = \Delta T(℃)$	Area $= 0.000707m^2$	$k = \frac{Q * L}{\Delta T * A}$ $\left(\frac{W}{m.K}\right)$
	24	20	0.02	41.2	0.000707	0.0503

Table C.2: Percentage reductions in moisture content and percentage increase in Thermal Conductivity of the ginger rhizomes at temperatures of 10℃-60℃ and drying time of 24 hours

Temperature (℃)	10℃	60℃	% Reductions in Moisture Content	10℃	60℃	% Increase in Thermal Conductivity
Time (Hours)	2	24		2	24	
Unblanched	88.84	6.63	92.54	0.4064	0.0553	86.39
Blanched	84.58	9.04	89.31	0.3290	0.0516	84.32
Peeled	88.74	8.56	90.35	0.3768	0.0483	87.18
Unpeeled	91.08	5.98	93.43	0.3397	0.0460	86.46

APPENDIX D

MATLAB Code developed for analyzing the experimental data, simulation and modelling of the temperature distribution of the ginger samples and comparing different plots, moisture content, moisture ratio etc.

```
% FINITE ELEMENT STUDY OF
% CONVECTIVE DRYING OF GINGER RHIZOMES
%
% BY
%
% GBASOUZOR AUSTIN IKECHUKWU
% NAU/PhD/2005247001F
%
% DEPARTMENT OF
% MECHANICAL/PRODUCTION ENGINEERING
% NNAMDI AZIKIWE UNIVERSITY, AWKA
%
% SUPERVISOR: PROF. S. N. OMENYI
%
% This application is for analysing the experimental
% data, simulation & modelling of temperature distribution
% of the ginger samples and comparing different plots.
% Moisture Content, Moisture Ratio and PDE of the Heat Transfer
%
%
% To begin, load the experimental data, select mode and
% click run button. You can view plots for temptertures
% 10,20,30,40,50,60 or simulate any drying temperature
% on simulation mode.
%
% You can compare plots on plots comparison mode


gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
'gui_Singleton',  gui_Singleton, ...
'gui_OpeningFcn', @simdryingginger_OpeningFcn, ...
'gui_OutputFcn',  @simdryingginger_OutputFcn, ...
'gui_LayoutFcn',  [] , ...
'gui_Callback',   []);
if nargin && ischar(varargin{1})
gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
[varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
%  --- Executes just before simdryingginger is made visible.

function simdryingginger_OpeningFcn(hObject, eventdata, handles, varargin)


handles.output = hObject;
```

```
% Update handles structure
guidata(hObject, handles);
% This sets up the initial plot - only do when we are invisible
% so window can get raised using simdryingginger.


function varargout = simdryingginger_OutputFcn(hObject, eventdata, handles)

varargout{1} = handles.output;

% --- Executes on button press in runpb.
function runpb_Callback(hObject, eventdata, handles)
%%Run Experiment or Simulation or Compare Results



%% Select Mode
m1=get(handles.analyseexprb, 'Value');
m2=get(handles.simrb, 'Value');
m3=get(handles.expvssimrb,'Value');
d=get(handles.loadexpdata,'Userdata')%Experimental data

if isempty(d)
   set(handles.displayedit, 'String', 'Load Experrimental Data');
else

%% Experimental Mode
if m1==1 && m2==0 && m3==0
delete(gca);
delete(gca);
str={'=====================EXPERIMENTAL MODE======================='}
set(handles.displayedit, 'String', str);
axes('position',[0.038 0.076 0.391 0.758]);%(handles.axes1);
hold off;



DT=d.t10(:,1);
DTs=DT*60*60;
P=ones(length(DT),1)*(str2double(get(handles.power,'String')));%Power     in
Watts
L=ones(length(DT),1)*(str2double(get(handles.length,'String')));%Length   in
meters (L4-L5)
A=ones(length(DT),1)*(str2double(get(handles.area,'String')));%Area



%% Get Experimental Drying Temperature
exptemp_sel_index = get(handles.expdrytemp, 'Value');

switch exptemp_sel_index
case 1

%% Drying Temperature at 10 DegC
T10=273.15+10; %K
%Unblanched
ubmc10=((d.t10(:,2)-d.t10(:,3))./d.t10(:,2))*100;
ubtdiff10=d.t10(:,4);
ubthermcon10=(P.*L)./(ubtdiff10.*A);
ubimc10=d.t10(:,5);
ublnMR10=log(ubmc10./ubimc10);
```

```
kub10=(sum(ubthermcon10))/length(ubthermcon10);


%Blanched
bmc10=((d.t10(:,6)-d.t10(:,7))./d.t10(:,6))*100;
btdiff10=d.t10(:,8);
bthermcon10=(P.*L)./(btdiff10.*A);
bimc10=d.t10(:,9);
blnMR10=log(bmc10./bimc10);
kb10=(sum(bthermcon10))/length(bthermcon10);

%Unpeeled
upmc10=((d.t10(:,10)-d.t10(:,11))./d.t10(:,10))*100;
uptdiff10=d.t10(:,12);
upthermcon10=(P.*L)./(uptdiff10.*A);
upimc10=d.t10(:,13);
uplnMR10=log(upmc10./upimc10);
kup10=(sum(upthermcon10))/length(upthermcon10);

%Peeled
pmc10=((d.t10(:,14)-d.t10(:,15))./d.t10(:,14))*100;
ptdiff10=d.t10(:,16);
pthermcon10=(P.*L)./(ptdiff10.*A);
pimc10=d.t10(:,17);
plnMR10=log(pmc10./pimc10);
kp10=(sum(pthermcon10))/length(pthermcon10);



case 2
%% Drying Temperature at 20 DegC
T20=273.15+20; %K
%Unblanched
ubmc20=((d.t20(:,2)-d.t20(:,3))./d.t20(:,2))*100;
ubtdiff20=d.t20(:,4);
ubthermcon20=(P.*L)./(ubtdiff20.*A);
ubimc20=d.t20(:,5);
ublnMR20=log(ubmc20./ubimc20);
kub20=(sum(ubthermcon20))/length(ubthermcon20);

%Blanched
bmc20=((d.t20(:,6)-d.t20(:,7))./d.t20(:,6))*100;
btdiff20=d.t20(:,8);
bthermcon20=(P.*L)./(btdiff20.*A);
bimc20=d.t20(:,9);
blnMR20=log(bmc20./bimc20);
kb20=(sum(bthermcon20))/length(bthermcon20);

%Unpeeled
upmc20=((d.t20(:,10)-d.t20(:,11))./d.t20(:,10))*100;
uptdiff20=d.t20(:,12);
upthermcon20=(P.*L)./(uptdiff20.*A);
upimc20=d.t20(:,13);
uplnMR20=log(upmc20./upimc20);
kup20=(sum(upthermcon20))/length(upthermcon20);

%Peeled
pmc20=((d.t20(:,14)-d.t20(:,15))./d.t20(:,14))*100;
ptdiff20=d.t20(:,16);
pthermcon20=(P.*L)./(ptdiff20.*A);
```

```
pimc20=d.t20(:,17);
plnMR20=log(pmc20./pimc20);
kp20=(sum(pthermcon20))/length(pthermcon20);

case 3
%% Drying Temperature at 30 DegC
T30=273.15+30; %K
%Unblanched
ubmc30=((d.t30(:,2)-d.t30(:,3))./d.t30(:,2))*100;
ubtdiff30=d.t30(:,4);
ubthermcon30=(P.*L)./(ubtdiff30.*A);
ubimc30=d.t30(:,5);
ublnMR30=log(ubmc30./ubimc30);
kub30=(sum(ubthermcon30))/length(ubthermcon30);

%Blanched
bmc30=((d.t30(:,6)-d.t30(:,7))./d.t30(:,6))*100;
btdiff30=d.t30(:,8);
bthermcon30=(P.*L)./(btdiff30.*A);
bimc30=d.t30(:,9);
blnMR30=log(bmc30./bimc30);
kb30=(sum(bthermcon30))/length(bthermcon30);

%Unpeeled
upmc30=((d.t30(:,10)-d.t30(:,11))./d.t30(:,10))*100;
uptdiff30=d.t30(:,12);
upthermcon30=(P.*L)./(uptdiff30.*A);
upimc30=d.t30(:,13);
uplnMR30=log(upmc30./upimc30);
kup30=(sum(upthermcon30))/length(upthermcon30);

%Peeled
pmc30=((d.t30(:,14)-d.t30(:,15))./d.t30(:,14))*100;
ptdiff30=d.t30(:,16);
pthermcon30=(P.*L)./(ptdiff30.*A);
pimc30=d.t30(:,17);
plnMR30=log(pmc30./pimc30);
kp30=(sum(pthermcon30))/length(pthermcon30);

case 4
%% Drying Temperature at 40 DegC
%Unblanched
T40=273.15+40; %K
ubmc40=((d.t40(:,2)-d.t40(:,3))./d.t40(:,2))*100;
ubtdiff40=d.t40(:,4);
ubthermcon40=(P.*L)./(ubtdiff40.*A);
ubimc40=d.t40(:,5);
ublnMR40=log(ubmc40./ubimc40);
kub40=(sum(ubthermcon40))/length(ubthermcon40);

%Blanched
bmc40=((d.t40(:,6)-d.t40(:,7))./d.t40(:,6))*100;
btdiff40=d.t40(:,8);
bthermcon40=(P.*L)./(btdiff40.*A);
bimc40=d.t40(:,9);
blnMR40=log(bmc40./bimc40);
kb40=(sum(bthermcon40))/length(bthermcon40);

%Unpeeled
upmc40=((d.t40(:,10)-d.t40(:,11))./d.t40(:,10))*100;
```

```
uptdiff40=d.t40(:,12);
upthermcon40=(P.*L)./(uptdiff40.*A);
upimc40=d.t40(:,13);
uplnMR40=log(upmc40./upimc40);
kup40=(sum(upthermcon40))/length(upthermcon40);

%Peeled
pmc40=((d.t40(:,14)-d.t40(:,15))./d.t40(:,14))*100;
ptdiff40=d.t40(:,16);
pthermcon40=(P.*L)./(ptdiff40.*A);
pimc40=d.t40(:,17);
plnMR40=log(pmc40./pimc40);
kp40=(sum(pthermcon40))/length(pthermcon40);

case 5
%% Drying Temperature at 50 DegC
T50=273.15+50; %K
%Unblanched
ubmc50=((d.t50(:,2)-d.t50(:,3))./d.t50(:,2))*100;
ubtdiff50=d.t50(:,4);
ubthermcon50=(P.*L)./(ubtdiff50.*A);
ubimc50=d.t50(:,5);
ublnMR50=log(ubmc50./ubimc50);
kub50=(sum(ubthermcon50))/length(ubthermcon50);

%Blanched
bmc50=((d.t50(:,6)-d.t50(:,7))./d.t50(:,6))*100;
btdiff50=d.t50(:,8);
bthermcon50=(P.*L)./(btdiff50.*A);
bimc50=d.t50(:,9);
blnMR50=log(bmc50./bimc50);
kb50=(sum(bthermcon50))/length(bthermcon50);

%Unpeeled
upmc50=((d.t50(:,10)-d.t50(:,11))./d.t50(:,10))*100;
uptdiff50=d.t50(:,12);
upthermcon50=(P.*L)./(uptdiff50.*A);
upimc50=d.t50(:,13);
uplnMR50=log(upmc50./upimc50);
kup50=(sum(upthermcon50))/length(upthermcon50);

%Peeled
pmc50=((d.t50(:,14)-d.t50(:,15))./d.t50(:,14))*100;
ptdiff50=d.t50(:,16);
pthermcon50=(P.*L)./(ptdiff50.*A);
pimc50=d.t50(:,17);
plnMR50=log(pmc50./pimc50);
kp50=(sum(pthermcon50))/length(pthermcon50);



case 6
%% Drying Temperature at 60 DegC
T60=273.15+60; %K
%Unblanched
ubmc60=((d.t60(:,2)-d.t60(:,3))./d.t60(:,2))*100;
ubtdiff60=d.t60(:,4);
ubthermcon60=(P.*L)./(ubtdiff60.*A);
ubimc60=d.t60(:,5);
ublnMR60=log(ubmc60./ubimc60);
kub60=(sum(ubthermcon60))/length(ubthermcon60);
```

```
%Blanched
bmc60=((d.t60(:,6)-d.t60(:,7))./d.t60(:,6))*100;
btdiff60=d.t60(:,8);
bthermcon60=(P.*L)./(btdiff60.*A);
bimc60=d.t60(:,9);
blnMR60=log(bmc60./bimc60);
kb60=(sum(bthermcon60))/length(bthermcon60);

%Unpeeled
upmc60=((d.t60(:,10)-d.t60(:,11))./d.t60(:,10))*100;
uptdiff60=d.t60(:,12);
upthermcon60=(P.*L)./(uptdiff60.*A);
upimc60=d.t60(:,13);
uplnMR60=log(upmc60./upimc60);
kup60=(sum(upthermcon60))/length(upthermcon60);

%Peeled
pmc60=((d.t60(:,14)-d.t60(:,15))./d.t60(:,14))*100;
ptdiff60=d.t60(:,16);
pthermcon60=(P.*L)./(ptdiff60.*A);
pimc60=d.t60(:,17);
plnMR60=log(pmc60./pimc60);
kp60=(sum(pthermcon60))/length(pthermcon60);
end



%% Plotting Graphs

plot_sel_index = get(handles.plottype, 'Value');

switch plot_sel_index

%% Plotting of Moisture Content
case 1
%10 degcel DT vs MC
if exptemp_sel_index==1
plot(DT,ubmc10,DT,ubmc10,'bo');
grid;
hold;

plot(DT,bmc10,DT,bmc10,'r+');
plot(DT,upmc10,DT,upmc10,'y*');
plot(DT,pmc10,DT,pmc10,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
```

```
'Drying Temperature - 10 DegCel',...
'','========================Data==========================='};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%20 degcel DT vs MC
elseif exptemp_sel_index==2
plot(DT,ubmc20,DT,ubmc20,'bo');
grid;
hold;

plot(DT,bmc20,DT,bmc20,'r+');
plot(DT,upmc20,DT,upmc20,'y*');
plot(DT,pmc20,DT,pmc20,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info============================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 20 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DT vs MC
elseif exptemp_sel_index==3
plot(DT,ubmc30,DT,ubmc30,'bo');
grid;
hold;

plot(DT,bmc30,DT,bmc30,'r+');
plot(DT,upmc30,DT,upmc30,'y*');
plot(DT,pmc30,DT,pmc30,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
```

```
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 30 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);


%40 degcel DT vs MC
elseif exptemp_sel_index==4
plot(DT,ubmc40,DT,ubmc40,'bo');
grid;
hold;

plot(DT,bmc40,DT,bmc40,'r+');
plot(DT,upmc40,DT,upmc40,'y*');
plot(DT,pmc40,DT,pmc40,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 40 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DT vs MC
elseif exptemp_sel_index==5
plot(DT,ubmc50,DT,ubmc50,'bo');
grid;
hold;
```

```
plot(DT,bmc50,DT,bmc50,'r+');
plot(DT,upmc50,DT,upmc50,'y*');
plot(DT,pmc50,DT,pmc50,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');
%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 50 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};



for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DT vs MC
else
plot(DT,ubmc60,DT,ubmc60,'bo');
grid;
hold;

plot(DT,bmc60,DT,bmc60,'r+');
plot(DT,upmc60,DT,upmc60,'y*');
plot(DT,pmc60,DT,pmc60,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 60 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};



for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);
```

```
end

%% Thermal Conductivity
case 2
%10 degcel DT vs thermcon
if exptemp_sel_index==1
plot(DT,ubthermcon10,DT,ubthermcon10,'bo');
grid;
hold;
plot(DT,bthermcon10,DT,bthermcon10,'r+');
plot(DT,upthermcon10,DT,upthermcon10,'y*');
plot(DT,pthermcon10,DT,pthermcon10,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 10 DegCel',...
'','=================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%20 degcel DT vs thermcon
elseif exptemp_sel_index==2
plot(DT,ubthermcon20,DT,ubthermcon20,'bo');
grid;
hold;
plot(DT,bthermcon20,DT,bthermcon20,'r+');
plot(DT,upthermcon20,DT,upthermcon20,'y*');
plot(DT,pthermcon20,DT,pthermcon20,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
```

```
'Drying Temperature - 20 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DT vs thermcon
elseif exptemp_sel_index==3
plot(DT,ubthermcon30,DT,ubthermcon30,'bo');
grid;
hold;
plot(DT,bthermcon30,DT,bthermcon30,'r+');
plot(DT,upthermcon30,DT,upthermcon30,'y*');
plot(DT,pthermcon30,DT,pthermcon30,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 30 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);



%40 degcel DT vs thermcon
elseif exptemp_sel_index==4
plot(DT,ubthermcon40,DT,ubthermcon40,'bo');
grid;
hold;
plot(DT,bthermcon40,DT,bthermcon40,'r+');
plot(DT,upthermcon40,DT,upthermcon40,'y*');
plot(DT,pthermcon40,DT,pthermcon40,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
```

```
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 40 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DT vs thermcon
elseif exptemp_sel_index==5
plot(DT,ubthermcon50,DT,ubthermcon50,'bo');
grid;
hold;
plot(DT,bthermcon50,DT,bthermcon50,'r+');
plot(DT,upthermcon50,DT,upthermcon50,'y*');
plot(DT,pthermcon50,DT,pthermcon50,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 50 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DT vs thermcon
else
plot(DT,ubthermcon60,DT,ubthermcon60,'bo');
grid;
hold;
plot(DT,bthermcon60,DT,bthermcon60,'r+');
plot(DT,upthermcon60,DT,upthermcon60,'y*');
plot(DT,pthermcon60,DT,pthermcon60,'msq');
xlabel('Drying Time,(Hour)');
```

```
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');


%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 60 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end
%% Plot of Moisture Ratio
case 3
%10 degcel DTs vs lnMR
if exptemp_sel_index==1
plot(DTs,ublnMR10,DTs,ublnMR10,'bo');
grid;
hold;
plot(DTs,blnMR10,DTs,blnMR10,'r+');
plot(DTs,uplnMR10,DTs,uplnMR10,'y*');
plot(DTs,plnMR10,DTs,plnMR10,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 10 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);
```

```
%20 degcel DTs vs lnMR
elseif exptemp_sel_index==2
plot(DTs,ublnMR20,DTs,ublnMR20,'bo');
grid;
hold;
plot(DTs,blnMR20,DTs,blnMR20,'r+');
plot(DTs,uplnMR20,DTs,uplnMR20,'y*');
plot(DTs,plnMR20,DTs,plnMR20,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 20 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DTs vs lnMR
elseif exptemp_sel_index==3
plot(DTs,ublnMR30,DTs,ublnMR30,'bo');
grid;
hold;
plot(DTs,blnMR30,DTs,blnMR30,'r+');
plot(DTs,uplnMR30,DTs,uplnMR30,'y*');
plot(DTs,plnMR30,DTs,plnMR30,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 30 DegCel',...
```

```
'','=======================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);


%40 degcel DTs vs lnMR
elseif exptemp_sel_index==4
plot(DTs,ublnMR40,DTs,ublnMR40,'bo');
grid;
hold;
plot(DTs,blnMR40,DTs,blnMR40,'r+');
plot(DTs,uplnMR40,DTs,uplnMR40,'y*');
plot(DTs,plnMR40,DTs,plnMR40,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info============================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 40 DegCel',...
'','=======================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DTs vs lnMR
elseif exptemp_sel_index==5
plot(DTs,ublnMR50,DTs,ublnMR50,'bo');
grid;
hold;
plot(DTs,blnMR50,DTs,blnMR50,'r+');
plot(DTs,uplnMR50,DTs,uplnMR50,'y*');
plot(DTs,plnMR50,DTs,plnMR50,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (50DegCel)
```

```
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 50 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DTs vs lnMR
else
plot(DTs,ublnMR60,DTs,ublnMR60,'bo');
grid;
hold;
plot(DTs,blnMR60,DTs,blnMR60,'r+');
plot(DTs,uplnMR60,DTs,uplnMR60,'y*');
plot(DTs,plnMR60,DTs,plnMR60,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');


%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 60 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end


%% Plot PDE Heat Transfer
% Boundary Conditions
```

```
% The bottom edge of the ginger is set to T degrees-Kelvin.
% The boundary conditions are defined below.
% the boundary conditions on these edges do not need to be set explicitly.
% A Dirichlet condition is set on all nodes on the bottom edge, edge
1,2,3,4
case 4
%PDE Parameters
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)

%The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the ginger surface

% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
model = createpde(numberOfPDE);

%% Geometry
%
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);



%PDE Mesh plot
pdegplot(model,'EdgeLabels','on');
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;

if exptemp_sel_index==1
%Unblanched
k=kub10;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T10);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
```

```
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;

figure;
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'



%Blanched
k=kb10;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T10);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
k=kup10;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T10);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
k=kp10;
c = thick*k;
```

```
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T10);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'






%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - PDE plots for Heat Transfer of Ginger',...
'Drying Temperature - 10 DegCel',...
'Unblanched Thermal Conductivity,(W/m.K):',num2str(kub10),...
'Blanched Thermal Conductivity,(W/m.K):',num2str(kb10),...
'Unpeeled Thermal Conductivity,(W/m.K):',num2str(kup10),...
'Peeled Thermal Conductivity,(W/m.K):',num2str(kp10),...
'','========================Data==========================='};



for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);




%20 degcel PDE
elseif exptemp_sel_index==2

%% PDE Parameters
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)
% The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the plate surface
```

```
% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
model = createpde(numberOfPDE);

%% Geometry
%
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);
%
%PDE Mesh plot

pdegplot(model,'EdgeLabels','on');
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;




%Unblanched
k=kub20;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T20);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;

figure;
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'



%Blanched
```

```
k=kb20;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T20);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
k=kup20;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T20);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
k=kp20;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T20);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
```

```
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'




%Display(20 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - PDE plots for Heat Transfer of Ginger',...
'Drying Temperature - 20 DegCel',...
'Unblanched Thermal Conductivity,(W/m.K):',num2str(kub20),...
'Blanched Thermal Conductivity,(W/m.K):',num2str(kb20),...
'Unpeeled Thermal Conductivity,(W/m.K):',num2str(kup20),...
'Peeled Thermal Conductivity,(W/m.K):',num2str(kp20)};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);



 %30 degcel PDE
elseif exptemp_sel_index==3



% PDE Parameters
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)
% The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the ginger surface

% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
model = createpde(numberOfPDE);

% Geometry
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);
%
%PDE Mesh plot

pdegplot(model,'EdgeLabels','on');
```

```
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;




%Unblanched
k=kub30;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T30);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;

figure;
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'



%Blanched
k=kb30;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T30);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
```

```
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
k=kup30;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T30);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
k=kp30;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T30);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'






%Display(30 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - PDE plots for Heat Transfer of Ginger',...
```

```
'Drying Temperature - 30 DegCel',...
'Unblanched Thermal Conductivity,(W/m.K):',num2str(kub30),...
'Blanched Thermal Conductivity,(W/m.K):',num2str(kb30),...
'Unpeeled Thermal Conductivity,(W/m.K):',num2str(kup30),...
'Peeled Thermal Conductivity,(W/m.K):',num2str(kp30),...
'','=======================Data============================'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);




%40 degcel PDE
elseif exptemp_sel_index==4



%% PDE Parameters
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)
% The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the plate surface

% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
model = createpde(numberOfPDE);

%% Geometry
%
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);
%
%PDE Mesh plot

pdegplot(model,'EdgeLabels','on');
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;




%Unblanched
k=kub40;
c = thick*k;
d = thick*rho*specificHeat;
```

```
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T40);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;

figure;
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'



%Blanched
k=kb40;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T40);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
k=kup40;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T40);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);
```

```
% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
k=kp40;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T40);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'





%Display(40 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info==============================',...
'Plot Type - PDE plots for Heat Transfer of Ginger',...
'Drying Temperature - 40 DegCel',...
'Unblanched Thermal Conductivity,(W/m.K):',num2str(kub40),...
'Blanched Thermal Conductivity,(W/m.K):',num2str(kb40),...
'Unpeeled Thermal Conductivity,(W/m.K):',num2str(kup40),...
'Peeled Thermal Conductivity,(W/m.K):',num2str(kp40),...
'','==========================Data=============================='};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);
```

```
%50 degcel DT vs MC
elseif exptemp_sel_index==5
%% PDE Parameters
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)
% The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the plate surface

% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
model = createpde(numberOfPDE);

%% Geometry
%
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);
%
%PDE Mesh plot

pdegplot(model,'EdgeLabels','on');
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;



%Unblanched
k=kub50;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T50);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;
```

```
figure;
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'



%Blanched
k=kb50;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T50);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
k=kup50;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T50);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
k=kp50;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T50);
setInitialConditions(model,0);% Initial guess
```

```
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'





%Display(50 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - PDE plots for Heat Transfer of Ginger',...
'Drying Temperature - 50 DegCel',...
'Unblanched Thermal Conductivity,(W/m.K):',num2str(kub50),...
'Blanched Thermal Conductivity,(W/m.K):',num2str(kb50),...
'Unpeeled Thermal Conductivity,(W/m.K):',num2str(kup50),...
'Peeled Thermal Conductivity,(W/m.K):',num2str(kp50),...
'','========================Data==========================='};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);




%60 degcel PDE
else



% PDE Parameters
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)
% The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the plate surface

% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
```

```
model = createpde(numberOfPDE);

%% Geometry
%
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);
%
%PDE Mesh plot

pdegplot(model,'EdgeLabels','on');
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;



%Unblanched
k=kub60;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T60);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;

figure;
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'




%Blanched
k=kb60;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
```

```
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T60);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
k=kup60;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T60);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
k=kp60;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',T60);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);


% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'
```

```
%Display(60 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info==========================',...
'Plot Type - PDE plots for Heat Transfer of Ginger',...
'Drying Temperature - 60 DegCel',...
'Unblanched Thermal Conductivity,(W/m.K):',num2str(kub60),...
'Blanched Thermal Conductivity,(W/m.K):',num2str(kb60),...
'Unpeeled Thermal Conductivity,(W/m.K):',num2str(kup60),...
'Peeled Thermal Conductivity,(W/m.K):',num2str(kp60)};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);




end
end

%%Simulation Mode
elseif m1==0 && m2==1 && m3==0
delete(gca);
delete(gca);
str={'====================SIMULATION MODE======================'};
set(handles.displayedit, 'String', str);
axes('position',[0.038 0.076 0.391 0.758]);%(handles.axes1);
hold off;

d=get(handles.loadexpdata,'Userdata')%Experimental data
DT=d.t10(:,1);
DTs=DT*60*60;
P=ones(length(DT),1)*(str2double(get(handles.power,'String')));%Power     in
Watts
L=ones(length(DT),1)*(str2double(get(handles.length,'String')));%Length   in
meters (L4-L5)
A=ones(length(DT),1)*(str2double(get(handles.area,'String')));%Area

T10=273.15+10; %K
%Unblanched
ubtdiff10=d.t10(:,4);
ubthermcon10=(P.*L)./(ubtdiff10.*A);
kub10=(sum(ubthermcon10))/length(ubthermcon10);



%Blanched
btdiff10=d.t10(:,8);
bthermcon10=(P.*L)./(btdiff10.*A);
kb10=(sum(bthermcon10))/length(bthermcon10);
```

```
%Unpeeled
uptdiff10=d.t10(:,12);
upthermcon10=(P.*L)./(uptdiff10.*A);
kup10=(sum(upthermcon10))/length(upthermcon10);

%Peeled
ptdiff10=d.t10(:,16);
pthermcon10=(P.*L)./(ptdiff10.*A);
kp10=(sum(pthermcon10))/length(pthermcon10);

%Drying Temperature at 20 DegC
T20=273.15+20; %K
%Unblanched
ubtdiff20=d.t20(:,4);
ubthermcon20=(P.*L)./(ubtdiff20.*A);
kub20=(sum(ubthermcon20))/length(ubthermcon20);

%Blanched
btdiff20=d.t20(:,8);
bthermcon20=(P.*L)./(btdiff20.*A);
kb20=(sum(bthermcon20))/length(bthermcon20);

%Unpeeled
uptdiff20=d.t20(:,12);
upthermcon20=(P.*L)./(uptdiff20.*A);
kup20=(sum(upthermcon20))/length(upthermcon20);

%Peeled
ptdiff20=d.t20(:,16);
pthermcon20=(P.*L)./(ptdiff20.*A);
kp20=(sum(pthermcon20))/length(pthermcon20);

%Drying Temperature at 30 DegC
T30=273.15+30; %K
%Unblanched
ubtdiff30=d.t30(:,4);
ubthermcon30=(P.*L)./(ubtdiff30.*A);
kub30=(sum(ubthermcon30))/length(ubthermcon30);

%Blanched
btdiff30=d.t30(:,8);
bthermcon30=(P.*L)./(btdiff30.*A);
kb30=(sum(bthermcon30))/length(bthermcon30);

%Unpeeled
uptdiff30=d.t30(:,12);
upthermcon30=(P.*L)./(uptdiff30.*A);
kup30=(sum(upthermcon30))/length(upthermcon30);

%Peeled
ptdiff30=d.t30(:,16);
pthermcon30=(P.*L)./(ptdiff30.*A);
kp30=(sum(pthermcon30))/length(pthermcon30);

%Drying Temperature at 40 DegC
T40=273.15+40; %K
%Unblanched
ubtdiff40=d.t40(:,4);
ubthermcon40=(P.*L)./(ubtdiff40.*A);
```

```
kub40=(sum(ubthermcon40))/length(ubthermcon40);

%Blanched
btdiff40=d.t40(:,8);
bthermcon40=(P.*L)./(btdiff40.*A);
kb40=(sum(bthermcon40))/length(bthermcon40);

%Unpeeled
uptdiff40=d.t40(:,12);
upthermcon40=(P.*L)./(uptdiff40.*A);
kup40=(sum(upthermcon40))/length(upthermcon40);

%Peeled
ptdiff40=d.t40(:,16);
pthermcon40=(P.*L)./(ptdiff40.*A);
kp40=(sum(pthermcon40))/length(pthermcon40);

%Drying Temperature at 50 DegC
T50=273.15+50; %K
%Unblanched
ubtdiff50=d.t50(:,4);
ubthermcon50=(P.*L)./(ubtdiff50.*A);
kub50=(sum(ubthermcon50))/length(ubthermcon50);

%Blanched
btdiff50=d.t50(:,8);
bthermcon50=(P.*L)./(btdiff50.*A);
kb50=(sum(bthermcon50))/length(bthermcon50);

%Unpeeled
uptdiff50=d.t50(:,12);
upthermcon50=(P.*L)./(uptdiff50.*A);
kup50=(sum(upthermcon50))/length(upthermcon50);

%Peeled
ptdiff50=d.t50(:,16);
pthermcon50=(P.*L)./(ptdiff50.*A);
kp50=(sum(pthermcon50))/length(pthermcon50);

%Drying Temperature at 60 DegC
T60=273.15+60; %K
%Unblanched
ubtdiff60=d.t60(:,4);
ubthermcon60=(P.*L)./(ubtdiff60.*A);
kub60=(sum(ubthermcon60))/length(ubthermcon60);

%Blanched
btdiff60=d.t60(:,8);
bthermcon60=(P.*L)./(btdiff60.*A);
kb60=(sum(bthermcon60))/length(bthermcon60);

%Unpeeled
uptdiff60=d.t60(:,12);
upthermcon60=(P.*L)./(uptdiff60.*A);
kup60=(sum(upthermcon60))/length(upthermcon60);

%Peeled
ptdiff60=d.t60(:,16);
pthermcon60=(P.*L)./(ptdiff60.*A);
```

```
kp60=(sum(pthermcon60))/length(pthermcon60);




% PDE Parameters
simtemp=[T10 T20 T30 T40 T50 T60]';
Temp=str2double(get(handles.simdrytemp,'string'));
rho = 405.77; % density of ginger, kg/m^3
specificHeat = 2090; % specific heat of ginger, J/(kg-K)
thick = .01; % plate thickness in meters
stefanBoltz = 5.670373e-8; % Stefan-Boltzmann constant, W/(m^2-K^4)
hCoeff = 1; % Convection coefficient, W/(m^2-K)
% The ambient temperature is assumed to be 300 degrees-Kelvin.
ta = 300;
emiss = .5; % emissivity of the plate surface

% Create the PDE Model with a single dependent variable
numberOfPDE = 1;
model = createpde(numberOfPDE);

%% Geometry
%
C= [4;0;0;1;0.5;0];
g=decsg(C);
%
% Convert the DECSG geometry into a geometry object
% on doing so it is appended to the PDEModel
geometryFromEdges(model,g);
%
%PDE Mesh plot

pdegplot(model,'EdgeLabels','on');
axis equal;
title 'Geometry With Edge Labels Displayed';

a = @(~,state) 2*hCoeff + 2*emiss*stefanBoltz*state.u.^3;
f = 2*hCoeff*ta + 2*emiss*stefanBoltz*ta^4;




%Unblanched
%Modelling
kub=[kub10 kub20 kub30 kub40 kub50 kub60]';
[expkub fub]=fit(simtemp,kub,'poly2');
p1=expkub.p1;
p2=expkub.p2;
p3=expkub.p3;
simkub= p1*(simtemp.^2) + p2*simtemp + p3;%Model
k1=p1*(Temp.^2) + p2*Temp + p3;%Model
k=k1;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',Temp);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);

% figure;
```

```
% pdeplot(model);
% axis equal
% title 'Sample Ginger With Triangular Element Mesh'
% xlabel 'X-coordinate, m'
% ylabel 'Y-coordinate, m'

%% Steady State Solution
% Because the a and f coefficients are functions of temperature (due to
% the radiation boundary conditions), |solvepde| automatically picks
% the nonlinear solver to obtain the solution.
R = solvepde(model);
u = R.NodalSolution;

h1=figure;
set(h1,'Name','Simulation of Drying of Ginger Rhizomes - PDE Heat
Transfer',...
'NumberTitle','off');
subplot(2,2,1);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unbleached Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'



%Blanched
%Modelling
kb=[kb10 kb20 kb30 kb40 kb50 kb60]';
[expkb fb]=fit(simtemp,kb,'poly2');
p1=expkb.p1;
p2=expkb.p2;
p3=expkb.p3;
simkb= p1*(simtemp.^2) + p2*simtemp + p3;%Model
k2=p1*(Temp.^2) + p2*Temp + p3;%Model
k=k2;
c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',Temp);
setInitialConditions(model,0);% Initial guess
hmax = 0.25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,2);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Blanched Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Unpeeled
%Modelling
kup=[kup10 kup20 kup30 kup40 kup50 kup60]';
[expkup fup]=fit(simtemp,kup,'poly2');
p1=expkup.p1;
```

```
p2=expkup.p2;
p3=expkup.p3;
simkup= p1*(simtemp.^2) + p2*simtemp + p3;%Model
k3=p1*(Temp.^2) + p2*Temp + p3;%Model
k=k3;

c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',Temp);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,3);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Unpeeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'

%Peeled
%Modelling
kp=[kp10 kp20 kp30 kp40 kp50 kp60]';
[expkp fp]=fit(simtemp,kp,'poly2');
p1=expkp.p1;
p2=expkp.p2;
p3=expkp.p3;
simkp= p1*(simtemp.^2) + p2*simtemp + p3;%Model
k4=p1*(Temp.^2) + p2*Temp + p3;%Model
k=k;

c = thick*k;
d = thick*rho*specificHeat;
specifyCoefficients(model,'m',0,'d',0,'c',c,'a',a,'f',f);
applyBoundaryCondition(model,'dirichlet','Edge',[1,2,3,4],'u',Temp);
setInitialConditions(model,0);% Initial guess
hmax = .25; % element size
msh = generateMesh(model,'Hmax',hmax);



% Steady State Solution
R = solvepde(model);
u = R.NodalSolution;

subplot(2,2,4);
pdeplot(model,'XYData',u,'Contour','on','ColorMap','jet');
title 'Temperature In The Peeled Ginger, Steady State Solution'
xlabel 'X-coordinate, m'
ylabel 'Y-coordinate, m'
```

```
%Display
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Simulation & Modelling Data====================',...
'Linear model Poly2:',...
     'y(x) = p1*x^2 + p2*x + p3',...
     'Coefficients (with 95% confidence bounds):',...
     'See Table Below'};



 for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%Goodness of Curve Table
 simtabledata=[Temp,Temp,Temp,Temp;
     expkub.p1,expkb.p1,expkup.p1,expkp.p1;...
     expkub.p2,expkb.p2,expkup.p2,expkp.p2;...
     expkub.p3,expkb.p3,expkup.p3,expkp.p3;...
fub.sse,fb.sse,fup.sse,fp.sse;...
fub.rsquare,fb.rsquare,fup.rsquare,fp.rsquare;...
  fub.dfe,fb.dfe,fup.dfe,fp.dfe;...
       fub.adjrsquare,fb.adjrsquare,fup.adjrsquare,fp.adjrsquare;...
        fub.rmse, fb.rmse , fup.rmse , fp.rmse;...
        k1,k2,k3,k4];



   set(handles.modeltable,'Data',[]);
   set(handles.modeltable,'Data',simtabledata);




%% Compare Mode
else
str={'=====================PLOT COMPARISON MODE=================='};
set(handles.displayedit, 'String', str);

d=get(handles.loadexpdata,'Userdata')%Experimental data
DT=d.t10(:,1);
DTs=DT*60*60;
P=ones(length(DT),1)*(str2double(get(handles.power,'String')));%Power in
Watts
L=ones(length(DT),1)*(str2double(get(handles.length,'String')));%Length in
meters (L4-L5)
A=ones(length(DT),1)*(str2double(get(handles.area,'String')));%Area

exptemp_sel_index = get(handles.expdrytemp, 'Value');

switch exptemp_sel_index
case 1
%Drying Temperature at 10 DegC

%Unblanched
ubmc10=((d.t10(:,2)-d.t10(:,3))./d.t10(:,2))*100;
```

```
ubtdiff10=d.t10(:,4);
ubthermcon10=(P.*L)./(ubtdiff10.*A);
ubimc10=d.t10(:,5);
ublnMR10=log(ubmc10./ubimc10);




%Blanched
bmc10=((d.t10(:,6)-d.t10(:,7))./d.t10(:,6))*100;
btdiff10=d.t10(:,8);
bthermcon10=(P.*L)./(btdiff10.*A);
bimc10=d.t10(:,9);
blnMR10=log(bmc10./bimc10);

%Unpeeled
upmc10=((d.t10(:,10)-d.t10(:,11))./d.t10(:,10))*100;
uptdiff10=d.t10(:,12);
upthermcon10=(P.*L)./(uptdiff10.*A);
upimc10=d.t10(:,13);
uplnMR10=log(upmc10./upimc10);

%Peeled
pmc10=((d.t10(:,14)-d.t10(:,15))./d.t10(:,14))*100;
ptdiff10=d.t10(:,16);
pthermcon10=(P.*L)./(ptdiff10.*A);
pimc10=d.t10(:,17);
plnMR10=log(pmc10./pimc10);



case 2
%Drying Temperature at 20 DegC
%Unblanched
ubmc20=((d.t20(:,2)-d.t20(:,3))./d.t20(:,2))*100;
ubtdiff20=d.t20(:,4);
ubthermcon20=(P.*L)./(ubtdiff20.*A);
ubimc20=d.t20(:,5);
ublnMR20=log(ubmc20./ubimc20);

%Blanched
bmc20=((d.t20(:,6)-d.t20(:,7))./d.t20(:,6))*100;
btdiff20=d.t20(:,8);
bthermcon20=(P.*L)./(btdiff20.*A);
bimc20=d.t20(:,9);
blnMR20=log(bmc20./bimc20);

%Unpeeled
upmc20=((d.t20(:,10)-d.t20(:,11))./d.t20(:,10))*100;
uptdiff20=d.t20(:,12);
upthermcon20=(P.*L)./(uptdiff20.*A);
upimc20=d.t20(:,13);
uplnMR20=log(upmc20./upimc20);

%Peeled
pmc20=((d.t20(:,14)-d.t20(:,15))./d.t20(:,14))*100;
ptdiff20=d.t20(:,16);
pthermcon20=(P.*L)./(ptdiff20.*A);
pimc20=d.t20(:,17);
plnMR20=log(pmc20./pimc20);
case 3
```

```
%Drying Temperature at 30 DegC
%Unblanched
ubmc30=((d.t30(:,2)-d.t30(:,3))./d.t30(:,2))*100;
ubtdiff30=d.t30(:,4);
ubthermcon30=(P.*L)./(ubtdiff30.*A);
ubimc30=d.t30(:,5);
ublnMR30=log(ubmc30./ubimc30);

%Blanched
bmc30=((d.t30(:,6)-d.t30(:,7))./d.t30(:,6))*100;
btdiff30=d.t30(:,8);
bthermcon30=(P.*L)./(btdiff30.*A);
bimc30=d.t30(:,9);
blnMR30=log(bmc30./bimc30);

%Unpeeled
upmc30=((d.t30(:,10)-d.t30(:,11))./d.t30(:,10))*100;
uptdiff30=d.t30(:,12);
upthermcon30=(P.*L)./(uptdiff30.*A);
upimc30=d.t30(:,13);
uplnMR30=log(upmc30./upimc30);

%Peeled
pmc30=((d.t30(:,14)-d.t30(:,15))./d.t30(:,14))*100;
ptdiff30=d.t30(:,16);
pthermcon30=(P.*L)./(ptdiff30.*A);
pimc30=d.t30(:,17);
plnMR30=log(pmc30./pimc30);
case 4
%Drying Temperature at 40 DegC
%Unblanched
ubmc40=((d.t40(:,2)-d.t40(:,3))./d.t40(:,2))*100;
ubtdiff40=d.t40(:,4);
ubthermcon40=(P.*L)./(ubtdiff40.*A);
ubimc40=d.t40(:,5);
ublnMR40=log(ubmc40./ubimc40);

%Blanched
bmc40=((d.t40(:,6)-d.t40(:,7))./d.t40(:,6))*100;
btdiff40=d.t40(:,8);
bthermcon40=(P.*L)./(btdiff40.*A);
bimc40=d.t40(:,9);
blnMR40=log(bmc40./bimc40);

%Unpeeled
upmc40=((d.t40(:,10)-d.t40(:,11))./d.t40(:,10))*100;
uptdiff40=d.t40(:,12);
upthermcon40=(P.*L)./(uptdiff40.*A);
upimc40=d.t40(:,13);
uplnMR40=log(upmc40./upimc40);

%Peeled
pmc40=((d.t40(:,14)-d.t40(:,15))./d.t40(:,14))*100;
ptdiff40=d.t40(:,16);
pthermcon40=(P.*L)./(ptdiff40.*A);
pimc40=d.t40(:,17);
plnMR40=log(pmc40./pimc40);
case 5
%Drying Temperature at 50 DegC
%Unblanched
```

```
ubmc50=((d.t50(:,2)-d.t50(:,3))./d.t50(:,2))*100;
ubtdiff50=d.t50(:,4);
ubthermcon50=(P.*L)./(ubtdiff50.*A);
ubimc50=d.t50(:,5);
ublnMR50=log(ubmc50./ubimc50);

%Blanched
bmc50=((d.t50(:,6)-d.t50(:,7))./d.t50(:,6))*100;
btdiff50=d.t50(:,8);
bthermcon50=(P.*L)./(btdiff50.*A);
bimc50=d.t50(:,9);
blnMR50=log(bmc50./bimc50);

%Unpeeled
upmc50=((d.t50(:,10)-d.t50(:,11))./d.t50(:,10))*100;
uptdiff50=d.t50(:,12);
upthermcon50=(P.*L)./(uptdiff50.*A);
upimc50=d.t50(:,13);
uplnMR50=log(upmc50./upimc50);

%Peeled
pmc50=((d.t50(:,14)-d.t50(:,15))./d.t50(:,14))*100;
ptdiff50=d.t50(:,16);
pthermcon50=(P.*L)./(ptdiff50.*A);
pimc50=d.t50(:,17);
plnMR50=log(pmc50./pimc50);
case 6
%Drying Temperature at 60 DegC
%Unblanched
ubmc60=((d.t60(:,2)-d.t60(:,3))./d.t60(:,2))*100;
ubtdiff60=d.t60(:,4);
ubthermcon60=(P.*L)./(ubtdiff60.*A);
ubimc60=d.t60(:,5);
ublnMR60=log(ubmc60./ubimc60);

%Blanched
bmc60=((d.t60(:,6)-d.t60(:,7))./d.t60(:,6))*100;
btdiff60=d.t60(:,8);
bthermcon60=(P.*L)./(btdiff60.*A);
bimc60=d.t60(:,9);
blnMR60=log(bmc60./bimc60);

%Unpeeled
upmc60=((d.t60(:,10)-d.t60(:,11))./d.t60(:,10))*100;
uptdiff60=d.t60(:,12);
upthermcon60=(P.*L)./(uptdiff60.*A);
upimc60=d.t60(:,13);
uplnMR60=log(upmc60./upimc60);

%Peeled
pmc60=((d.t60(:,14)-d.t60(:,15))./d.t60(:,14))*100;
ptdiff60=d.t60(:,16);
pthermcon60=(P.*L)./(ptdiff60.*A);
pimc60=d.t60(:,17);
plnMR60=log(pmc60./pimc60);
end

%% Plot 1
h=figure;
set(h,'Name','Simulation of Drying of Ginger Rhizomes - Plot Comparism',...
```

```
'NumberTitle','off');
subplot(2,1,1);
plot_sel_index = get(handles.plottype, 'Value');

switch plot_sel_index

%% Plotting of Moisture Content
case 1
if exptemp_sel_index==1
plot(DT,ubmc10,DT,ubmc10,'bo');
grid;
hold;

plot(DT,bmc10,DT,bmc10,'r+');
plot(DT,upmc10,DT,upmc10,'y*');
plot(DT,pmc10,DT,pmc10,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 10 DegCel',...
'','=======================Data==========================='};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

% table{2,length(DT)+1}=[];
% table(1,1:2)={'Drying Time(Hr)','Moisture Content(%)'};
% DT1=cellstr(num2str(DT));
% Submc10=cellstr(num2str(ubmc10));
% table(2:length(DT)+1,1)=DT1;
% table(2:length(DT)+1,2)=Submc10;
% % statdisptable(table,'Experimental Data','Drying Time Vs Moisture
Content');

%20 degcel DT vs MC
elseif exptemp_sel_index==2
plot(DT,ubmc20,DT,ubmc20,'bo');
grid;
hold;

plot(DT,bmc20,DT,bmc20,'r+');
plot(DT,upmc20,DT,upmc20,'y*');
plot(DT,pmc20,DT,pmc20,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
```

```
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 20 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DT vs MC
elseif exptemp_sel_index==3
plot(DT,ubmc30,DT,ubmc30,'bo');
grid;
hold;

plot(DT,bmc30,DT,bmc30,'r+');
plot(DT,upmc30,DT,upmc30,'y*');
plot(DT,pmc30,DT,pmc30,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 30 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);


%40 degcel DT vs MC
```

```
elseif exptemp_sel_index==4
plot(DT,ubmc40,DT,ubmc40,'bo');
grid;
hold;

plot(DT,bmc40,DT,bmc40,'r+');
plot(DT,upmc40,DT,upmc40,'y*');
plot(DT,pmc40,DT,pmc40,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 40 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DT vs MC
elseif exptemp_sel_index==5
plot(DT,ubmc50,DT,ubmc50,'bo');
grid;
hold;

plot(DT,bmc50,DT,bmc50,'r+');
plot(DT,upmc50,DT,upmc50,'y*');
plot(DT,pmc50,DT,pmc50,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');
%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 50 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};
```

```
for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DT vs MC
else
plot(DT,ubmc60,DT,ubmc60,'bo');
grid;
hold;

plot(DT,bmc60,DT,bmc60,'r+');
plot(DT,upmc60,DT,upmc60,'y*');
plot(DT,pmc60,DT,pmc60,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 60 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end

%% Thermal Conductivity
case 2
if exptemp_sel_index==1
plot(DT,ubthermcon10,DT,ubthermcon10,'bo');
grid;
hold;
plot(DT,bthermcon10,DT,bthermcon10,'r+');
plot(DT,upthermcon10,DT,upthermcon10,'y*');
plot(DT,pthermcon10,DT,pthermcon10,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
```

```
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 10 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%20 degcel DT vs thermcon
elseif exptemp_sel_index==2
plot(DT,ubthermcon20,DT,ubthermcon20,'bo');
grid;
hold;
plot(DT,bthermcon20,DT,bthermcon20,'r+');
plot(DT,upthermcon20,DT,upthermcon20,'y*');
plot(DT,pthermcon20,DT,pthermcon20,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 20 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DT vs thermcon
elseif exptemp_sel_index==3
plot(DT,ubthermcon30,DT,ubthermcon30,'bo');
grid;
hold;
plot(DT,bthermcon30,DT,bthermcon30,'r+');
plot(DT,upthermcon30,DT,upthermcon30,'y*');
plot(DT,pthermcon30,DT,pthermcon30,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
```

```
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 30 DegCel',...
'','==================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);


%40 degcel DT vs thermcon
elseif exptemp_sel_index==4
plot(DT,ubthermcon40,DT,ubthermcon40,'bo');
grid;
hold;
plot(DT,bthermcon40,DT,bthermcon40,'r+');
plot(DT,upthermcon40,DT,upthermcon40,'y*');
plot(DT,pthermcon40,DT,pthermcon40,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 40 DegCel',...
'','==================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DT vs thermcon
elseif exptemp_sel_index==5
plot(DT,ubthermcon50,DT,ubthermcon50,'bo');
```

```
grid;
hold;
plot(DT,bthermcon50,DT,bthermcon50,'r+');
plot(DT,upthermcon50,DT,upthermcon50,'y*');
plot(DT,pthermcon50,DT,pthermcon50,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 50 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DT vs thermcon
else
plot(DT,ubthermcon60,DT,ubthermcon60,'bo');
grid;
hold;
plot(DT,bthermcon60,DT,bthermcon60,'r+');
plot(DT,upthermcon60,DT,upthermcon60,'y*');
plot(DT,pthermcon60,DT,pthermcon60,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');



%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 60 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
```

```
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end
%% Plot of Moisture Ratio
case 3

if exptemp_sel_index==1
plot(DTs,ublnMR10,DTs,ublnMR10,'bo');
grid;
hold;
plot(DTs,blnMR10,DTs,blnMR10,'r+');
plot(DTs,uplnMR10,DTs,uplnMR10,'y*');
plot(DTs,plnMR10,DTs,plnMR10,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 10 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%20 degcel DTs vs lnMR
elseif exptemp_sel_index==2
plot(DTs,ublnMR20,DTs,ublnMR20,'bo');
grid;
hold;
plot(DTs,blnMR20,DTs,blnMR20,'r+');
plot(DTs,uplnMR20,DTs,uplnMR20,'y*');
plot(DTs,plnMR20,DTs,plnMR20,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
```

```
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 20 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DTs vs lnMR
elseif exptemp_sel_index==3
plot(DTs,ublnMR30,DTs,ublnMR30,'bo');
grid;
hold;
plot(DTs,blnMR30,DTs,blnMR30,'r+');
plot(DTs,uplnMR30,DTs,uplnMR30,'y*');
plot(DTs,plnMR30,DTs,plnMR30,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 30 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);


%40 degcel DTs vs lnMR
elseif exptemp_sel_index==4
plot(DTs,ublnMR40,DTs,ublnMR40,'bo');
grid;
hold;
plot(DTs,blnMR40,DTs,blnMR40,'r+');
plot(DTs,uplnMR40,DTs,uplnMR40,'y*');
plot(DTs,plnMR40,DTs,plnMR40,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
```

```
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 40 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};



for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DTs vs lnMR
elseif exptemp_sel_index==5
plot(DTs,ublnMR50,DTs,ublnMR50,'bo');
grid;
hold;
plot(DTs,blnMR50,DTs,blnMR50,'r+');
plot(DTs,uplnMR50,DTs,uplnMR50,'y*');
plot(DTs,plnMR50,DTs,plnMR50,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 50 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};



for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DTs vs lnMR
else
plot(DTs,ublnMR60,DTs,ublnMR60,'bo');
```

```
grid;
hold;
plot(DTs,blnMR60,DTs,blnMR60,'r+');
plot(DTs,uplnMR60,DTs,uplnMR60,'y*');
plot(DTs,plnMR60,DTs,plnMR60,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');


%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 60 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);
end



end

%% Plot 2

subplot(2,1,2);

plot_sel_index2 = get(handles.plottype2, 'Value');
%axes('position',[0.038 0.035 0.391 0.350])
switch plot_sel_index2

%% Plotting of Moisture Content
case 1
if exptemp_sel_index==1
plot(DT,ubmc10,DT,ubmc10,'bo');
grid;
hold;

plot(DT,bmc10,DT,bmc10,'r+');
plot(DT,upmc10,DT,upmc10,'y*');
plot(DT,pmc10,DT,pmc10,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');
```

```
%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 10 DegCel',...
'','========================Data==========================='};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

% table{2,length(DT)+1}=[];
% table(1,1:2)={'Drying Time(Hr)','Moisture Content(%)'};
% DT1=cellstr(num2str(DT));
% Submc10=cellstr(num2str(ubmc10));
% table(2:length(DT)+1,1)=DT1;
% table(2:length(DT)+1,2)=Submc10;
% % statdisptable(table,'Experimental Data','Drying Time Vs Moisture
Content');

%20 degcel DT vs MC
elseif exptemp_sel_index==2
plot(DT,ubmc20,DT,ubmc20,'bo');
grid;
hold;

plot(DT,bmc20,DT,bmc20,'r+');
plot(DT,upmc20,DT,upmc20,'y*');
plot(DT,pmc20,DT,pmc20,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 20 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
```

```
set(handles.displayedit, 'String', str);

%30 degcel DT vs MC
elseif exptemp_sel_index==3
plot(DT,ubmc30,DT,ubmc30,'bo');
grid;
hold;

plot(DT,bmc30,DT,bmc30,'r+');
plot(DT,upmc30,DT,upmc30,'y*');
plot(DT,pmc30,DT,pmc30,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','=================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 30 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);



%40 degcel DT vs MC
elseif exptemp_sel_index==4
plot(DT,ubmc40,DT,ubmc40,'bo');
grid;
hold;

plot(DT,bmc40,DT,bmc40,'r+');
plot(DT,upmc40,DT,upmc40,'y*');
plot(DT,pmc40,DT,pmc40,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','=================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
```

```
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 40 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DT vs MC
elseif exptemp_sel_index==5
plot(DT,ubmc50,DT,ubmc50,'bo');
grid;
hold;

plot(DT,bmc50,DT,bmc50,'r+');
plot(DT,upmc50,DT,upmc50,'y*');
plot(DT,pmc50,DT,pmc50,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');
%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 50 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DT vs MC
else
plot(DT,ubmc60,DT,ubmc60,'bo');
grid;
hold;

plot(DT,bmc60,DT,bmc60,'r+');
plot(DT,upmc60,DT,upmc60,'y*');
plot(DT,pmc60,DT,pmc60,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Moisture Content,(%)');
title('Plot of Drying Time Vs Moisture Content');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');
```

```
%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info==========================',...
'Plot Type - Drying Time Vs Moisture Content',...
'Drying Temperature - 60 DegCel',...
'','==================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};



for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end

%% Thermal Conductivity
case 2
if exptemp_sel_index==1
plot(DT,ubthermcon10,DT,ubthermcon10,'bo');
grid;
hold;
plot(DT,bthermcon10,DT,bthermcon10,'r+');
plot(DT,upthermcon10,DT,upthermcon10,'y*');
plot(DT,pthermcon10,DT,pthermcon10,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info==========================',...
lot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 10 DegCel',...
'','==================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};



for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%20 degcel DT vs thermcon
elseif exptemp_sel_index==2
plot(DT,ubthermcon20,DT,ubthermcon20,'bo');
grid;
```

```
hold;
plot(DT,bthermcon20,DT,bthermcon20,'r+');
plot(DT,upthermcon20,DT,upthermcon20,'y*');
plot(DT,pthermcon20,DT,pthermcon20,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 20 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DT vs thermcon
elseif exptemp_sel_index==3
plot(DT,ubthermcon30,DT,ubthermcon30,'bo');
grid;
hold;
plot(DT,bthermcon30,DT,bthermcon30,'r+');
plot(DT,upthermcon30,DT,upthermcon30,'y*');
plot(DT,pthermcon30,DT,pthermcon30,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 30 DegCel',...
'','====================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
```

```
set(handles.displayedit, 'String', str);


%40 degcel DT vs thermcon
elseif exptemp_sel_index==4
plot(DT,ubthermcon40,DT,ubthermcon40,'bo');
grid;
hold;
plot(DT,bthermcon40,DT,bthermcon40,'r+');
plot(DT,upthermcon40,DT,upthermcon40,'y*');
plot(DT,pthermcon40,DT,pthermcon40,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 40 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%50 degcel DT vs thermcon
elseif exptemp_sel_index==5
plot(DT,ubthermcon50,DT,ubthermcon50,'bo');
grid;
hold;
plot(DT,bthermcon50,DT,bthermcon50,'r+');
plot(DT,upthermcon50,DT,upthermcon50,'y*');
plot(DT,pthermcon50,DT,pthermcon50,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 50 DegCel',...
```

```
'','=================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DT vs thermcon
else
plot(DT,ubthermcon60,DT,ubthermcon60,'bo');
grid;
hold;
plot(DT,bthermcon60,DT,bthermcon60,'r+');
plot(DT,upthermcon60,DT,upthermcon60,'y*');
plot(DT,pthermcon60,DT,pthermcon60,'msq');
xlabel('Drying Time,(Hour)');
ylabel('Thermal Conductivity,(W/m.K)');
title('Plot of Drying Time Vs Thermal Conductivity');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');


%Display (60DegCel)
str2={'','=================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Thermal Conductivity',...
'Drying Temperature - 60 DegCel',...
'','=================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end
%% Plot of Moisture Ratio
case 3

if exptemp_sel_index==1
plot(DTs,ublnMR10,DTs,ublnMR10,'bo');
grid;
hold;
plot(DTs,blnMR10,DTs,blnMR10,'r+');
plot(DTs,uplnMR10,DTs,uplnMR10,'y*');
plot(DTs,plnMR10,DTs,plnMR10,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');
```

```
%Display(10 DegCel)
str2={'','==================Experimental Data:=================',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 10 DegCel',...
'','================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%20 degcel DTs vs lnMR
elseif exptemp_sel_index==2
plot(DTs,ublnMR20,DTs,ublnMR20,'bo');
grid;
hold;
plot(DTs,blnMR20,DTs,blnMR20,'r+');
plot(DTs,uplnMR20,DTs,uplnMR20,'y*');
plot(DTs,plnMR20,DTs,plnMR20,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (20DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 20 DegCel',...
'','================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%30 degcel DTs vs lnMR
elseif exptemp_sel_index==3
plot(DTs,ublnMR30,DTs,ublnMR30,'bo');
grid;
hold;
plot(DTs,blnMR30,DTs,blnMR30,'r+');
plot(DTs,uplnMR30,DTs,uplnMR30,'y*');
```

```
plot(DTs,plnMR30,DTs,plnMR30,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (30DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 30 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);



%40 degcel DTs vs lnMR
elseif exptemp_sel_index==4
plot(DTs,ublnMR40,DTs,ublnMR40,'bo');
grid;
hold;
plot(DTs,blnMR40,DTs,blnMR40,'r+');
plot(DTs,uplnMR40,DTs,uplnMR40,'y*');
plot(DTs,plnMR40,DTs,plnMR40,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (40DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying  Time:  7200  #  14400  #  28800  #  36000   #  50400  #  57600  #  86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','==================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 40 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2)
str(end+1)=str2(i);
end
```

```
set(handles.displayedit, 'String', str);

%50 degcel DTs vs lnMR
elseif exptemp_sel_index==5
plot(DTs,ublnMR50,DTs,ublnMR50,'bo');
grid;
hold;
plot(DTs,blnMR50,DTs,blnMR50,'r+');
plot(DTs,uplnMR50,DTs,uplnMR50,'y*');
plot(DTs,plnMR50,DTs,plnMR50,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');

%Display (50DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 50 DegCel',...
'','==================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

%60 degcel DTs vs lnMR
else
plot(DTs,ublnMR60,DTs,ublnMR60,'bo');
grid;
hold;
plot(DTs,blnMR60,DTs,blnMR60,'r+');
plot(DTs,uplnMR60,DTs,uplnMR60,'y*');
plot(DTs,plnMR60,DTs,plnMR60,'msq');
xlabel('Drying Time,(Seconds)');
ylabel('ln MR');
title('Plot of Drying Time Vs Moisture Ratio ');
legend('','Unblanched','','Blanched','','Unpeeled','','Peeled','location','
NorthEastOutside');


%Display (60DegCel)
str2={'','==================Experimental Data:=================',...
'Experimental Data:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 7200 # 14400 # 28800 # 36000  # 50400 # 57600 # 86400
Seconds',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','=================Plot Info===========================',...
```

```
'Plot Type - Drying Time Vs Moisture Ratio ',...
'Drying Temperature - 60 DegCel',...
'','===================================================',...
'Select Temperature , Plot Type and Click Run To View another Plot'};


for i=1:length(str2);
str(end+1)=str2(i);
end
set(handles.displayedit, 'String', str);

end
end

end
end


function  plottype_CreateFcn(hObject, eventdata, handles)
% hObject    handle to plottype (see GCBO)

if         ispc         &&         isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end

set(hObject, 'String', {'Drying Time Vs Moisture Content', 'Drying Time Vs
Thermal Conductivity',...
'Drying Time Vs Moisture Ratio', 'PDE Heat Transfer'});

function displayedit_Callback(hObject, eventdata, handles)


function displayedit_CreateFcn(hObject, eventdata, handles)

if         ispc         &&         isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end




% --- Executes on button press in analyseexprb.
function analyseexprb_Callback(hObject, eventdata, handles)
set(handles.analyseexprb, 'Value', 1);
set(handles.expvssimrb, 'Value', 0);
set(handles.simrb, 'Value', 0);
info1={'Mode: Experimental Result Analysis'};
info1{end+1}='Load Data to Run';
set(handles.displayedit, 'String', info1);
set(handles.plottype2, 'Enable','off');
set(handles.plottype, 'String', {'Drying Time Vs Moisture Content', 'Drying
Time Vs Thermal Conductivity',...
'Drying Time Vs Moisture Ratio','PDE Heat Transfer'});
set(handles.expdrytemp, 'Enable','on');
set(handles.modeltable, 'Visible','off');
set(handles.simdrytemp, 'Enable','off');
```

```
% --- Executes on button press in simrb.
function simrb_Callback(hObject, eventdata, handles)
set(handles.simrb, 'Value', 1);
set(handles.expvssimrb, 'Value', 0);
set(handles.analyseexprb, 'Value', 0);
info1={'Mode : Simulation Mode'};
info1{end+1}='Load Data to Run';
set(handles.displayedit, 'String', info1);
set(handles.plottype2, 'Enable','off');
set(handles.plottype, 'String', {'PDE Heat Transfer'});
set(handles.expdrytemp, 'Enable','off');
set(handles.modeltable, 'Visible','on');
set(handles.simdrytemp, 'Enable','on');
% --- Executes on button press in expvssimrb.

function expvssimrb_Callback(hObject, eventdata, handles)
set(handles.expvssimrb, 'Value', 1);
set(handles.analyseexprb, 'Value', 0);
set(handles.simrb, 'Value', 0);
info1={'Mode : Plot Comparison '};
info1{end+1}='Load data, Select Plot 1 and Plot 2 then Click Run';
set(handles.displayedit, 'String', info1);
set(handles.plottype2, 'Enable','on');
set(handles.plottype, 'String', {'Drying Time Vs Moisture Content', 'Drying
Time Vs Thermal Conductivity',...
'Drying Time Vs Moisture Ratio'});
set(handles.expdrytemp, 'Enable','on');
set(handles.modeltable, 'Visible','off');
set(handles.simdrytemp, 'Enable','off');

% --- Executes on button press in Exit.
function Exit_Callback(hObject, eventdata, handles)
selection = questdlg(['Close ' get(handles.figure1,'Name') '?'],...
['Close ' get(handles.figure1,'Name') '...'],...
'Yes','No','Yes');
if strcmp(selection,'No')
return;
end

if ishandle('Simulation of Drying of Ginger Rhizomes - PDE Heat Transfer')
close 'Simulation of Drying of Ginger Rhizomes - PDE Heat Transfer';
end

if ishandle('Simulation of Drying of Ginger Rhizomes - Plot Comparism')
close 'Simulation of Drying of Ginger Rhizomes - Plot Comparism';
end

close();




% --- Executes on button press in help.
function help_Callback(hObject, eventdata, handles)
hlp={help('simdryingginger')};
set(handles.displayedit, 'String', hlp);



% --- Executes on button press in reset.
```

```
function reset_Callback(hObject, eventdata, handles)
set(handles.analyseexprb, 'Value', 1);
set(handles.expvssimrb, 'Value', 0);
set(handles.simrb, 'Value', 0);
info1={'Mode: Experimental Result Analysis'};
info1{end+1}='Load Data to Run';
set(handles.displayedit, 'String', info1);
set(handles.plottype2, 'Enable','off');
set(handles.plottype, 'String', {'Drying Time Vs Moisture Content', 'Drying
Time Vs Thermal Conductivity',...
'Drying Time Vs Moisture Ratio','PDE Heat Transfer'});
set(handles.expdrytemp, 'Enable','on');
 set(handles.modeltable,'Data',[]);
set(handles.modeltable, 'Visible','off');
delete(gca);
delete(gca);
axes('position',[0.038 0.076 0.391 0.758]);%(handles.axes1);
hold off;
set(handles.simdrytemp,'String','35');
set(handles.power,'String','20');
set(handles.length,'String','0.000707');
set(handles.area,'String','0.02');
% --- Executes on button press in loadexpdata.
function loadexpdata_Callback(hObject, eventdata, handles)
[FileName,PathName] = uigetfile('*.xls;*.xlsx','Load Excel Sheet Containing
Experimental Data');
file=[PathName,FileName];
str={'File Path:'};
str1={file};
str(end+1)=str1;
str2={'','================================================',...
'Experimental Data for the following has been loaded:',...
'Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled',...
'Initial Weight and Weight After Drying',...
'Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs',...
'Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel',...
'','================================================',...
'Select Temperature , Plot Type and Click Run To View Plot'};

for i=1:length(str2);
str(end+1)=str2(i);
end
expdata.t10=xlsread(file,'1');
expdata.t20=xlsread(file,'2');
expdata.t30=xlsread(file,'3');
expdata.t40=xlsread(file,'4');
expdata.t50=xlsread(file,'5');
expdata.t60=xlsread(file,'6');

set(handles.displayedit, 'String', str);
set(handles.loadexpdata,'Userdata',expdata);




% --- Executes on selection change in expdrytemp.
function expdrytemp_Callback(~, eventdata, handles)
% hObject    handle to expdrytemp (see GCBO)
```

```
% --- Executes during object creation, after setting all properties.
function expdrytemp_CreateFcn(hObject, eventdata, handles)
% hObject    handle to expdrytemp (see GCBO)

if         ispc         &&         isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end
set(hObject, 'String', {'10','20','30','40','50','60'});




function simdrytemp_CreateFcn(hObject, ~, handles)
% hObject    handle to expdrytemp (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if         ispc         &&         isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end
function simdrytemp_Callback(hObject, eventdata, handles)









% --- Executes when selected object is changed in mode.
function mode_SelectionChangedFcn(hObject, eventdata, handles)
% hObject    handle to the selected object in mode
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)




function power_Callback(hObject, eventdata, handles)
% hObject    handle to power (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of power as text
%        str2double(get(hObject,'String')) returns contents of power as a
double



% --- Executes during object creation, after setting all properties.
function power_CreateFcn(hObject, eventdata, handles)
% hObject    handle to power (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end



function length_Callback(hObject, eventdata, handles)
% hObject    handle to length (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of length as text
%        str2double(get(hObject,'String')) returns contents of length as a
double


% --- Executes during object creation, after setting all properties.
function length_CreateFcn(hObject, eventdata, handles)
% hObject    handle to length (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end



function area_Callback(hObject, eventdata, handles)
% hObject    handle to area (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of area as text
%        str2double(get(hObject,'String')) returns contents of area as a
double


% --- Executes during object creation, after setting all properties.
function area_CreateFcn(hObject, eventdata, handles)
% hObject    handle to area (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end
```

```
% --- Executes on selection change in plottype2.
function plottype2_Callback(hObject, eventdata, handles)
% hObject    handle to length (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)



% --- Executes during object creation, after setting all properties.
function plottype2_CreateFcn(hObject, eventdata, handles)

if         ispc          &&          isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end
set(hObject, 'String', {'Drying Time Vs Moisture Content', 'Drying Time Vs
Thermal Conductivity',...
'Drying Time Vs Moisture Ratio'});

function figure1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to figure1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Add the current directory to the path, s the pwd might change thru' the
% gui. Remove the directory from the path when gui is closed
% (See figure1_DeleteFcn)
setappdata(hObject, 'StartPath', pwd);
addpath(pwd);
```

APPENDIX D

Temperature distribution for the ginger samples at various temperature

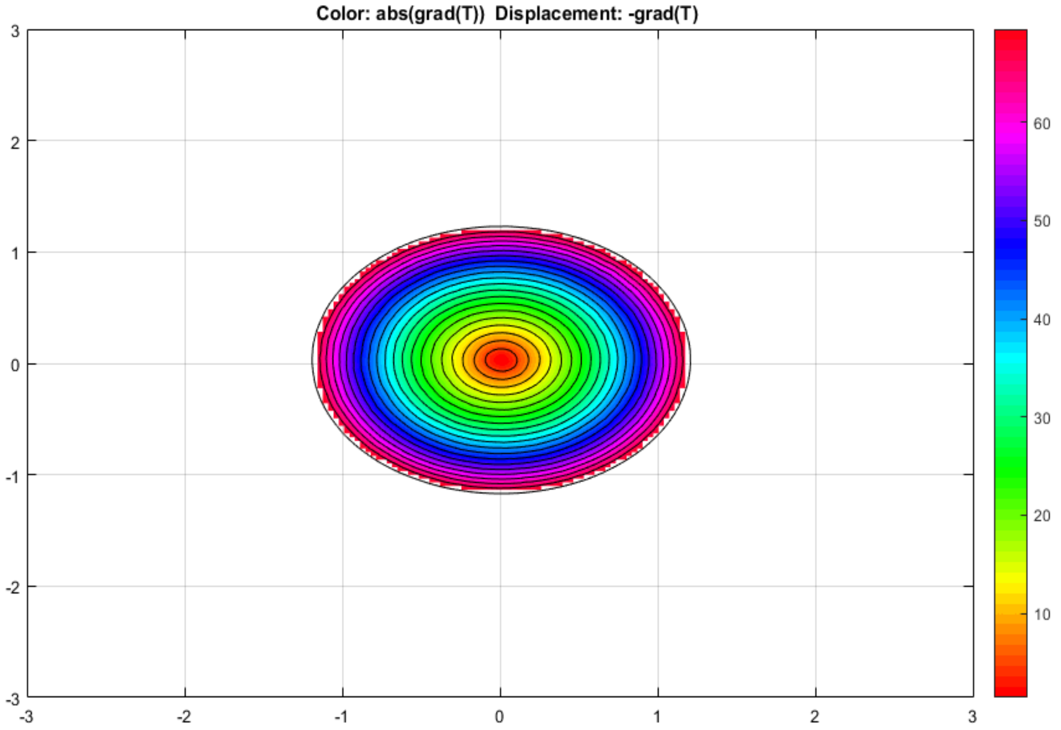


Figure D1: Temperature distribution for the Peeled at 10℃

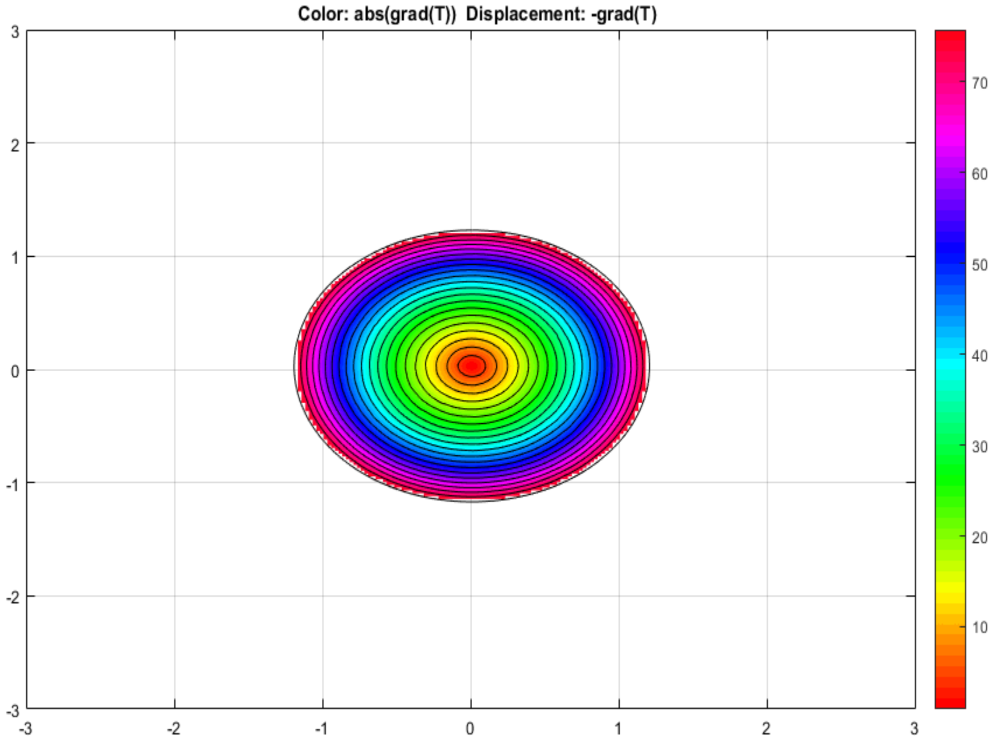


Figure D2 Temperature distribution for the Unpeeled at 10℃

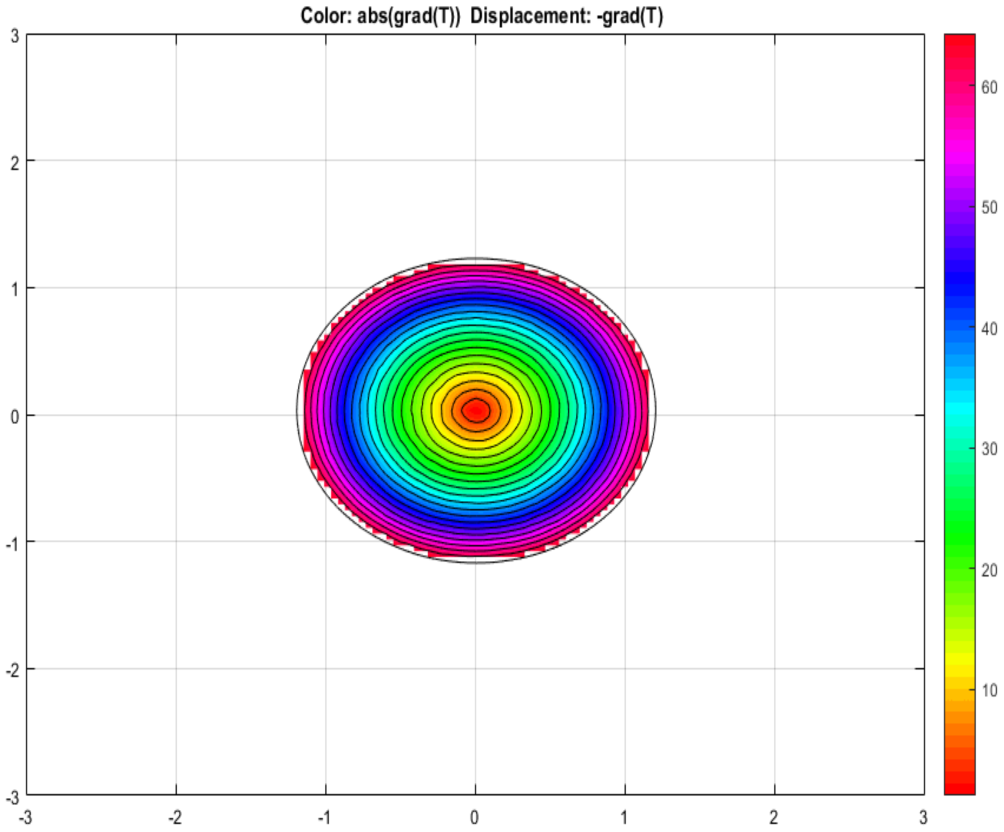


Figure D3 Temperature distribution for the Unblanched at 20℃

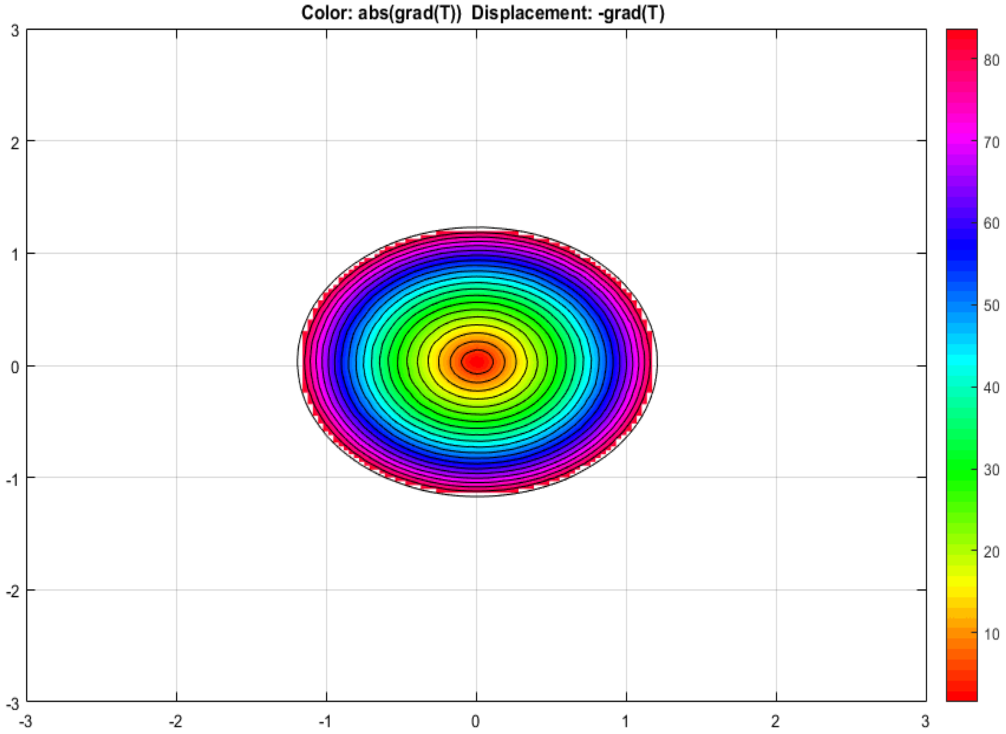


Figure D4 Temperature distribution for the Blanched at 20℃

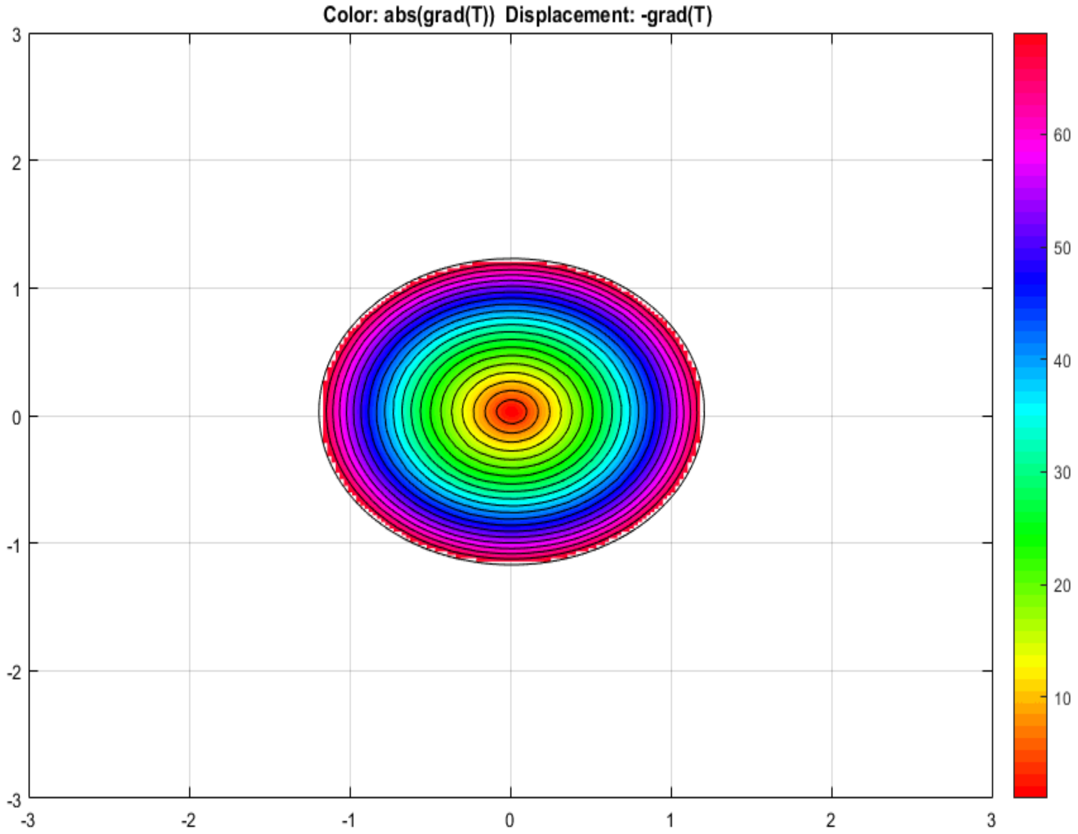


Figure D5 Temperature distribution for the Peeled at 20℃

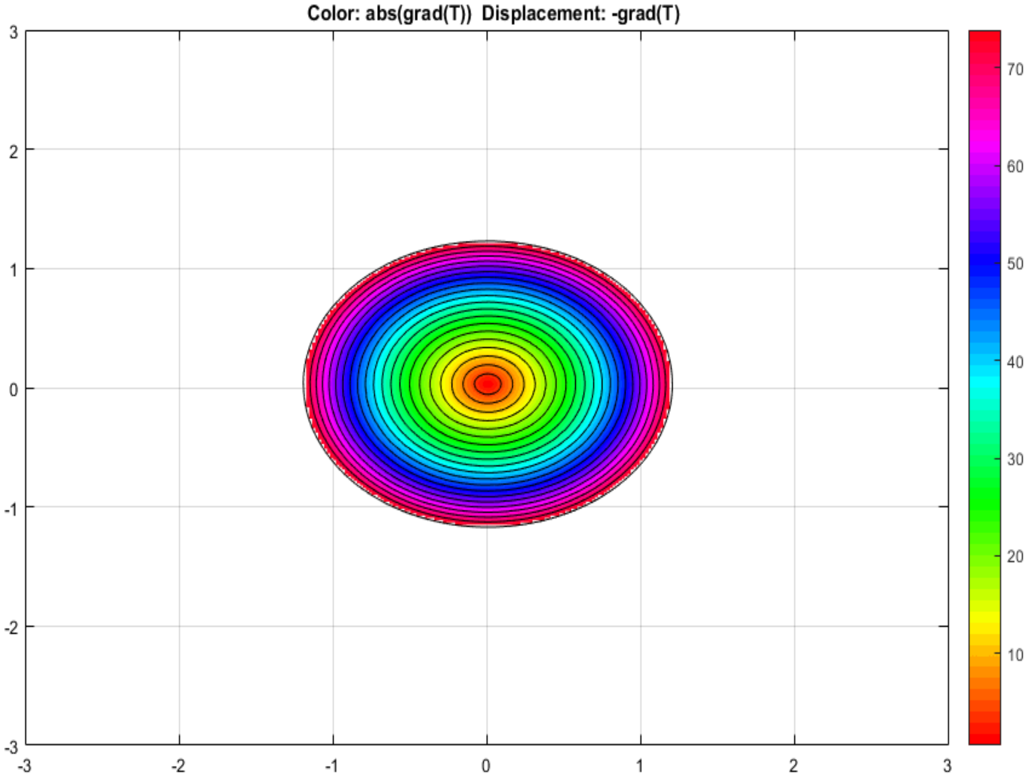


Figure D6 Temperature distribution for the Unpeeled at 20℃

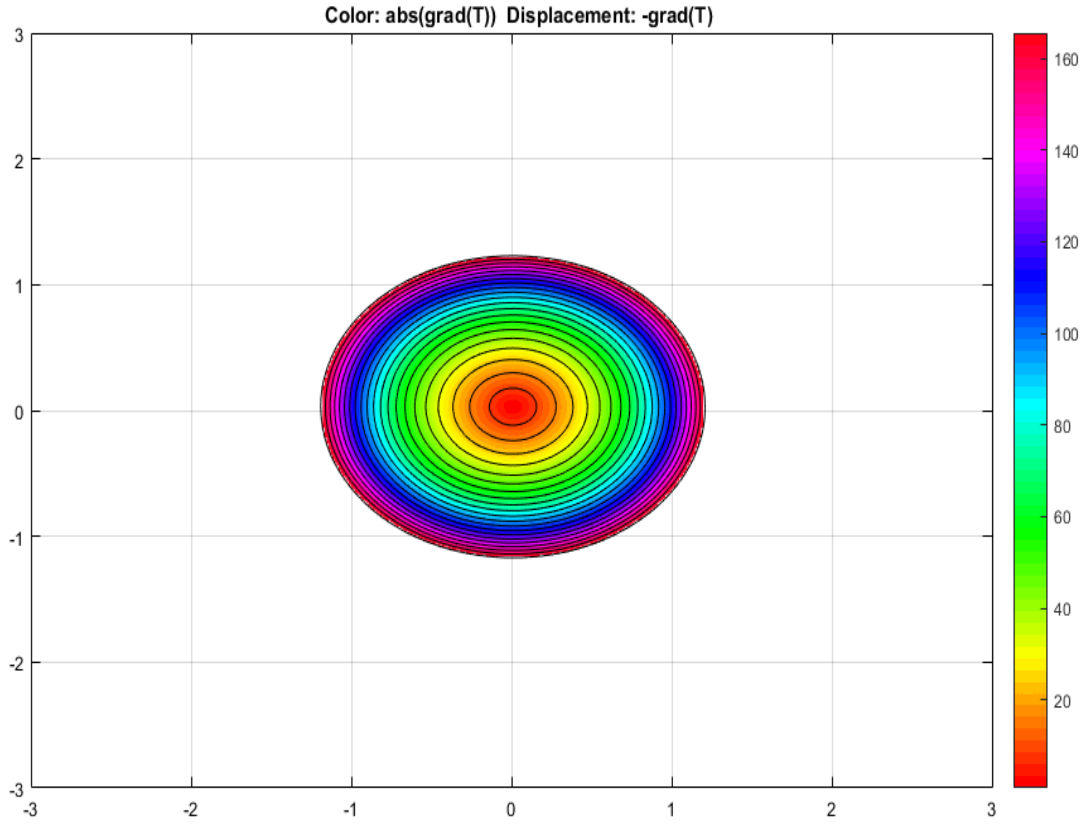


Figure D7 Temperature distribution for the unblanched at 30℃

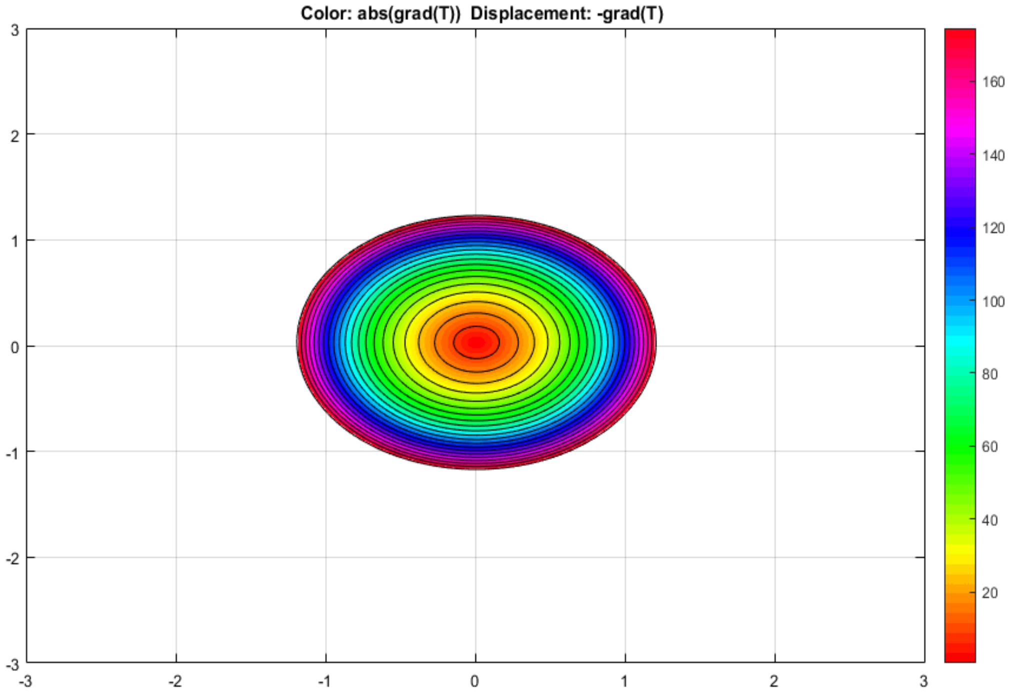


Figure D8 Temperature distribution for the Blanched at 30℃

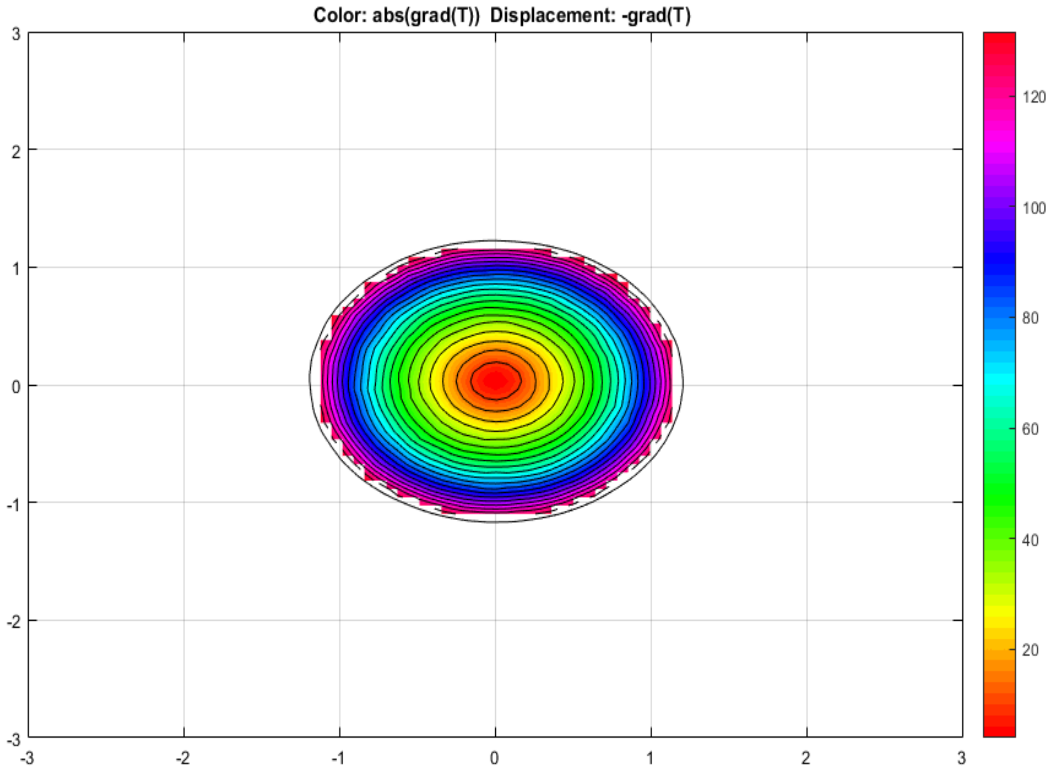


Figure D9 Temperature distribution for the Peeled at 30℃

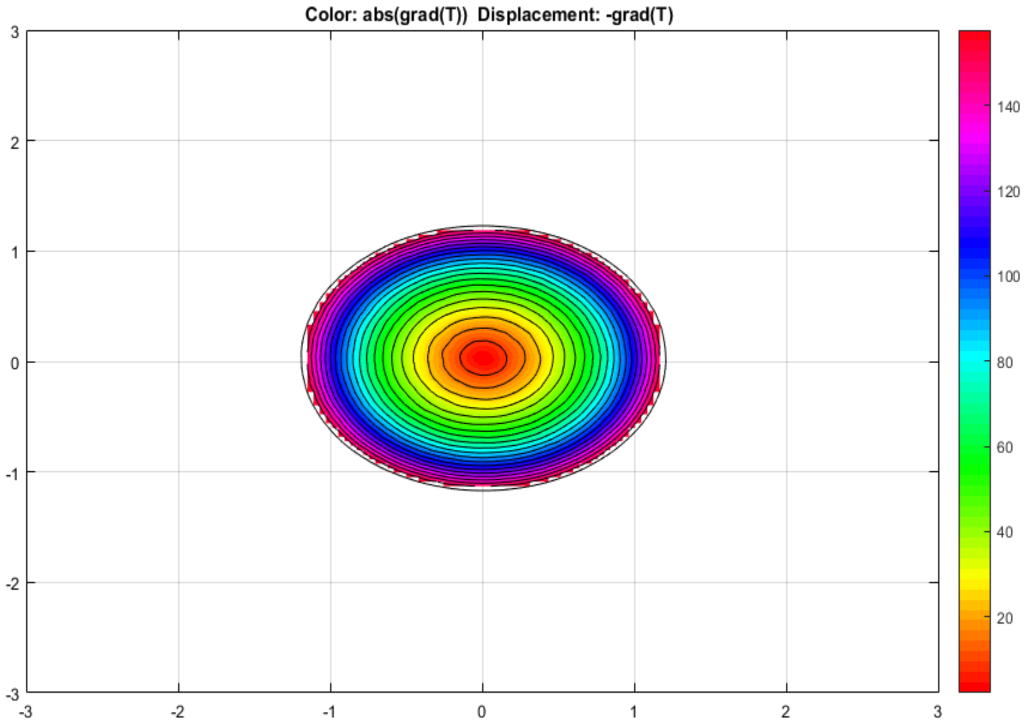


Figure D10 Temperature distribution for the unpeeled at 30℃

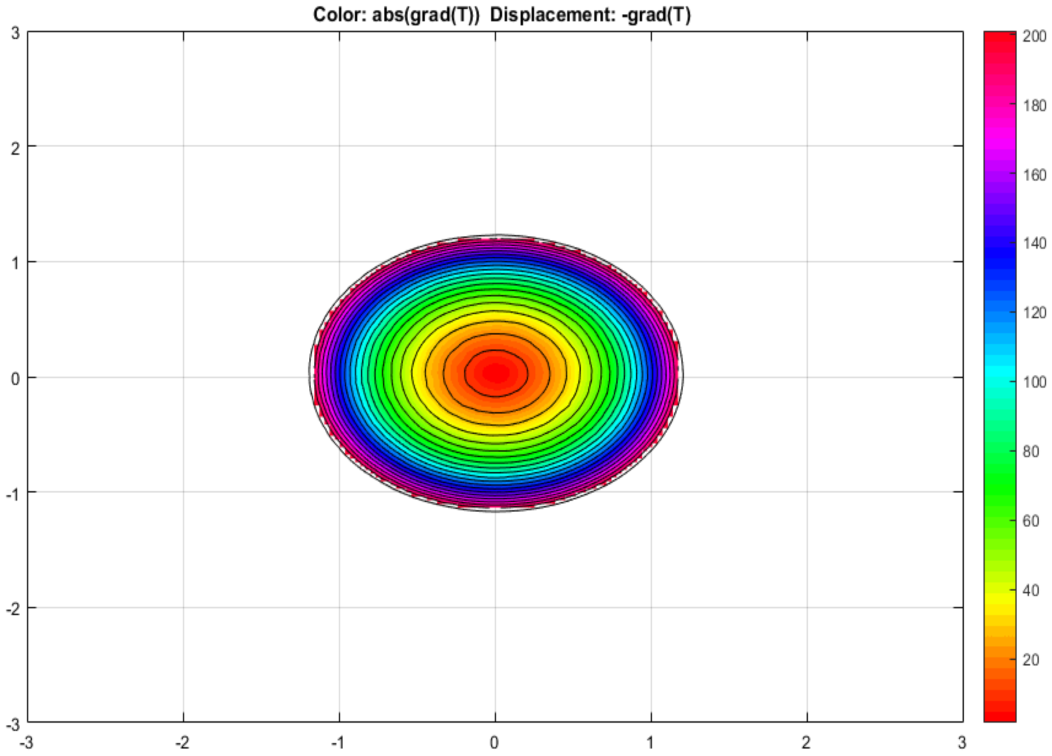


Figure D11 Temperature distribution for the unblanched at 40℃

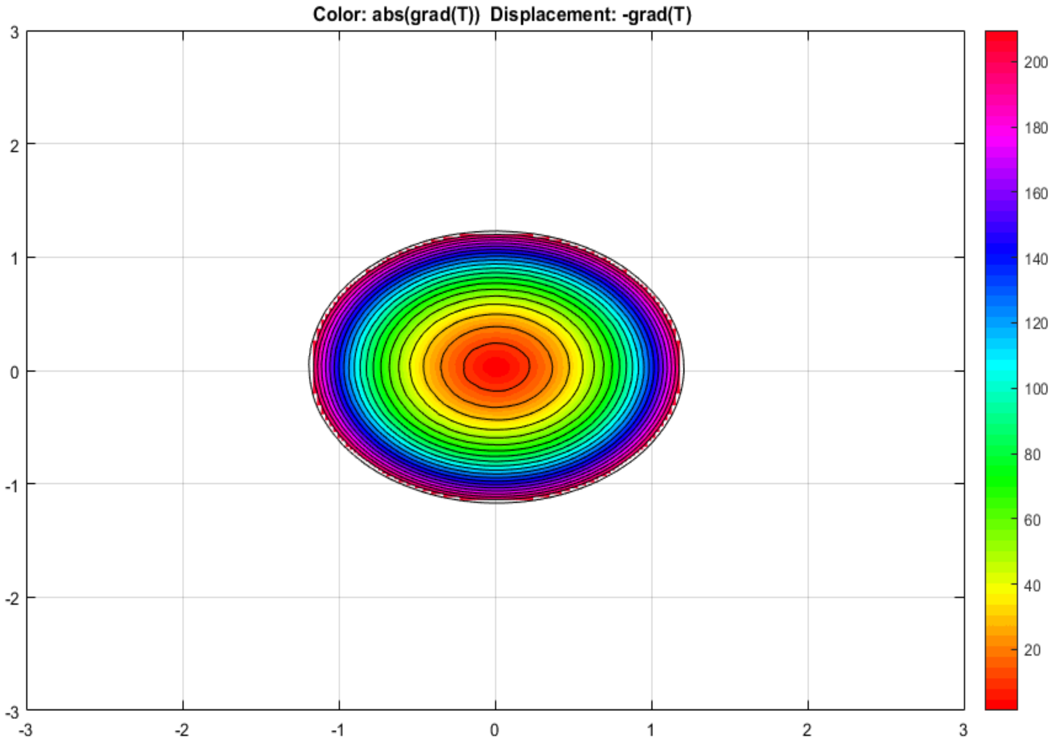


Figure D12 Temperature distribution for the Blanched at 40℃

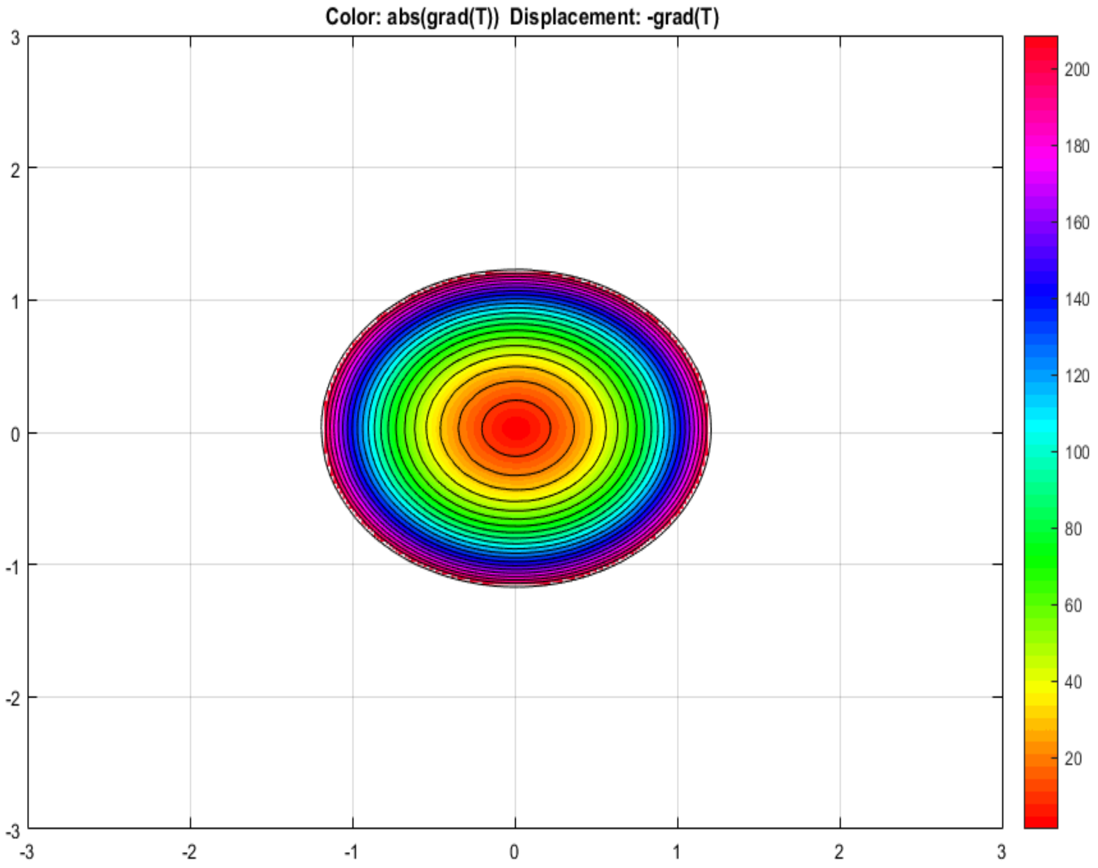


Figure D13 Temperature distribution for the Peeled at 40℃

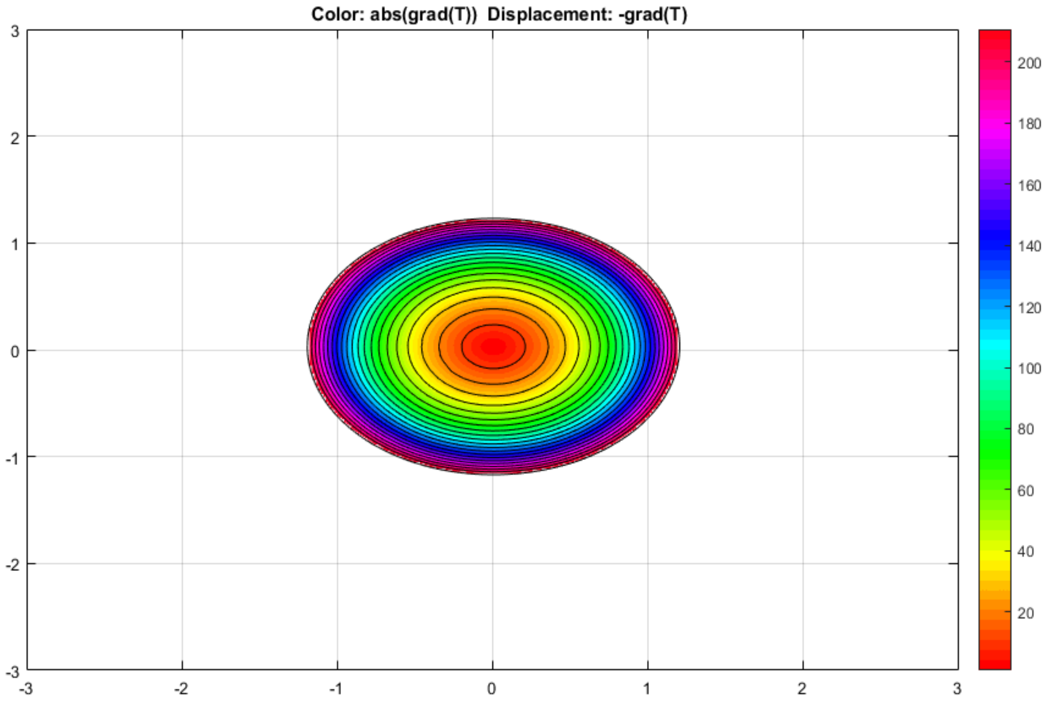


Figure D14 Temperature distribution for the unpeeled at 40℃

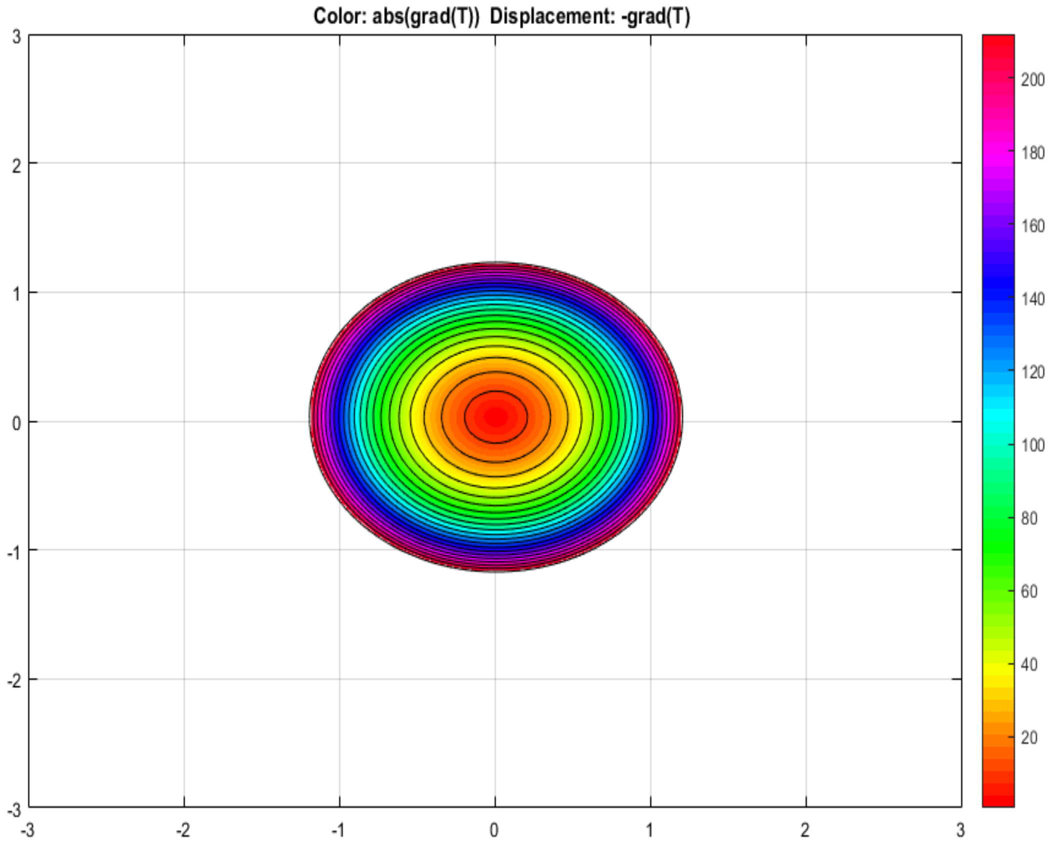


Figure D15 Temperature distribution for the unblanched at 50℃

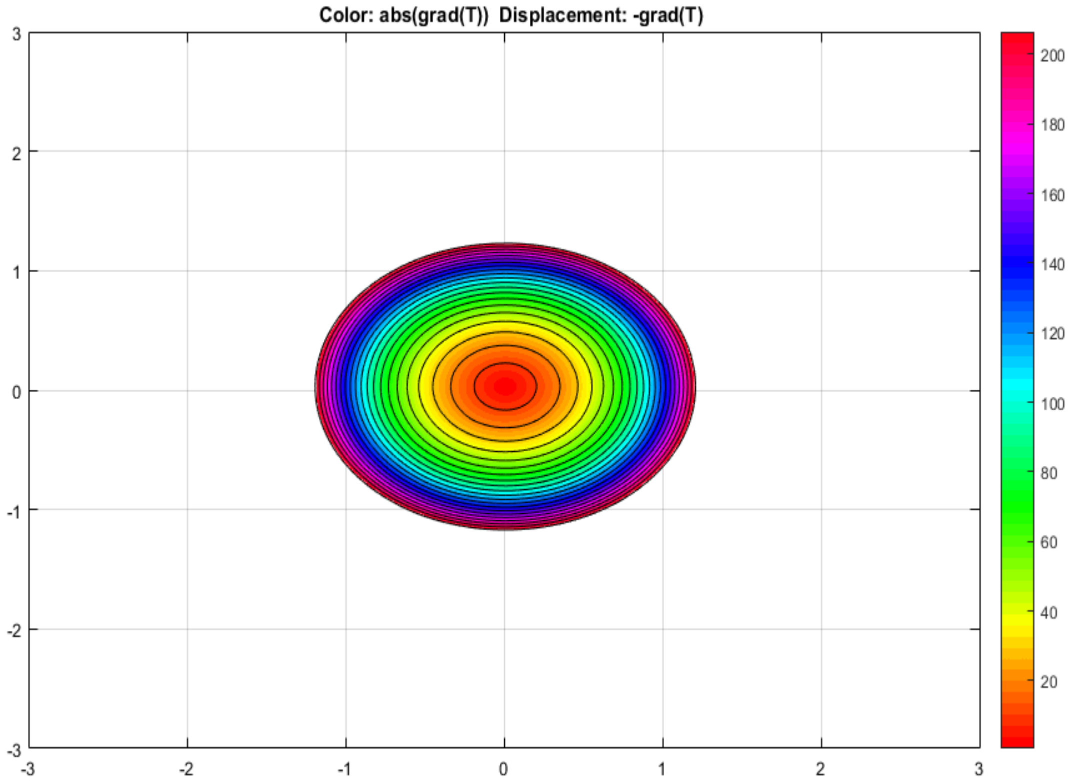


Figure D16 Temperature distribution for the Blanched at 50℃

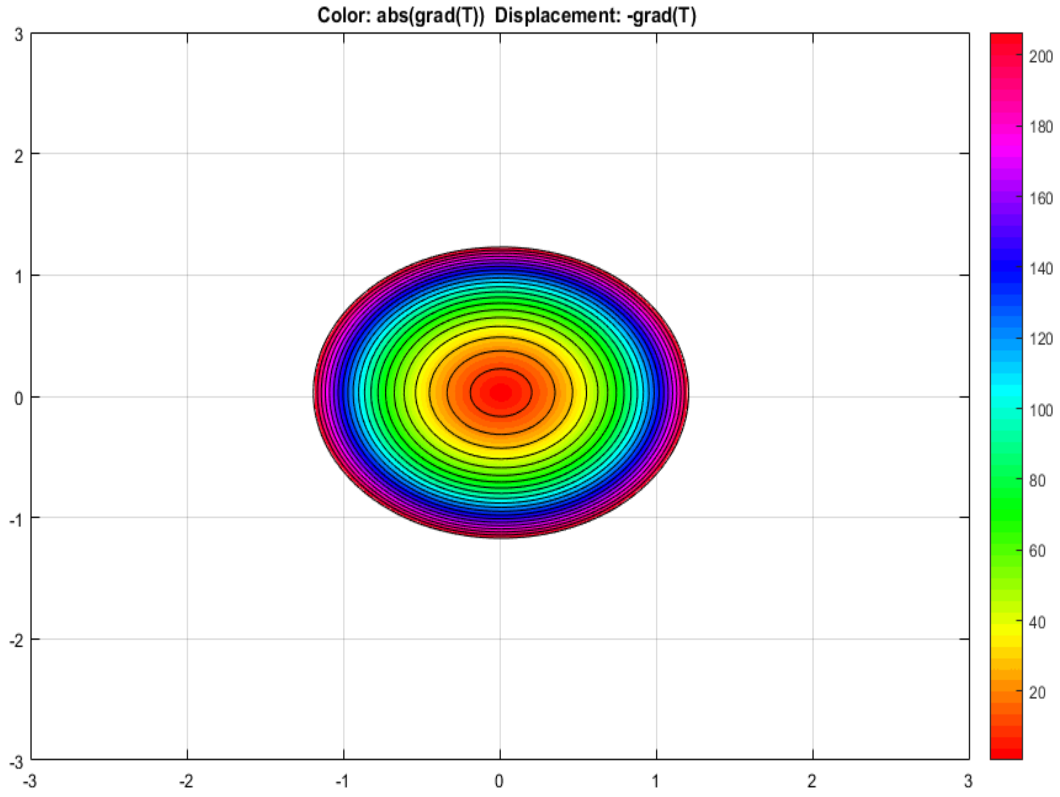


Figure D17 Temperature distribution for the Peeled at 50℃

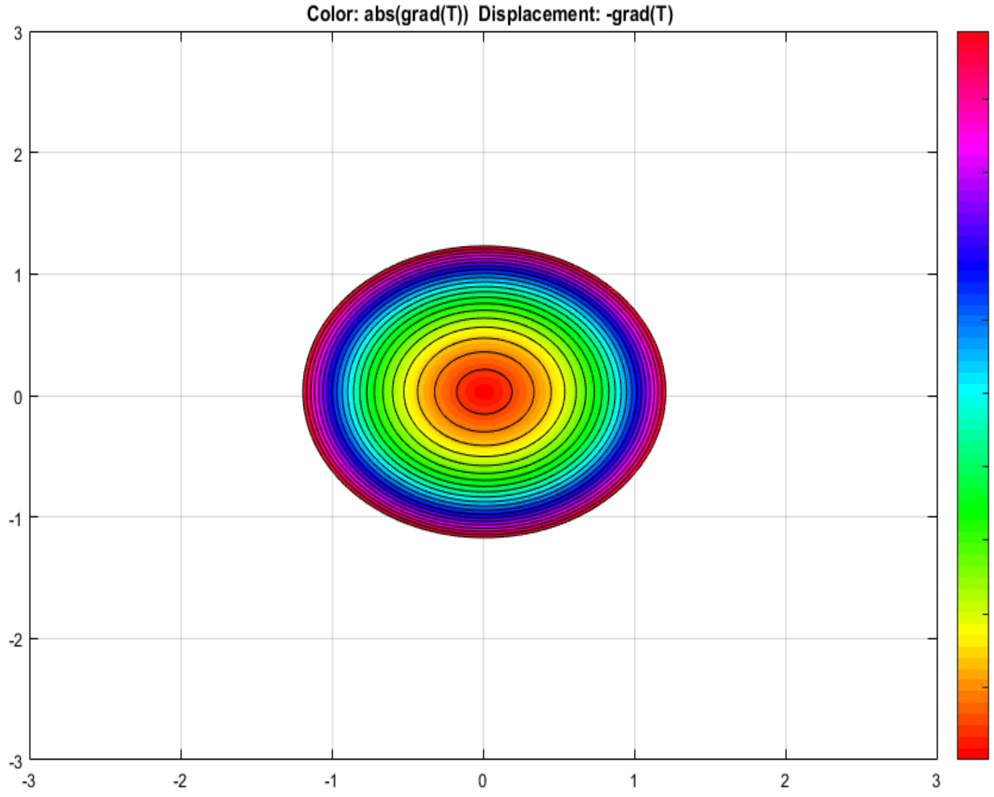
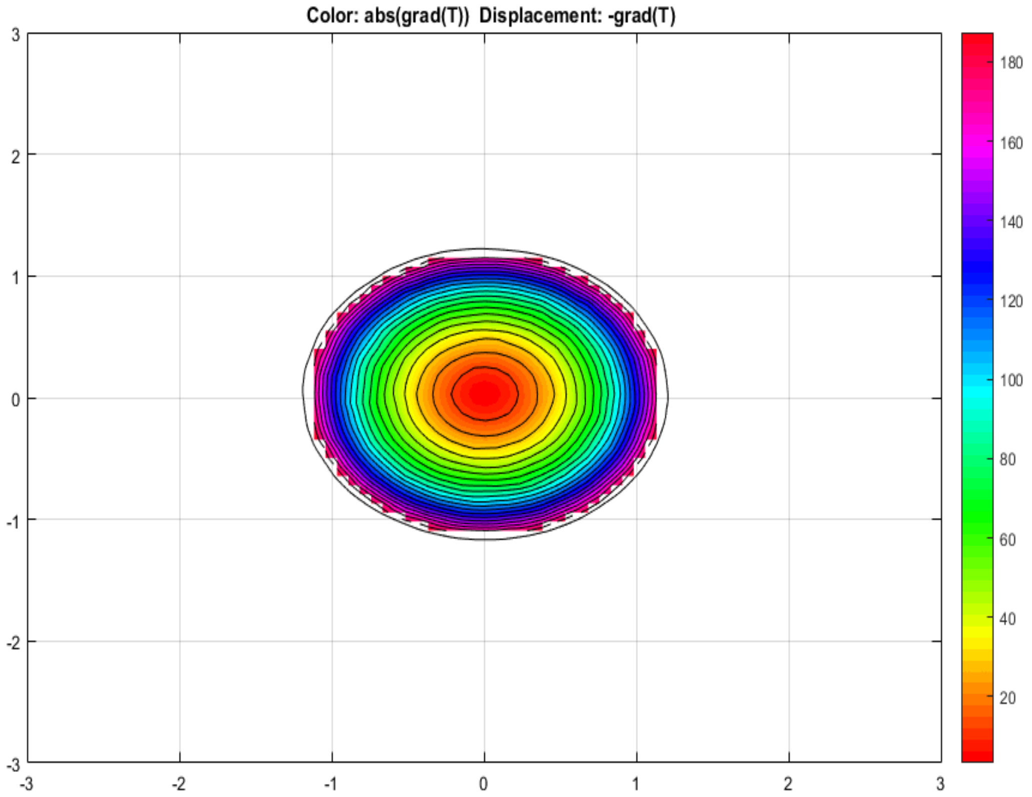


Figure D18 Temperature distribution for the unpeeled at 50℃



FigureD19 Temperature distribution for the unblanched at 60℃

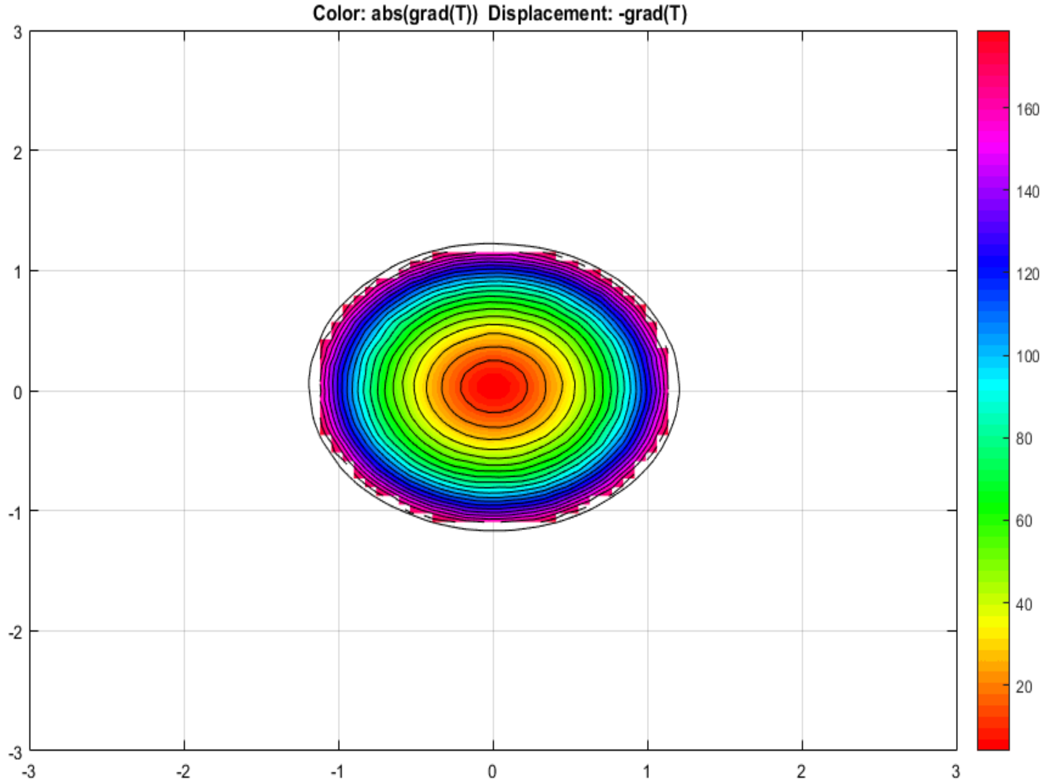


Figure D20 Temperature distribution for the blanched at 60℃

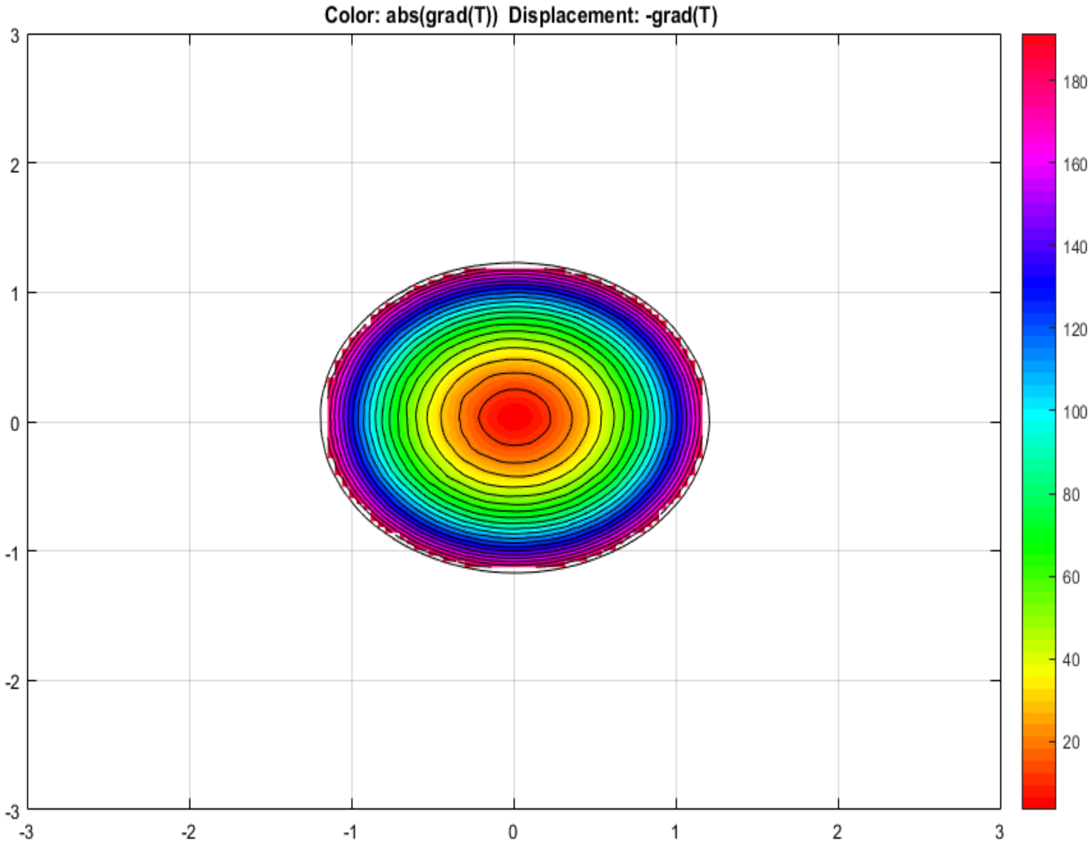


Figure D21 Temperature distribution for the Peeled at 60℃

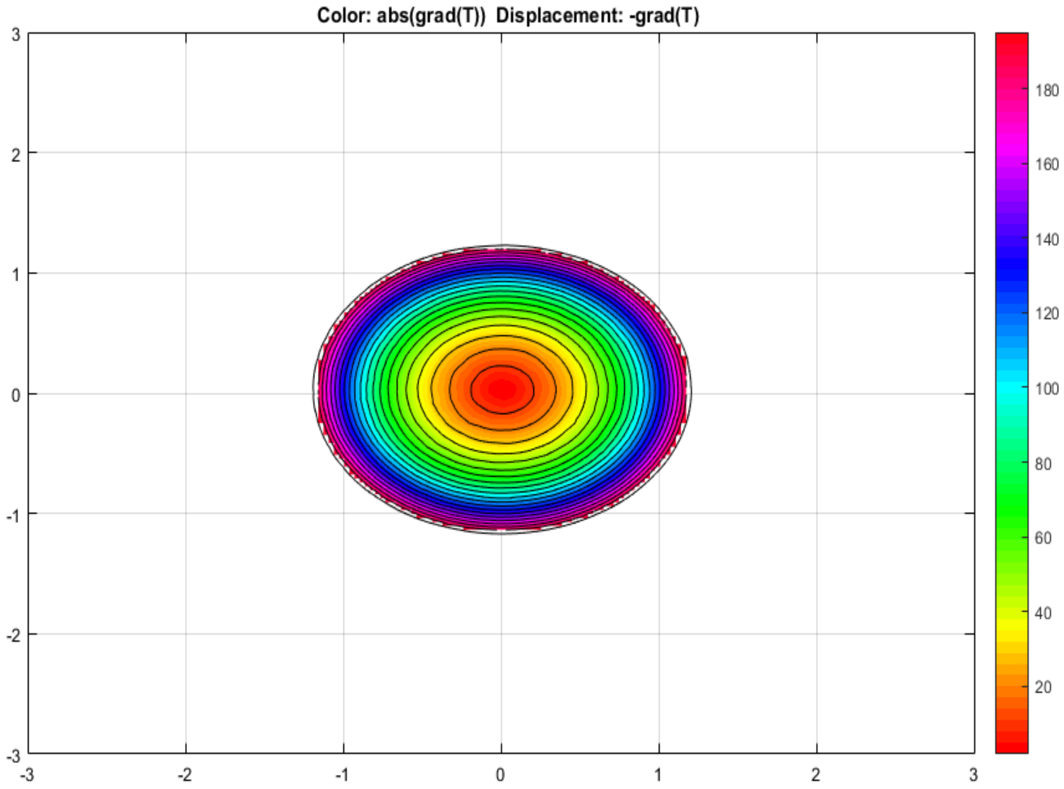
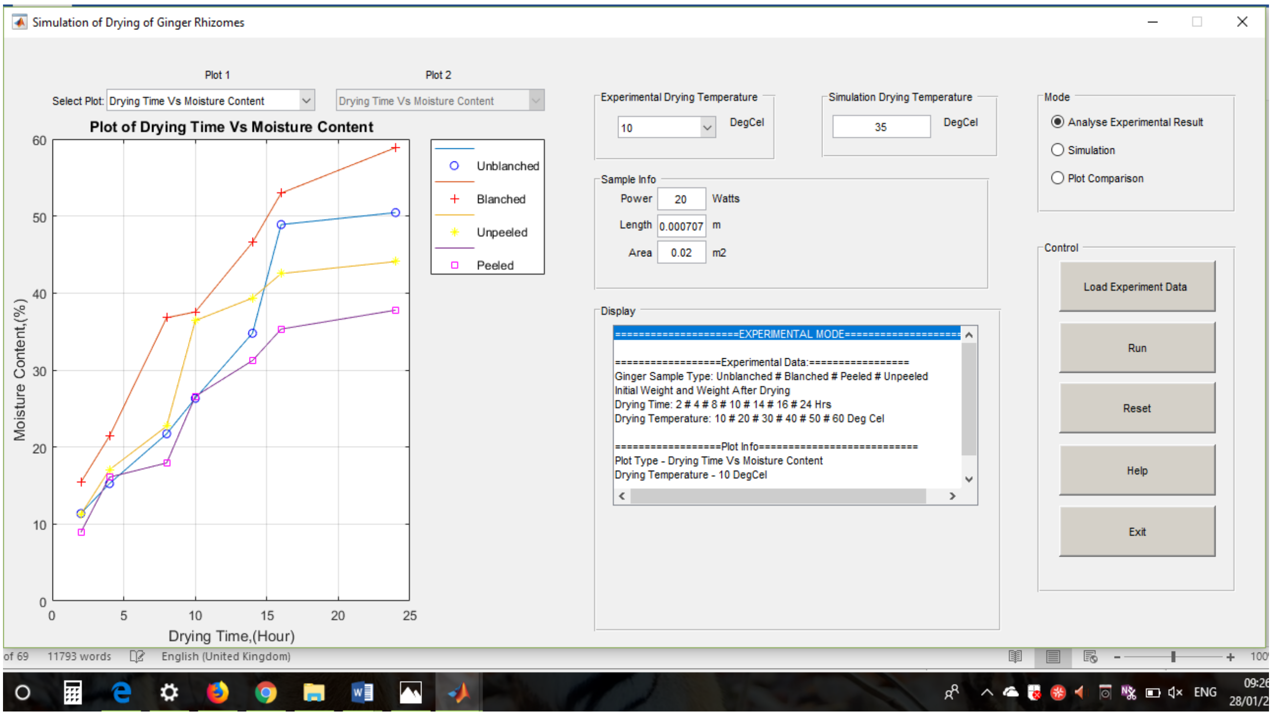


Figure D22 Temperature distribution for the unpeeled at 60℃

APPENDIX E

Screen shots of the various simulations performed for the ginger rhizomes



Select Plot: Drying Time Vs Moisture Content

Drying Time Vs Moisture Content

Experimental Drying Temperature: 10 DegCel

Simulation Drying Temperature: 35 DegCel

Mode:
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

Sample Info:
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

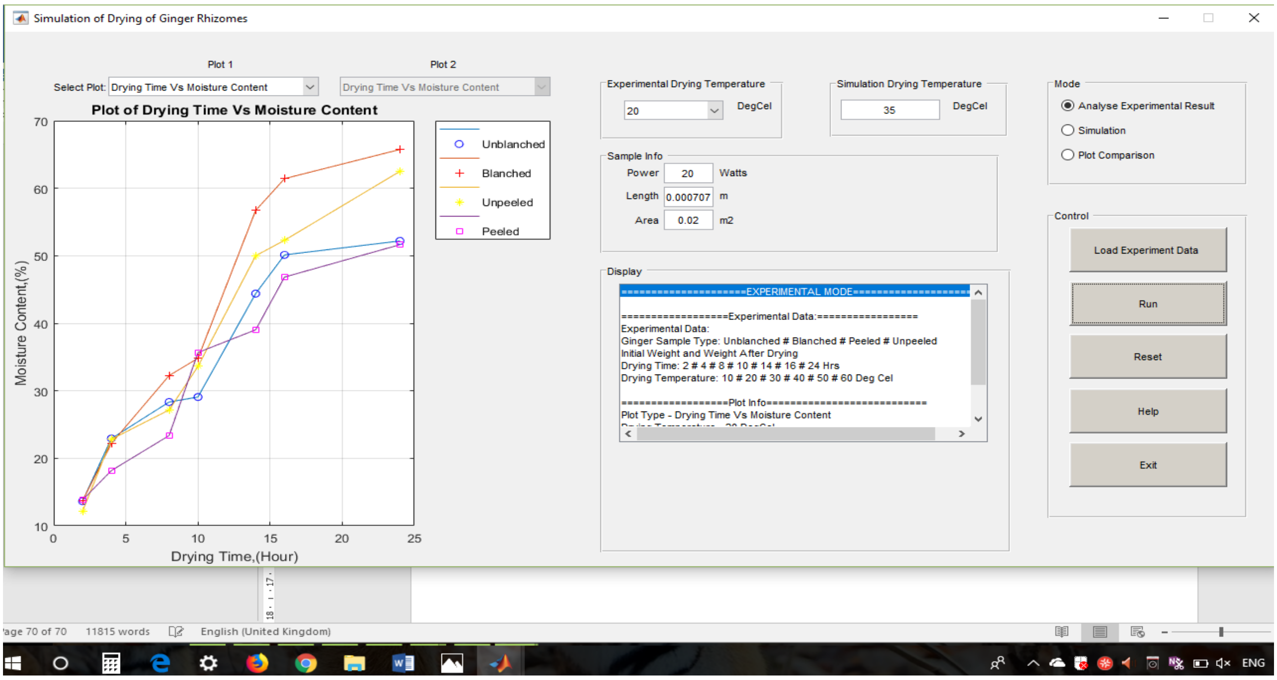
Display

```
=====================EXPERIMENTAL MODE====================

==================Experimental Data:=================
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - Drying Time Vs Moisture Content
Drying Temperature - 10 DegCel
```

Fig E1. Plot of Drying Time vs. Moisture Content for 10℃



Select Plot: Drying Time Vs Moisture Content

Experimental Drying Temperature: 20 DegCel

Simulation Drying Temperature: 35 DegCel

Mode:
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

Sample Info:
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

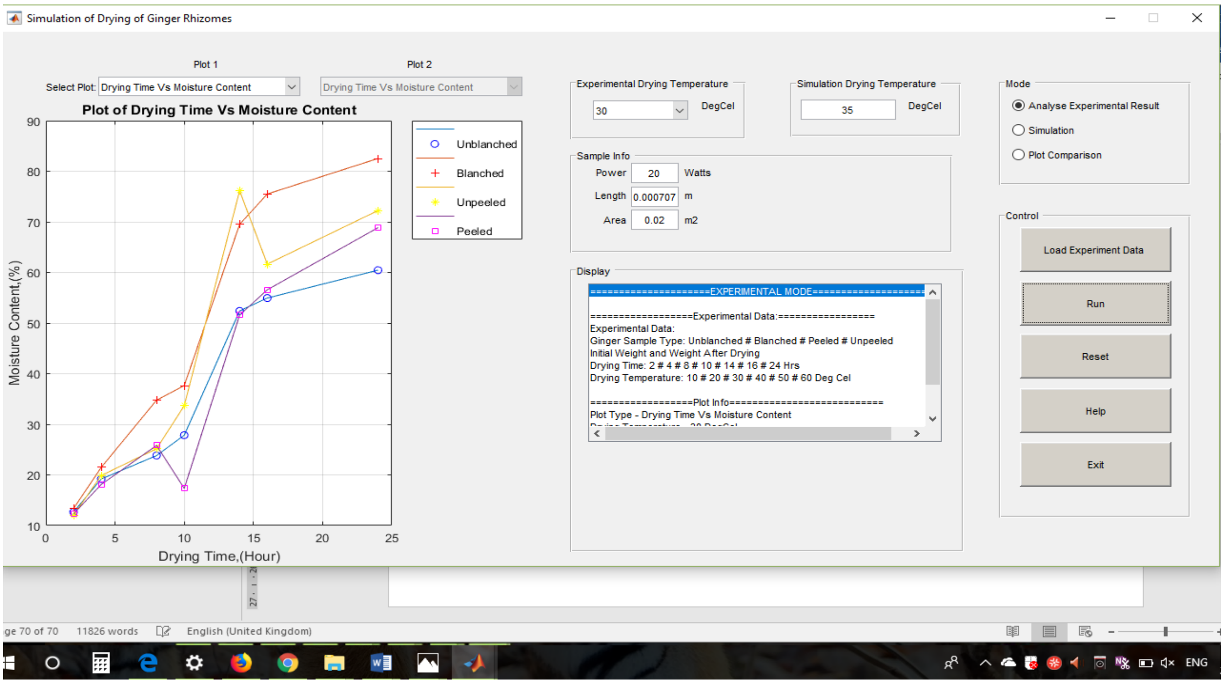
Display:

```
=====================EXPERIMENTAL MODE=====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info=============================
Plot Type - Drying Time Vs Moisture Content
```

Fig E2. Plot of Drying Time vs. Moisture Content for 20℃



Select Plot: Drying Time Vs Moisture Content

Experimental Drying Temperature: 30 DegCel

Simulation Drying Temperature: 35 DegCel

Mode:
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

Sample Info:
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

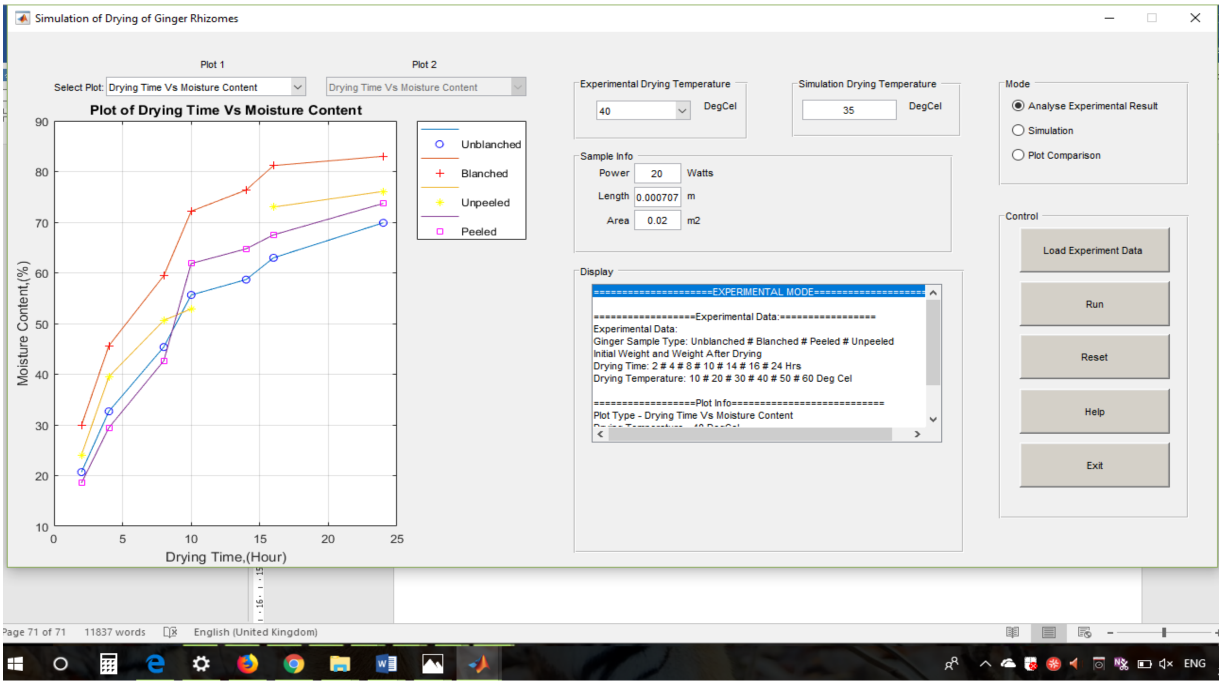
Display:

```
=====================EXPERIMENTAL MODE=====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info=============================
Plot Type - Drying Time Vs Moisture Content
```

Fig E3. Plot of Drying Time vs. Moisture Content for 30℃



Experimental Drying Temperature: 40 DegCel

Simulation Drying Temperature: 35 DegCel

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

Sample Info
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

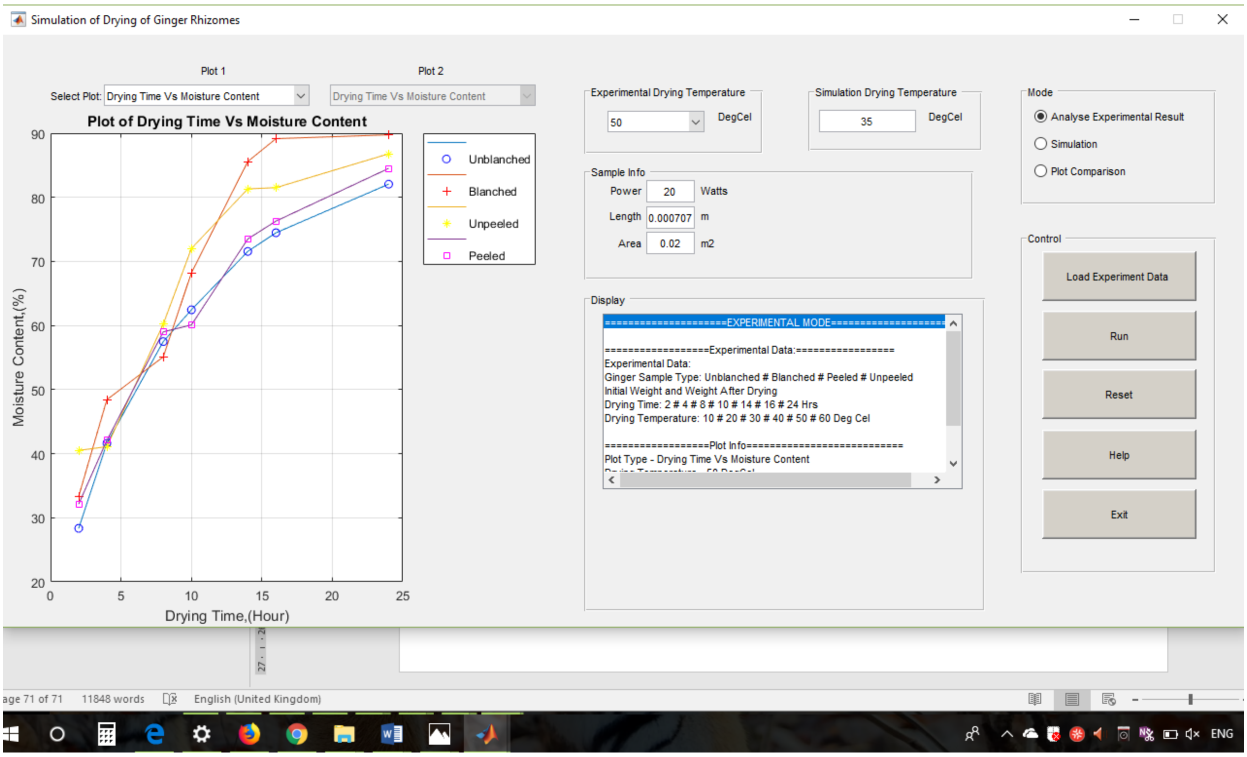
Display

```
====================EXPERIMENTAL MODE====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - Drying Time Vs Moisture Content
```

Fig E4. Plot of Drying Time vs. Moisture Content for 40℃



Experimental Drying Temperature: 50 DegCel

Simulation Drying Temperature: 35 DegCel

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

Sample Info
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

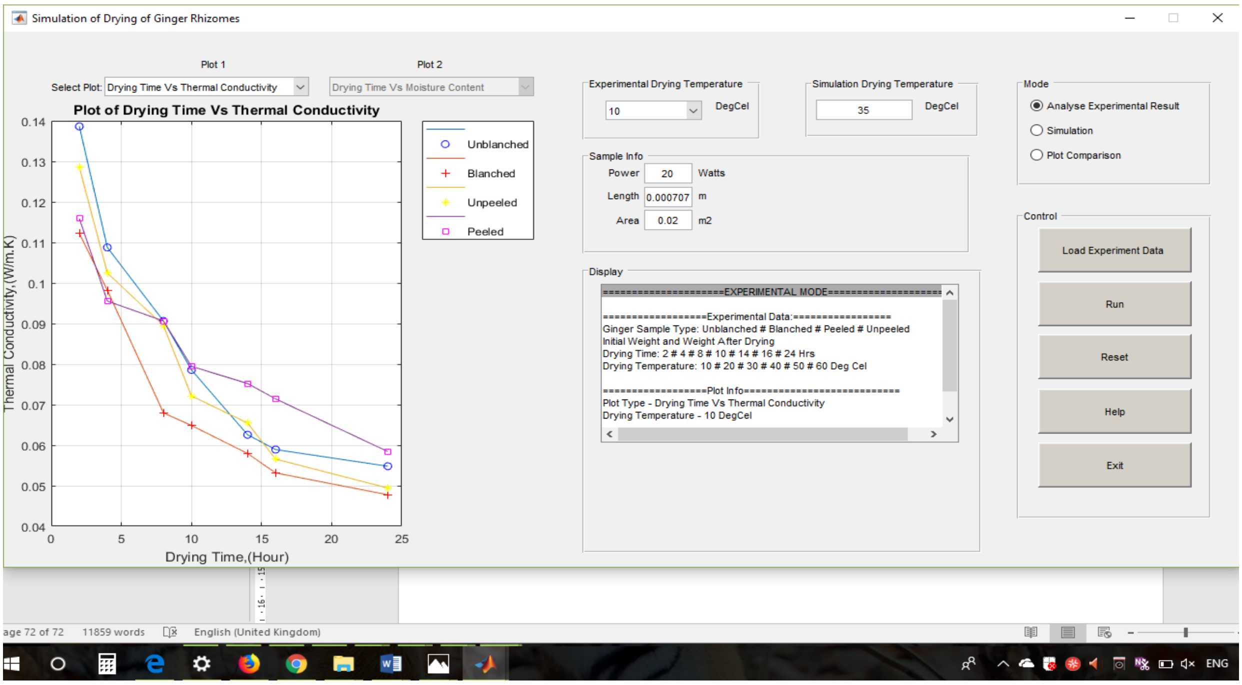
Display

```
====================EXPERIMENTAL MODE====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - Drying Time Vs Moisture Content
```

Fig E5. Plot of Drying Time vs. Moisture Content for 50℃



Select Plot: Drying Time Vs Thermal Conductivity

Experimental Drying Temperature: 10 DegCel

Simulation Drying Temperature: 35 DegCel

Sample Info
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

Mode
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

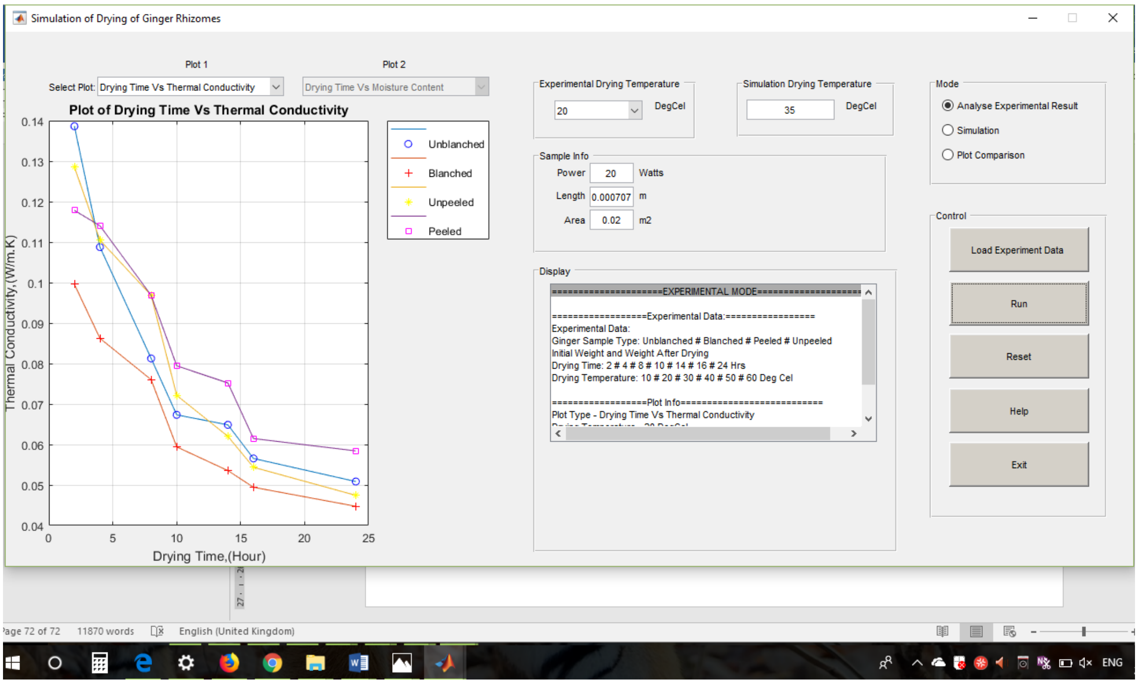
Display

```
====================EXPERIMENTAL MODE====================

==================Experimental Data:==================
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - Drying Time Vs Thermal Conductivity
Drying Temperature - 10 DegCel
```

Fig E6. Plot of Drying Time vs. Thermal Conductivity for 10℃



Select Plot: Drying Time Vs Thermal Conductivity

Experimental Drying Temperature: 20 DegCel

Simulation Drying Temperature: 35 DegCel

Sample Info
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

Mode
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

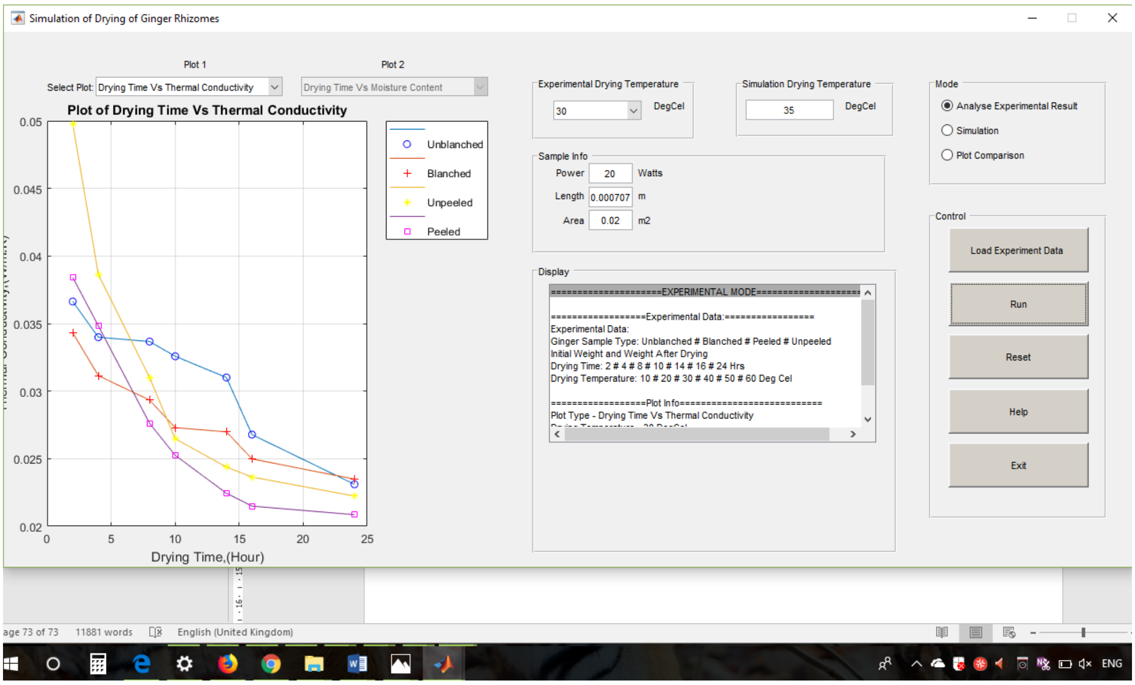
Display

```
====================EXPERIMENTAL MODE====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - Drying Time Vs Thermal Conductivity
Drying Temperature - 20 DegCel
```

Fig E7. Plot of Drying Time vs. Thermal Conductivity for 20℃



Select Plot: Drying Time Vs Thermal Conductivity

Drying Time Vs Moisture Content

Experimental Drying Temperature: 30 DegCel

Simulation Drying Temperature: 35 DegCel

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

Sample Info
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

Display

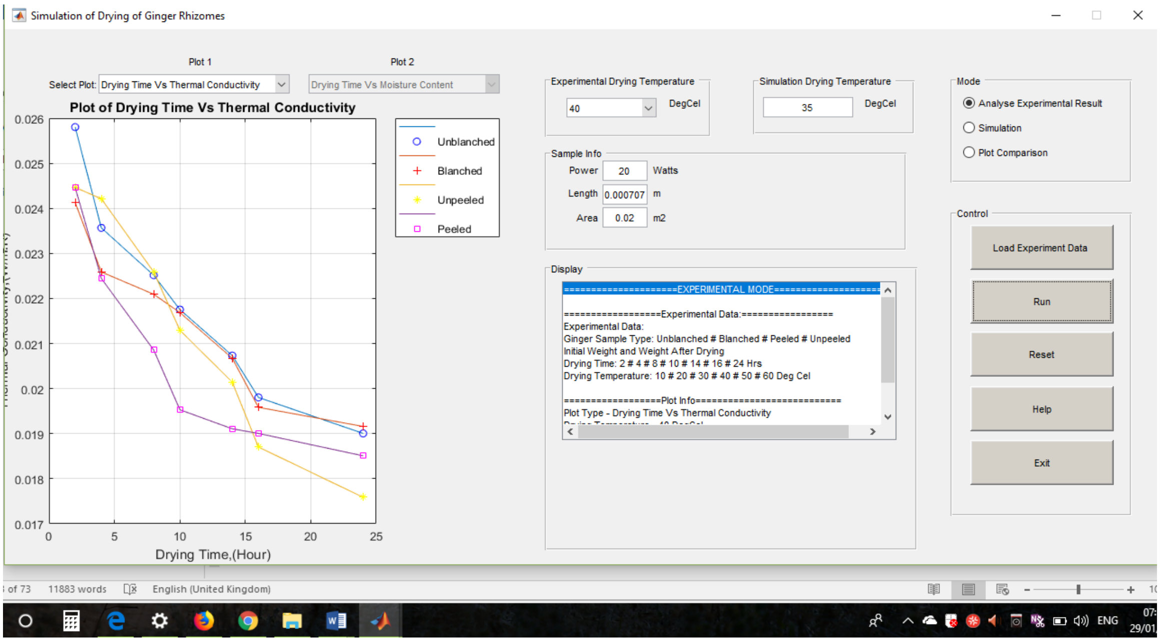
```
====================EXPERIMENTAL MODE===================

=================Experimental Data:=================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

=================Plot Info===========================
Plot Type - Drying Time Vs Thermal Conductivity
```

age 73 of 73 11881 words English (United Kingdom)

Fig E8. Plot of Drying Time vs. Thermal Conductivity for 30°C



Select Plot: Drying Time Vs Thermal Conductivity

Drying Time Vs Moisture Content

Experimental Drying Temperature: 40 DegCel

Simulation Drying Temperature: 35 DegCel

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

Sample Info
Power 20 Watts
Length 0.000707 m
Area 0.02 m2

Display

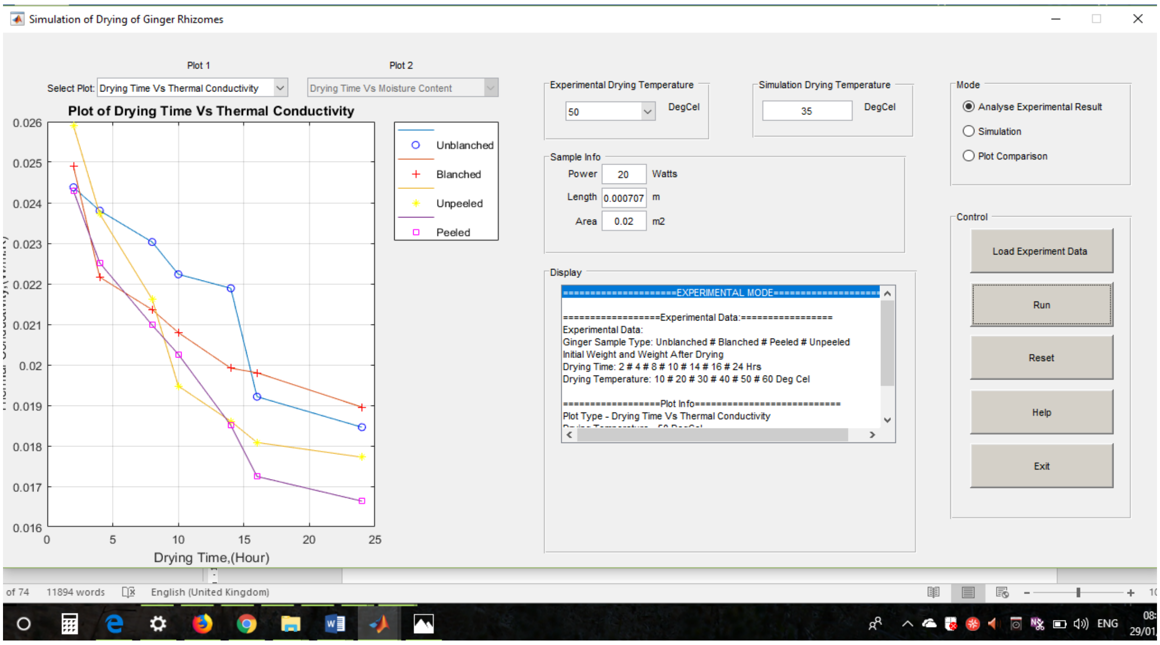
```
====================EXPERIMENTAL MODE===================

=================Experimental Data:=================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

=================Plot Info===========================
Plot Type - Drying Time Vs Thermal Conductivity
```

of 73 11883 words English (United Kingdom)

Fig E9. Plot of Drying Time vs. Thermal Conductivity for 40°C



Plot 1
Select Plot: Drying Time Vs Thermal Conductivity
Plot 2
Drying Time Vs Moisture Content

Experimental Drying Temperature: 50 DegCel
Simulation Drying Temperature: 35 DegCel

Mode
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

Sample Info
Power: 20 Watts
Length: 0.000707 m
Area: 0.02 m2

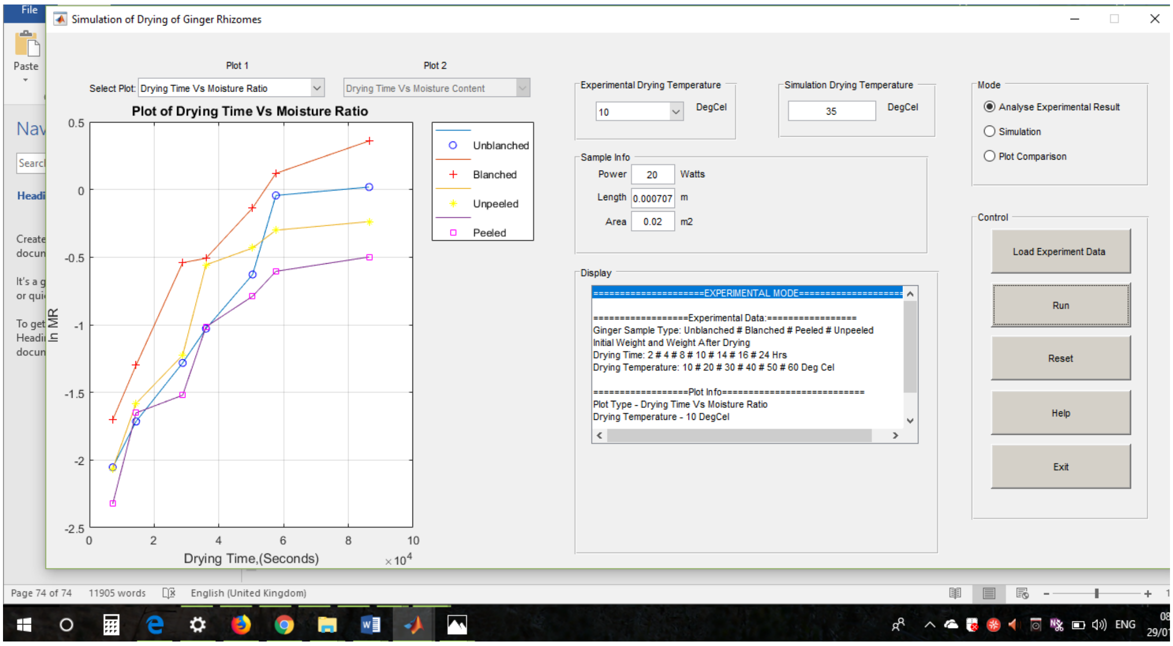
Display

```
====================EXPERIMENTAL MODE====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info=============================
Plot Type - Drying Time Vs Thermal Conductivity
```

Fig E10. Plot of Drying Time vs. Thermal Conductivity for 50℃



Plot 1
Select Plot: Drying Time Vs Moisture Ratio
Plot 2
Drying Time Vs Moisture Content

Experimental Drying Temperature: 10 DegCel
Simulation Drying Temperature: 35 DegCel

Mode
● Analyse Experimental Result
○ Simulation
○ Plot Comparison

Sample Info
Power: 20 Watts
Length: 0.000707 m
Area: 0.02 m2

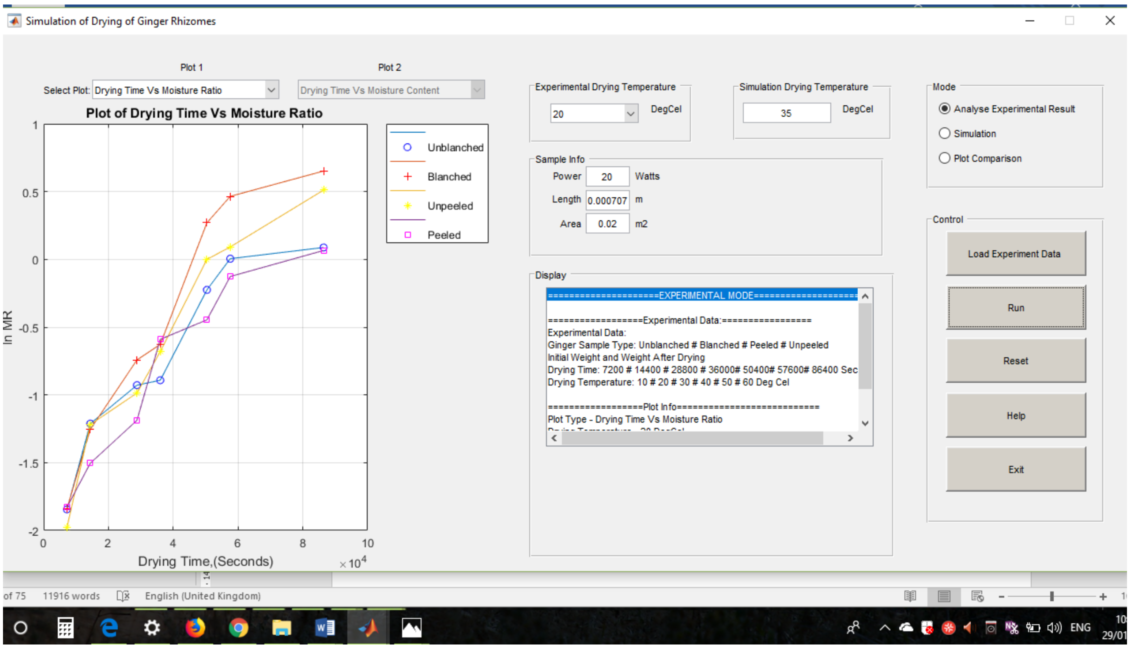
Display

```
====================EXPERIMENTAL MODE====================

==================Experimental Data:==================
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info=============================
Plot Type - Drying Time Vs Moisture Ratio
Drying Temperature - 10 DegCel
```

Fig E11. Plot of Drying Time vs. Moisture Ratio for 10℃



Experimental Drying Temperature: 20 DegCel

Simulation Drying Temperature: 35 DegCel

Sample Info

Power 20 Watts

Length 0.000707 m

Area 0.02 m2

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

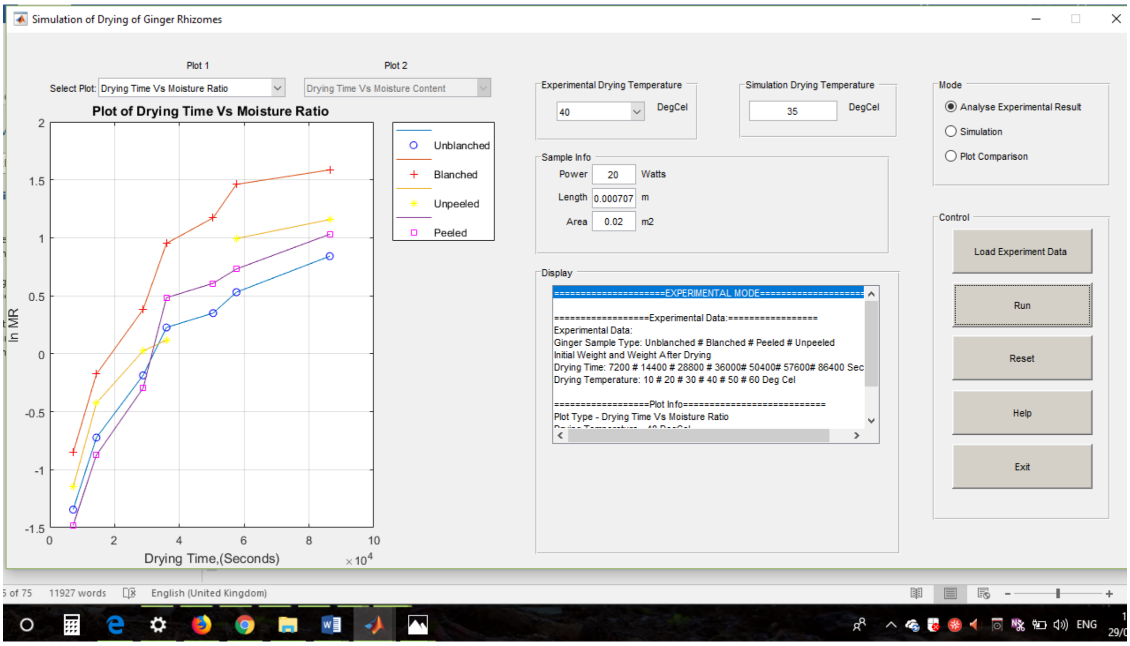
Display

```
=====================EXPERIMENTAL MODE=====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 7200 # 14400 # 28800 # 36000# 50400# 57600# 86400 Sec
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info==============================
Plot Type - Drying Time Vs Moisture Ratio
```

Fig E12. Plot of Drying Time vs. Moisture Ratio for 20℃



Experimental Drying Temperature: 40 DegCel

Simulation Drying Temperature: 35 DegCel

Sample Info

Power 20 Watts

Length 0.000707 m

Area 0.02 m2

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

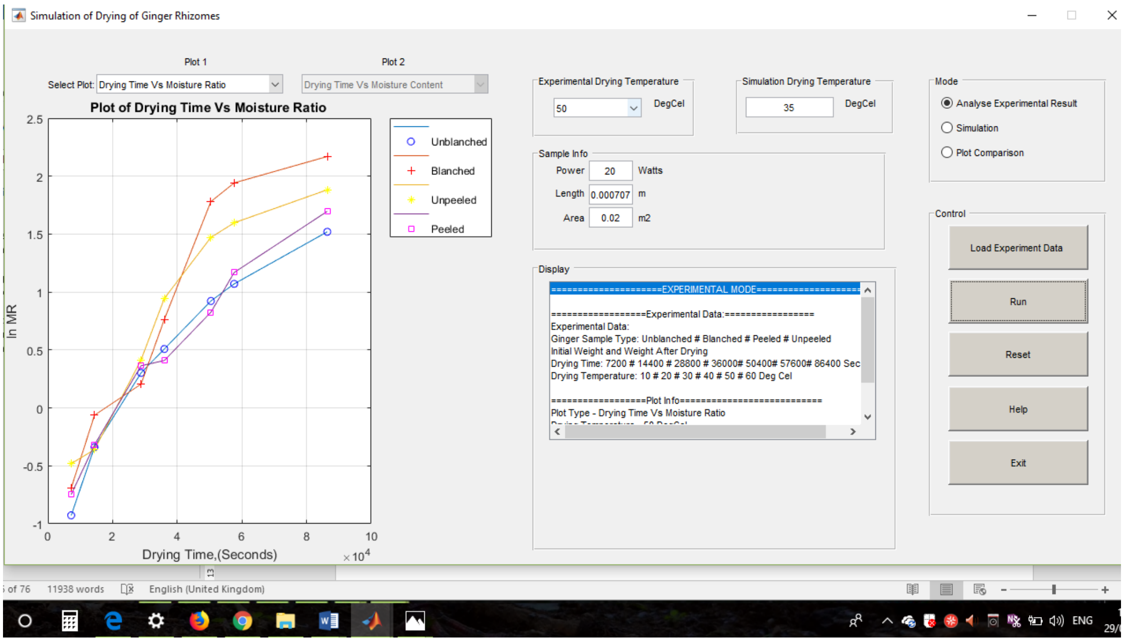
Display

```
=====================EXPERIMENTAL MODE=====================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 7200 # 14400 # 28800 # 36000# 50400# 57600# 86400 Sec
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info==============================
Plot Type - Drying Time Vs Moisture Ratio
```

Fig E13. Plot of Drying Time vs. Moisture Ratio for 40℃



Select Plot: Drying Time Vs Moisture Ratio

Drying Time Vs Moisture Content

Experimental Drying Temperature: 50 DegCel

Simulation Drying Temperature: 35 DegCel

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

Sample Info

Power: 20 Watts

Length: 0.000707 m

Area: 0.02 m2

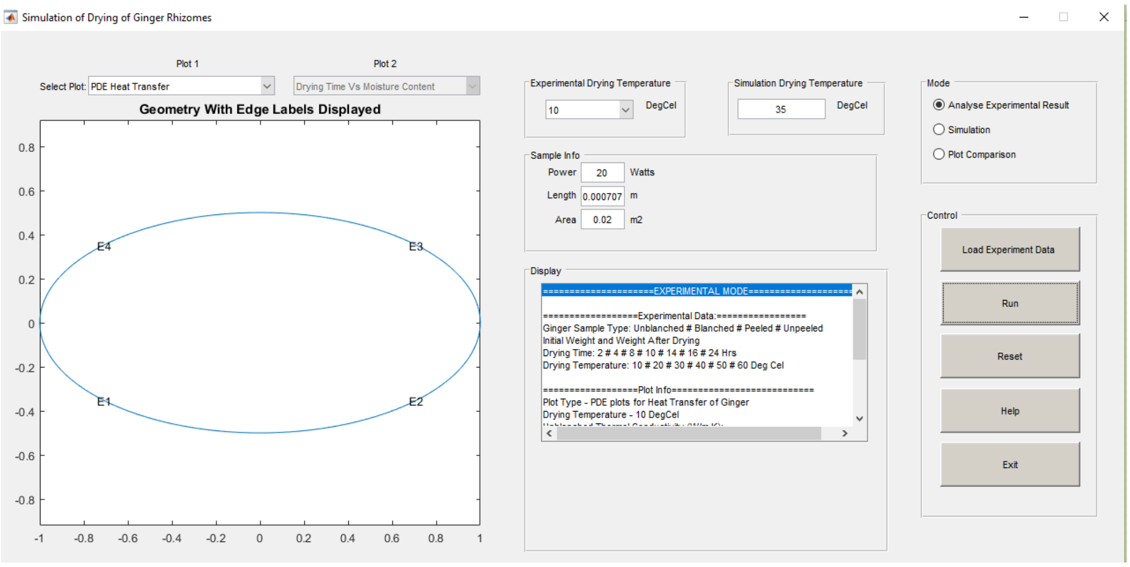
Display

```
====================EXPERIMENTAL MODE===================

==================Experimental Data:==================
Experimental Data:
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 7200 # 14400 # 28800 # 36000# 50400# 57600# 86400 Sec
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - Drying Time Vs Moisture Ratio
```

Fig E14. Plot of Drying Time vs. Moisture Ratio for 50℃



Select Plot: PDE Heat Transfer

Drying Time Vs Moisture Content

Experimental Drying Temperature: 10 DegCel

Simulation Drying Temperature: 35 DegCel

Mode: ● Analyse Experimental Result ○ Simulation ○ Plot Comparison

Sample Info

Power: 20 Watts

Length: 0.000707 m

Area: 0.02 m2

Display

```
====================EXPERIMENTAL MODE===================

==================Experimental Data:==================
Ginger Sample Type: Unblanched # Blanched # Peeled # Unpeeled
Initial Weight and Weight After Drying
Drying Time: 2 # 4 # 8 # 10 # 14 # 16 # 24 Hrs
Drying Temperature: 10 # 20 # 30 # 40 # 50 # 60 Deg Cel

==================Plot Info============================
Plot Type - PDE plots for Heat Transfer of Ginger
Drying Temperature - 10 DegCel
```

Fig E15. Geometry with Edge labels displayed

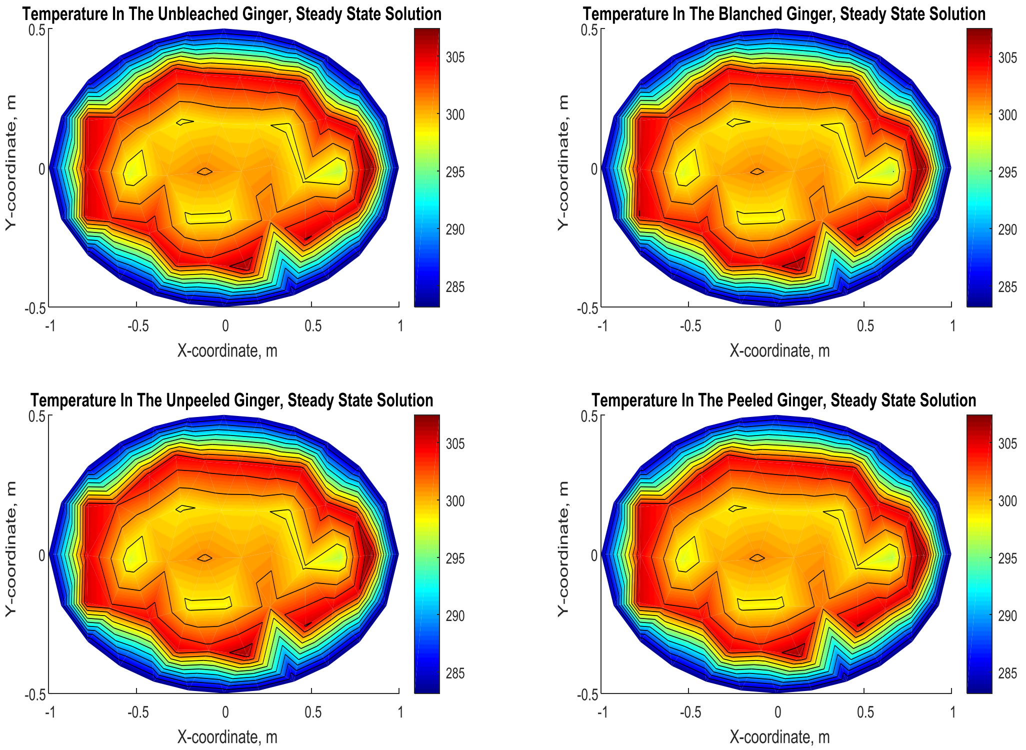


Fig E16. PDE Heat transfer for the Ginger samples at 10℃

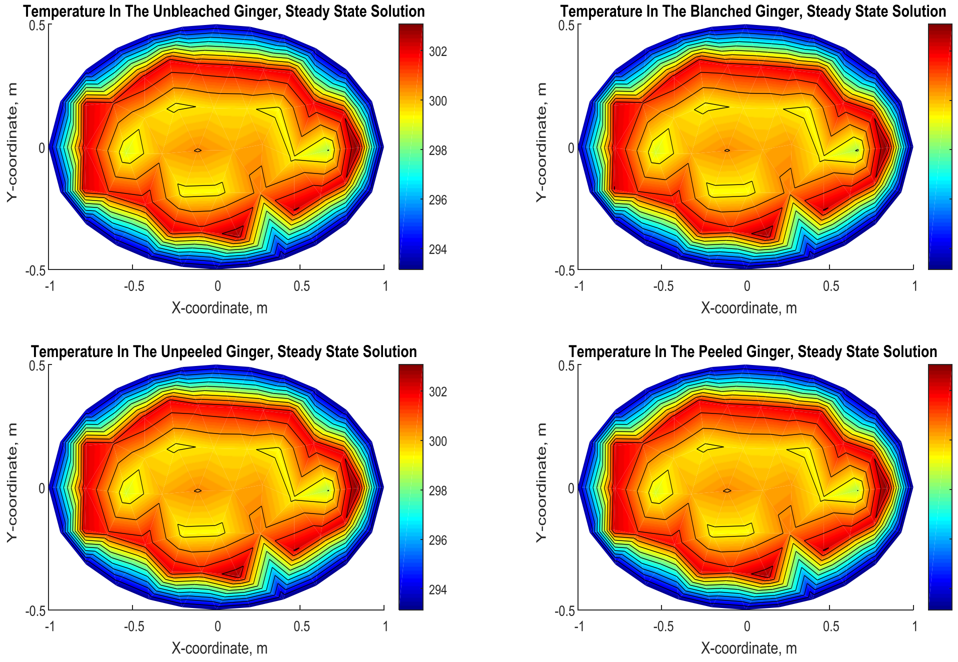


Fig E17. PDE Heat transfer for the Ginger samples at 20℃

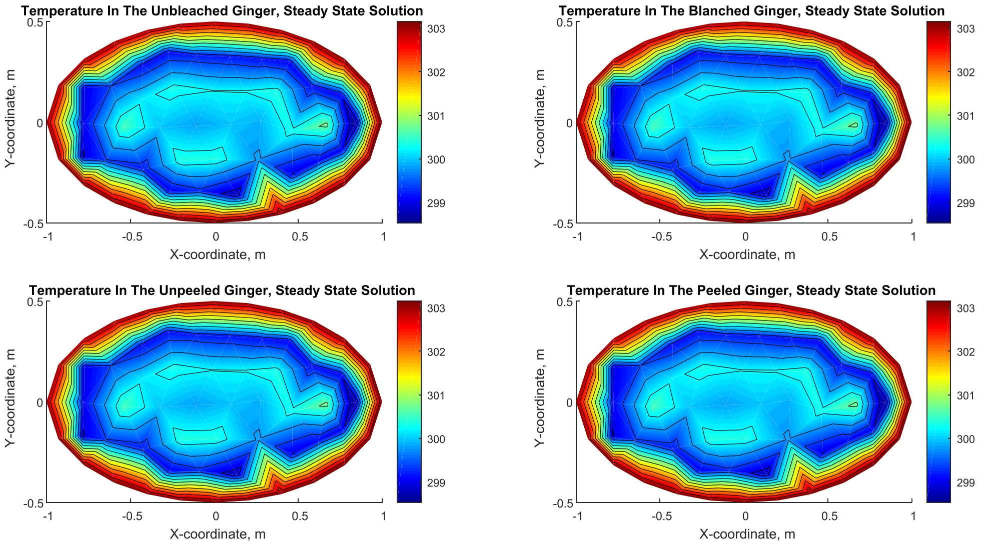


Fig E18. PDE Heat transfer for the Ginger samples at 30℃

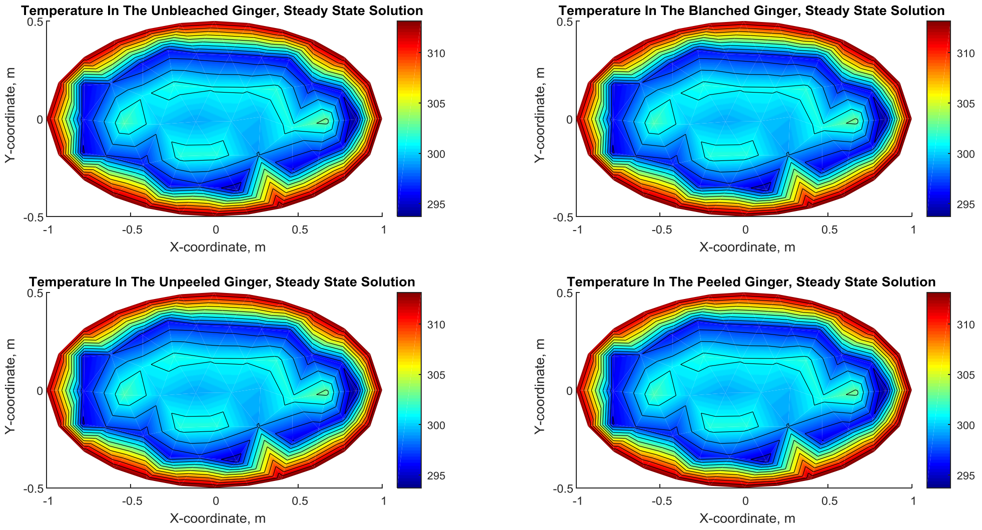


Fig E19. PDE Heat transfer for the Ginger samples at 40℃

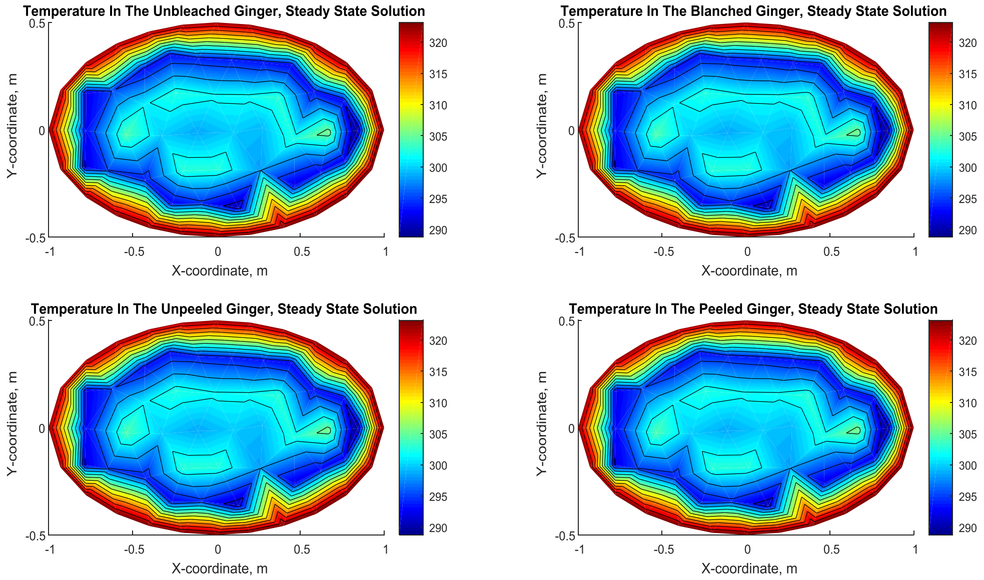


Fig E20. PDE Heat transfer for the Ginger samples at 50℃

APPENDIX F

RESEARCH PICTURES FROM HAWKE SCHOOL OF ENGINEERING, UNIVERSITY OF GREENWICH, UNITED KINGDOM

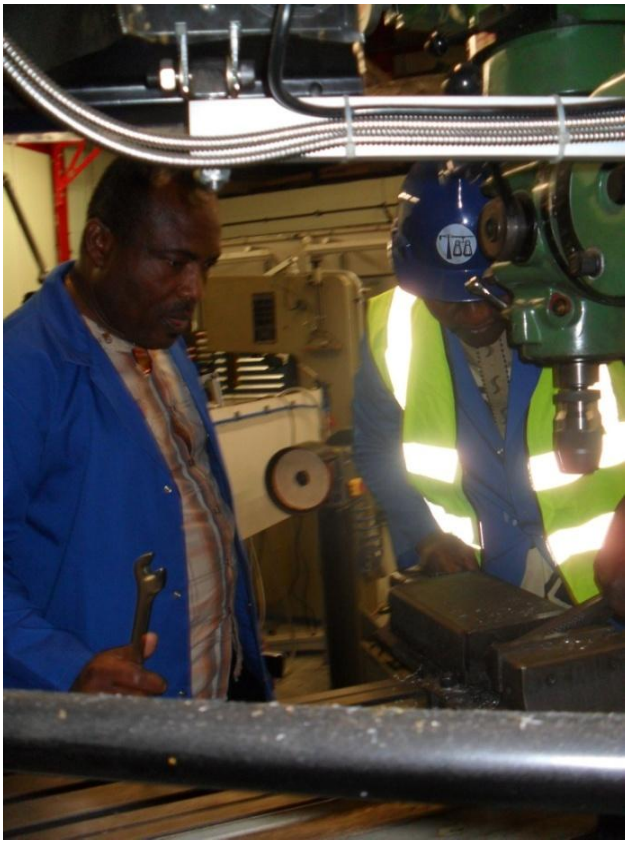

PLEASE
DO NOT TURN OFF
EXPERIMENT
IN
PROGRESS
ARS-0680
Temperature & Humidity Chamber


MANTIS
analysistech

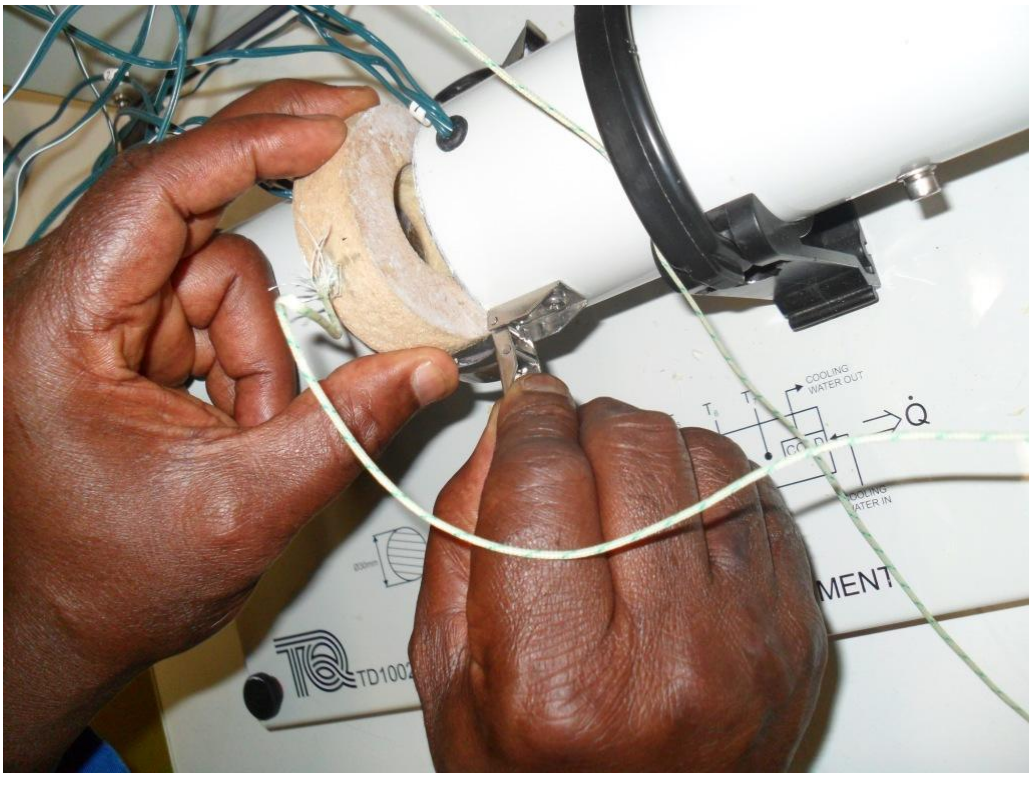

Do Not
Experiment
IN
PROGRESS
2012
ARB-0680
CAUTION


RTRITE
18-T-10
METAL
AND
PLASTIC

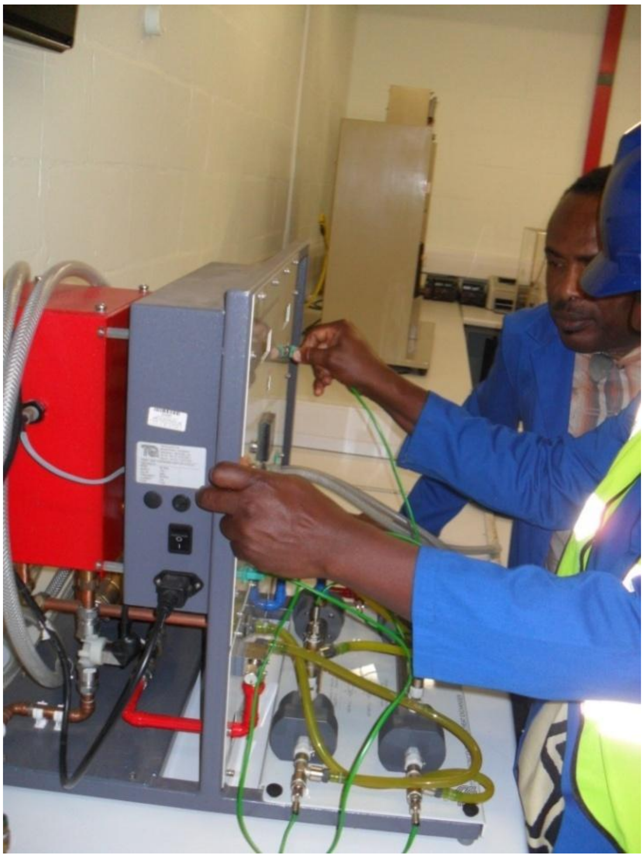

TBB
THINK SAFETY
ACT SAFELY



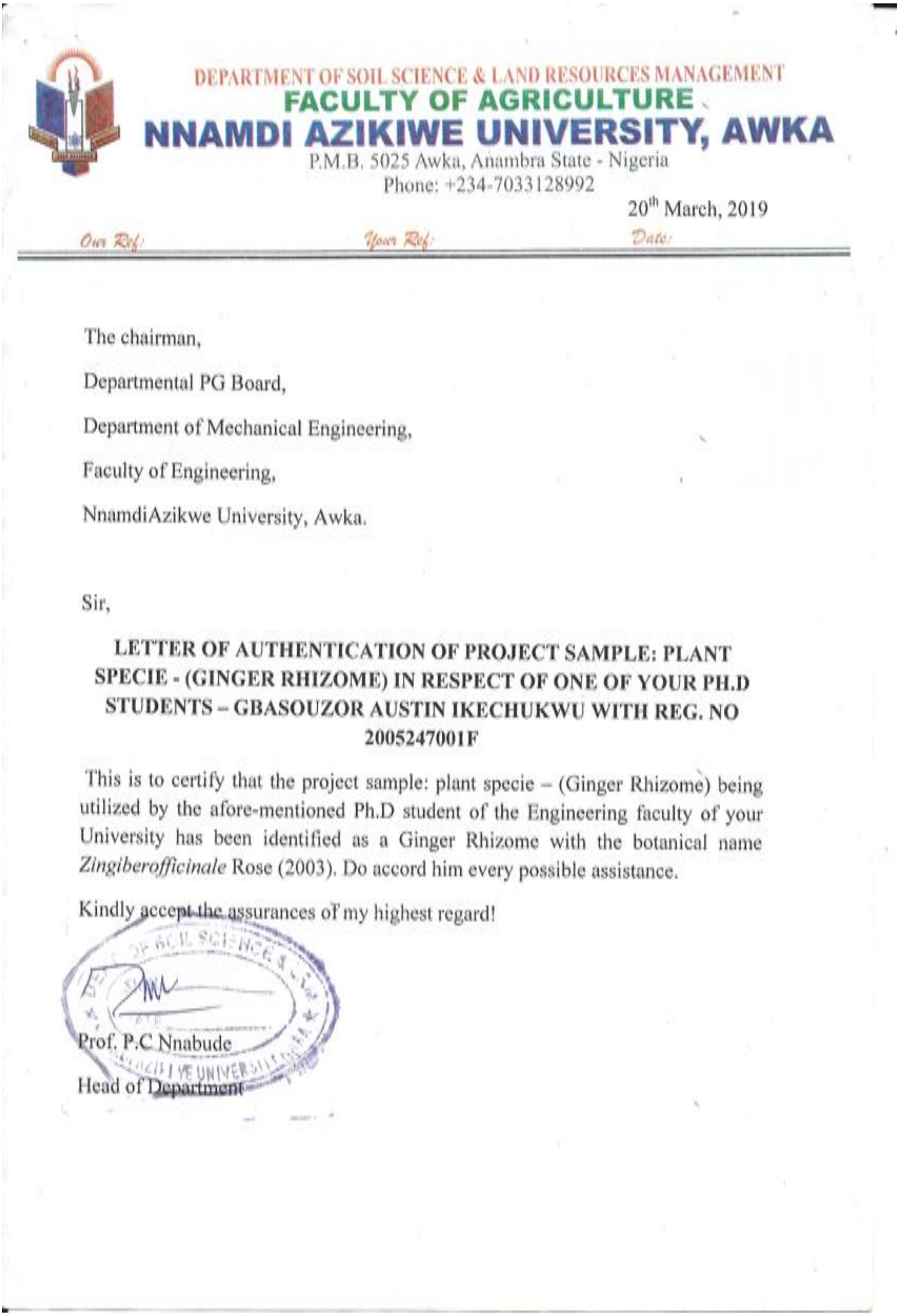

TD1002 HEAT TRANSFER EXPERIMENT BASE UNIT
HEATER


COOLING WATER OUT
$\dot{Q}$
COOLING WATER IN
MENT
TD1002


TARTRIT
18-T-1
From
METAL
AND
PLASTIC
ONLY



APPENDIX G
LETTER OF IDENTIFICATION OF PROJECT SAMPLE



DEPARTMENT OF SOIL SCIENCE & LAND RESOURCES MANAGEMENT
FACULTY OF AGRICULTURE
NNAMDI AZIKIWE UNIVERSITY, AWKA
P.M.B. 5025 Awka, Anambra State - Nigeria
Phone: +234-7033128992

20th March, 2019

Our Ref: Your Ref: Date:

The chairman,
Departmental PG Board,
Department of Mechanical Engineering,
Faculty of Engineering,
NnamdiAzikwe University, Awka.

Sir,

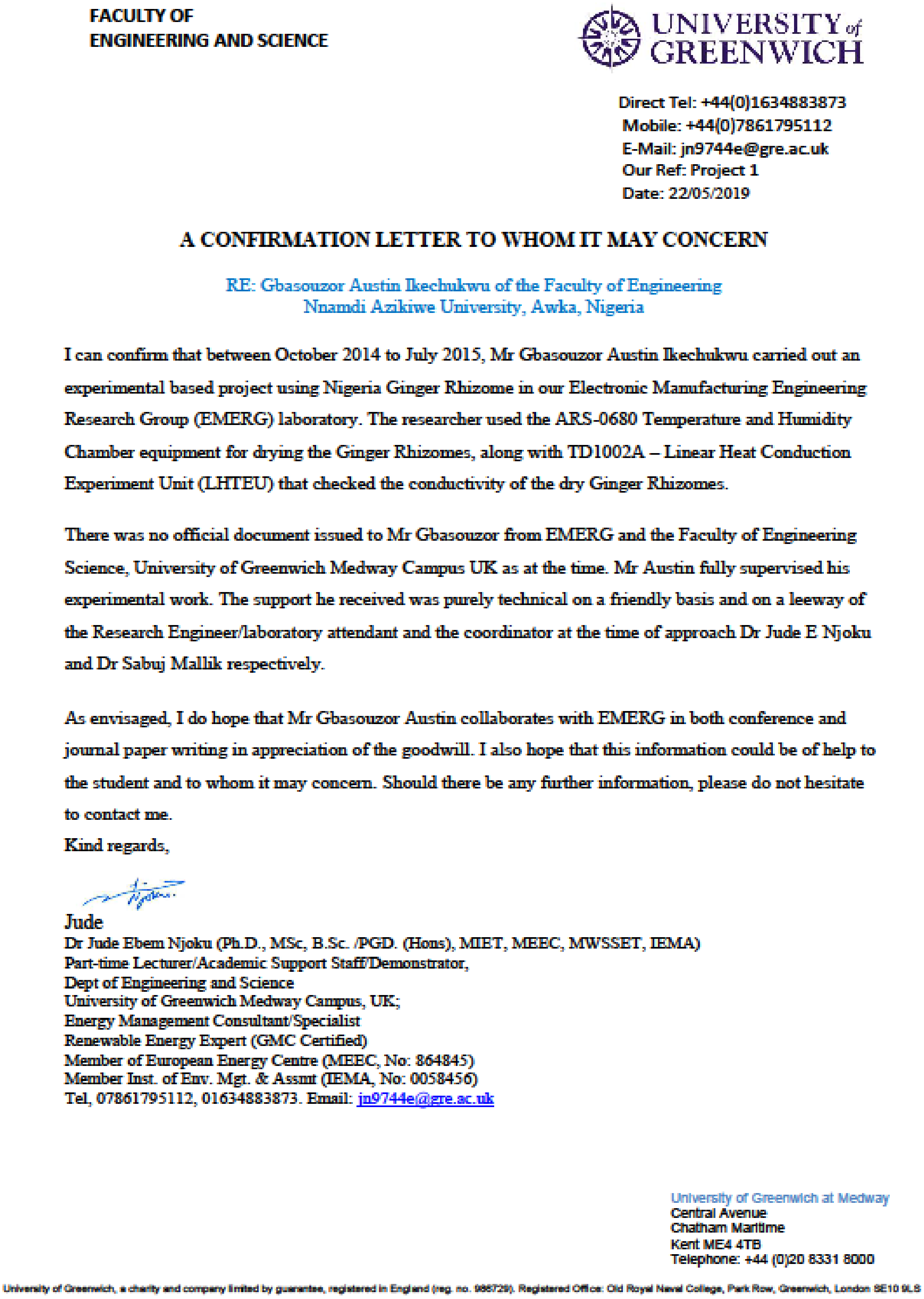
LETTER OF AUTHENTICATION OF PROJECT SAMPLE: PLANT SPECIE - (GINGER RHIZOME) IN RESPECT OF ONE OF YOUR PH.D STUDENTS – GBASOUZOR AUSTIN IKECHUKWU WITH REG. NO 2005247001F

This is to certify that the project sample: plant specie – (Ginger Rhizome) being utilized by the afore-mentioned Ph.D student of the Engineering faculty of your University has been identified as a Ginger Rhizome with the botanical name *Zingiberofficinale* Rose (2003). Do accord him every possible assistance.

Kindly accept the assurances of my highest regard!

Prof. P.C Nnabude
Head of Department

APPENDIX H
COMFIRMATION LETTERS FROM RESEARCH INSTITUTIONS



**FACULTY OF
ENGINEERING AND SCIENCE**

UNIVERSITY of GREENWICH

Direct Tel: +44(0)1634883873
Mobile: +44(0)7861795112
E-Mail: jn9744e@gre.ac.uk
Our Ref: Project 1
Date: 22/05/2019

A CONFIRMATION LETTER TO WHOM IT MAY CONCERN

RE: Gbasouzor Austin Ikechukwu of the Faculty of Engineering
Nnamdi Azikiwe University, Awka, Nigeria

I can confirm that between October 2014 to July 2015, Mr Gbasouzor Austin Ikechukwu carried out an experimental based project using Nigeria Ginger Rhizome in our Electronic Manufacturing Engineering Research Group (EMERG) laboratory. The researcher used the ARS-0680 Temperature and Humidity Chamber equipment for drying the Ginger Rhizomes, along with TD1002A – Linear Heat Conduction Experiment Unit (LHTEU) that checked the conductivity of the dry Ginger Rhizomes.

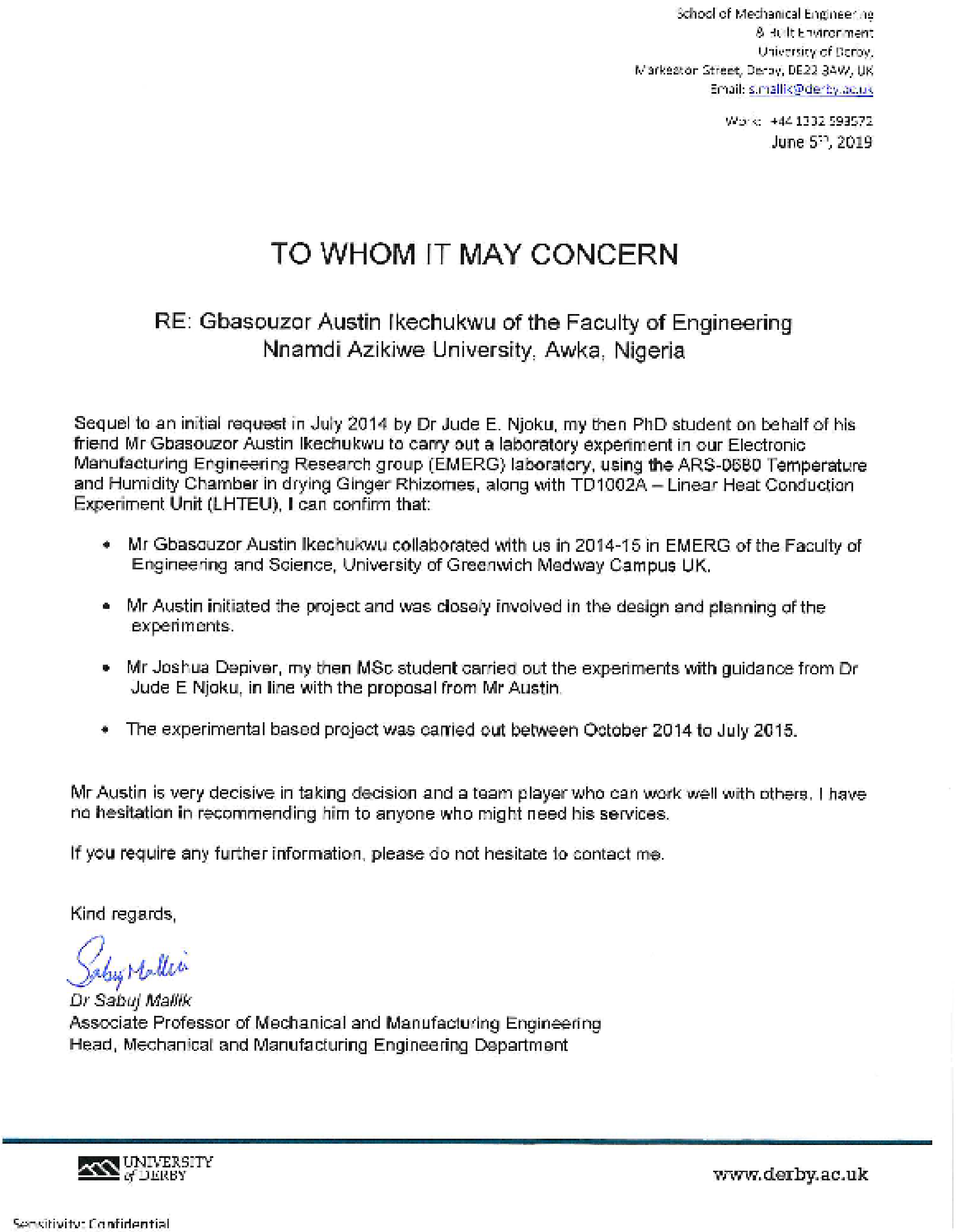
There was no official document issued to Mr Gbasouzor from EMERG and the Faculty of Engineering Science, University of Greenwich Medway Campus UK as at the time. Mr Austin fully supervised his experimental work. The support he received was purely technical on a friendly basis and on a leeway of the Research Engineer/laboratory attendant and the coordinator at the time of approach Dr Jude E Njoku and Dr Sabuj Mallik respectively.

As envisaged, I do hope that Mr Gbasouzor Austin collaborates with EMERG in both conference and journal paper writing in appreciation of the goodwill. I also hope that this information could be of help to the student and to whom it may concern. Should there be any further information, please do not hesitate to contact me.

Kind regards,

Jude
Dr Jude Ebem Njoku (Ph.D., MSc, B.Sc. /PGD. (Hons), MIET, MEEC, MWSSET, IEMA)
Part-time Lecturer/Academic Support Staff/Demonstrator,
Dept of Engineering and Science
University of Greenwich Medway Campus, UK;
Energy Management Consultant/Specialist
Renewable Energy Expert (GMC Certified)
Member of European Energy Centre (MEEC, No: 864845)
Member Inst. of Env. Mgt. & Assmt (IEMA, No: 0058456)
Tel, 07861795112, 01634883873. Email: jn9744e@gre.ac.uk

University of Greenwich at Medway
Central Avenue
Chatham Maritime
Kent ME4 4TB
Telephone: +44 (0)20 8331 8000



School of Mechanical Engineering
& Built Environment
University of Derby,
Markeaton Street, Derby, DE22 3AW, UK
Email: s.mallik@derby.ac.uk

Work: +44 1332 593572
June 5th, 2019

TO WHOM IT MAY CONCERN

RE: Gbasouzor Austin Ikechukwu of the Faculty of Engineering Nnamdi Azikiwe University, Awka, Nigeria

Sequel to an initial request in July 2014 by Dr Jude E. Njoku, my then PhD student on behalf of his friend Mr Gbasouzor Austin Ikechukwu to carry out a laboratory experiment in our Electronic Manufacturing Engineering Research group (EMERG) laboratory, using the ARS-0680 Temperature and Humidity Chamber in drying Ginger Rhizomes, along with TD1002A – Linear Heat Conduction Experiment Unit (LHTEU), I can confirm that:

- Mr Gbasouzor Austin Ikechukwu collaborated with us in 2014-15 in EMERG of the Faculty of Engineering and Science, University of Greenwich Medway Campus UK.
- Mr Austin initiated the project and was closely involved in the design and planning of the experiments.
- Mr Joshua Depiver, my then MSc student carried out the experiments with guidance from Dr Jude E Njoku, in line with the proposal from Mr Austin.
- The experimental based project was carried out between October 2014 to July 2015.

Mr Austin is very decisive in taking decision and a team player who can work well with others. I have no hesitation in recommending him to anyone who might need his services.

If you require any further information, please do not hesitate to contact me.

Kind regards,

Dr Sabuj Mallik
Associate Professor of Mechanical and Manufacturing Engineering
Head, Mechanical and Manufacturing Engineering Department