EVALUATING EFFECTS OF DRYING METHOD USING COLOUR IMAGE ANALYSIS ON QUALITY OF MACADAMIA NUTS

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Evaluating Effects of Drying Method Using Colour Image Analysis on Quality of Macadamia Nuts

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or institution of higher learning.

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This thesis has been submitted for examination with our approval as the University supervisors.

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DEDICATION

To my Lord Jesus Christ for giving me the opportunity to meet the people of Embu who grow these nuts and to my family for prayer support and comfort during this study. Glory be to God who is worthy of all praises.

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ABSTRACT

With increased demand for macadamia nuts, more emphasis is being placed on high quality and safety standards in both postharvest processing and final quality of the processed macadamia nuts. The need for accurate, fast, objective, and cost-effective drying, and quality determination of these nuts continues to grow. In Kenya, the annual production has increased from 11,000 metric tons of Nuts-In-Shell (NIS) in 2009 to 41,164 metric tons in 2018, which accounted for 19 per cent of growth. However, it is losing approximately 30% of its harvest due to poor postharvest practices, premature harvesting, and erratic farm-gate prices influenced by brokers, among others. This has been due to farmers' having poor storage program leading to internal respiration and other chemical changes. As a result, Kenya has lost grip of the European Union market since the buyers from EU have classified Kenyan macadamia as of inferior quality compared to those from countries such as Australia, Brazil among other. The objective of this research was to evaluate the effect of drying methods on the quality of dried macadamia nuts using colour image analysis. The study involved drying of two varieties of macadamia nuts, namely KRG-15 and MRG-20 and evaluating their quality using colour image analysis. The nuts were dried using an oven dryer at (temperatures of 50°C, 60°C and 50-60°C), solar tent dryer, solar tent-oven (at 60℃) as well as solar tent-microwave (MW). A colour index was determined by measuring colour parameter using CIELab model and RGB colour model. It was observed that there is a strong correlation ($P<0.05$) between normalized colours C'.b and C'.r and the total colour change. Another strong correlation was observed between normalized colours C'. b and the Browning Index (BI). This revealed that colour is important in the prediction of browning of the nuts through image analysis and this was used for grading both KRG-15 and MRG-20 nuts irrespective of the drying method. Based on the grading developed, oven drying of MRG-20 at 50^{o}C and 60^{o}C produces 1st and 2nd grade nuts, respectively. On the other hand, oven drying of KRG-15 nuts at 50˚C and 60^{o}C 2nd and 3rd grade nuts, respectively. This means that it is not advisable to mix KRG-15 and MRG-20 nuts. Solar tent-MW produced the least quality nuts with a BI of 49.03 and 88.21 for KRG-15 and MRG-20, respectively. Solar tent, oven drying at 50^{o}C and solar tent-oven (at 60^{o}C) produced the best quality nuts with a BI of 25.52-30.82 for KRG-15 and 28.95-29.78 for MRG-20. Oven-50 and oven 50-60 drying produced the best quality MRG-20 nuts with the BI of 28.00 and 29.88 respectively. However, the same drying methods produced low quality KRG-15 nuts with BI of 35.73 and 37.06, respectively. From the above findings, it was observed that for one to achieve grade one commercial nuts, one had to dry MRG-20 without mixing KRG-15 using oven drying method at a temperature of 50˚C. However, this process takes longer. In the event of mixing KRG-15 and MRG-20, it was observed that using either solar tent dryer or solar tent-oven (60^{o}C) drying method produced 1st grade commercial nuts. However, Techno-Economic analysis and optimization analysis is further required to evaluate the performance of these drying methods before they can be adapted for on-farm application.

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NOTATIONS

a*	Hunter lab redness and greenness parameter
ANOVA	Analysis of variance
ΔE	Total colour difference
b*	Hunter lab yellowness and blueness parameter
BI	Browning Index
C.b	Original colour blue from RGB extract
C.g	Original colour green from RGB extract
C.r	Original colour red from RGB extract
C'b	Normalized blue
C'g	Normalized green
C'r	Normalized Red
Chi.sq	chi square
CIE	Commission Internationale de l'Eclairage
Cr	Chroma
D65	Natural light
d.b	Wet basis (g/g of water)
F	Florescent light
FFA	Free Fatty Acid
ho	Hue angle (°)
I.R	Infra-red

KRG-15	Kirinyaga-15
L	Lightness
MR	Moisture ratio
M.C.	Moisture content
MRG-20	Muranga-20
MW	Microwave
NIS	Nuts-In-Shell
R^2	Coefficient of determination
RH	Relative humidity (%)
RMSE	Root mean square error
RGB	Red, Green and Blue
Solar Tent-60˚C	solar tent drying of nuts followed by oven drying at 60˚C
Solar Tent –MW	solar tent drying of nuts followed by microwave drying
Oven 50-60℃	Oven drying at 50 then oven drying at 60C
WI	Whiteness Index
χ^2	Chi square

CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

Macadamia as a nuts tree is found in the family of Proteaceae. This nuts tree was first introduced in Kenya in 1946 from Australia as high value cash crop for export (Muthoka et al., 2008); which is the leading world producer of the nuts, followed by U.S.A, South Africa, Guatemala, and Kenya. Although the macadamia nuts are found in the family of Proteaceae, only the Macadamia *integrifolia,* which are Maiden and Betche and Macadamia *tetraphylla* L. and their hybrid are of commercial importance (Wallace et. al, 1996). These species are cultivated for their edible nuts.

Globally, the market for these nuts is projected to grow at a compound annual growth rate (CAGR) of about 6.8% during the period of 2020-2025 (Reportlinker, 2020). This is because people have become health conscious and value these nuts as healthy nuts, hence they are taken as daily snacks in their everyday diet. Their demand is notably in European countries, North America, and parts of Asia. These nuts are widely used in the different industrial segment, including but not limited to food and beverage industry, cosmetic industry, among others. This is because macadamia nuts have the highest monounsaturated fatty acids among edible oils ranging from 73-80%. They contain oleic acid which is a potent inhibitor of fatty acid and cholesterol synthesis (Francesco et al., 2007). This lowers the level of fatty acid formation hence lower the risk of heart disease due to decreased levels of cholesterol and triglyceride (Grag et al., 2003; Salmolin and Grosvenor, 2000). This is one attribute that makes it popular, as they are readily acceptable as olive oil in many diets.

In Kenya, macadamia nuts are predominantly grown in coffee growing regions mainly areas such as Meru, Machakos, Murang’a, Kiambu, Kirinyaga, Bungoma and Embu (Ondabu, Lusike, & Watani, 2007). There are four varieties of macadamia nuts that are suitable for planting in Kenya. These include: MRG-20, KRG-15, KMB-3, and

EMB-1 (Ondabu, Lusike, & Watani, 2007). However, other new varieties from Meru, (MRU-24 and MRU-25), Wondanyi (TTW-2), Embu (EMB-H and EMB-2) and Kiambu (KMB-4 and KMB-25) are being investigated which can be grown in the main coffee or coffee/tea zones. (Ondabu, Lusike, & Watani, 2007). It is estimated that over 100,000 small scale rural producers grow macadamia nuts alongside 500 large scale farmers and company farms in Kenya (citation required). Eighty-three (83%) percent of this processed macadamia nuts was sold to USA, Japan, and china in (state the year) (Mbaka J.N., 2009).

The annual production increased from 11,000 metric tons of Nuts-In-Shell (NIS) in 2009 to 41,164 metric tons in 2018 (Gitonga et. al., 2018). This was due to most farmers in central Kenya embracing this nut (farmbizafrica, 2020). This has employed over a hundred thousand small-scale farmers, who earn approximately Kshs. 92 million per year (Kenya Investment Network, 2016). In 2018, approximately 6,400 tons of macadamia kernels were exported at a value of KES 8.8 billion (Quiroz, Kuepper, Wachira, & Emmott, 2019). The world's demand for macadamia nuts is over 20,000 metric tons of kernels per year (Gitonga et. al., 2008). Most of the produce by farmers is sold to Kenya Nuts Company, Meganuts, Farmnuts, Afrochina, Asia star among other for processing firms.

Macadamia nuts production is projected to increase from the current production of forty-two thousand metric tons (NIS) to sixty thousand metric tons (NIS) by the year 2022 (Tridge, 2020). In addition, the quantity of macadamia to be processed daily would increase with the production. It would therefore be necessary to develop dryers that can handle a large quantity of macadamia nuts at once or that can dry same volume as present but at a shorter drying time, without spoilage. This would entail increasing handling volumes or reducing handling time. The disadvantage of the first option is that it would require larger space, which would mean redesigning the processing plant or acquisition of new sites. Thus, the best option would be to design dryers in a manner to handle the more quantities of macadamia nuts within a shorter period than at present state.

Macadamia nuts are harvested at a moisture content of about 20-30% (w.b.). Drying of these nuts is achieved in two stages. In the first stage, according to Borompichaichartkul et al., 2009, the Nuts-In-Shell (NIS) are dried on-farm to a moisture content of 7.5-11.1% (w.b.), at a temperature of 25-45°C and a relative humidity of 20%. This is done to ensure that the nuts can be stored for long without decline in quality (agrimac macadamias 2005). In the second stage, NIS are then taken to the processing company for farther drying to enable easier shelling. Drying not only reduces the rate of respiration, and chemical and enzymic reactions but also contributes to eating quality such as kernel colour and texture (Warangkana, 2012). In Kenya, the industrial drying is done by use of controlled heating using steam, in which macadamia nuts shells are used as the biofuel to provide the required heat for the process.

1.2. Problem Statement

Macadamia sector has become a lucrative cash crop alongside tea and coffee. The bulk of these production is produced by the small-scale farmers, who are expected to increase in number with the increase of production as projected. However, Kenya losses up to 30% of its harvest due to poor postharvest practices, premature harvesting, erratic farm-gate prices influenced by brokers, among others (Quiroz, Kuepper, Wachira, & Emmott, 2019). This according to Murioga et al., (2016) has seen Kenya's global ranking position drop from position 2 to 4.

This global competition has resulted in the influx of foreign companies coming to Kenya to buy the unprocessed nuts directly from the farmers. This competition has resulted to farmers hoarding their produce waiting for the best price in the market. As a result, these nuts undergo internal respiration and other chemical changes, thereby leading to weight loss and deterioration of appearance. In addition, they collect and mix the different varieties as they await collection by the macadamia people, who are involved in the collection of these nuts for processing. As a result, European Union (EU) buyers, who are among Kenya's major consumers of its dried macadamia nuts, have classified Kenyan macadamia as inferior quality compared to those from countries such as Australia, Brazil among other (Quiroz, Kuepper, Wachira, & Emmott, 2019).

To improve the global competitiveness of Kenya's macadamia nuts, there is need to reduce on-farm losses as well as improve the quality of drying. This would entail increasing handling volumes or reducing handling time of macadamia drying process. The disadvantage of the first option is that it would require larger space, which would mean redesigning the processing plant or acquisition of new sites. The best option would be to design dryers in such a manner that they can handle the more quantities of macadamia nuts within a shorter period than at present state.

1.3. Objectives

1.3.1. General Objective

The general objective of this study was to evaluate the effect of drying methods on the quality of dried macadamia nuts using colour image analysis.

1.3.2. Specific Objectives

(i) To develop colour index using imaging technique for evaluating quality of macadamia nuts.

(ii) To determine the effect of temperature on the quality of different species of macadamia nuts

(iii) To evaluate the performance of hybrid tent dryer, a combination of hybrid tent dryer and microwave dryer; combination of solar tent dryer and oven drying at 60˚C; combination of oven drying at 50˚C then 60˚C in the drying of the KRG-15, and MRG-20 macadamia nuts.

1.4. Justification

In order to ensure that the processing companies are prepared address this poor access to EU market and at the same time to meet the capability to process forty-two thousand metric tons per year, farmers should be involved in the on-farm drying process since farmers tend to hoard these nuts for better prices. The capital cost of putting up modern dryers may be very expensive both for the companies and the farmers. Hence, there is need for adaptation of such dryers as indirect solar dryers to–reduce the cost of production. This requires evaluation of the effect of drying temperature and method on the quality of dried macadamia nuts.

Three main factors have been identified to influence the quality of processed macadamia namely: - shell thickness, Oil content and sucrose content. There is need to monitor and evaluate these factors in real-time and non-destructively during drying of macadamia. This study used image analysis technique to evaluate the quality of macadamia dried under different drying methods and temperature. Image analysis was used to generate a colour index to help in classification of dried nuts, and in selecting the dryer that yield best quality of nuts as well as to develop procedure for handling the various varieties of nuts during drying process.

1.5. Scope of Study

This study evaluated the effect of different drying methods on the quality of two different varieties of macadamia nuts in terms of colour using image analysis technique. Machine vision colour was correlated with human eye perception of the final colour and the image texture properties. The drying methods used in the study were: oven air drying at temperatures of 50°C, 60°C and a combination of 50°C and 60°C; solar tent drying, solar tent- oven (at 60°C) as well as solar tent-MW. Two macadamia varieties namely KRG-15 and MRG-20 were studied. The study was carried out at the department of Agricultural and Biosystems Engineering Department of Jomo Kenyatta University of Agriculture and Technology in Kenya, which according to Kamwere et. al. (2015), is located in Juja with a longitude of 37.05°E longitude, latitude of 1.19°S latitude and an altitude of 1550 above the sea level.

CHAPTER TWO

LITERATURE REVIEW

2.1 Drying Concepts

Drying is among the oldest methods used to preserve food. It is usually simple compared to other methods of preservation. Food is preserved by removal of sufficient moisture to prevent biochemical and microbial activities that lead to spoilage. Because of low moisture content, well-dried foods can be stored over a long period since spoilage organisms cannot grow.

Several methods are used in the drying of the nuts-in- shell (NIS) but not all food drying methods can be used in drying of macadamia nuts. This is because each biological material requires different drying conditions due to their difference in biological and the chemical properties that are either to be preserved or to be altered. This NIS are harvested at moisture content of 20-30% (w.b.), with their natural oils yet to fully develop (creative, 2013). These need to be air dried in shade, for at least three weeks to reduce the moisture content and to allow for oils to fully develop. Industrial drying of these NIS is carried out to a moisture content of 1.5 % (w.b.) for various reasons. When the nuts are dried, they tend to shrink, hence facilitate breaking them open without damaging the nuts, and prevents bits of them sticking to the inside of the shell. Drying macadamia nuts helps to increase their storage life, with up to two years of storage. Finally, drying these nuts is a prerequisite for correct roasting (creative, 2013).

Macadamia nuts are rich in monounsaturated fatty acid (73-80%). The presence oleic acid helps to inhibit the synthesis of fatty acid and cholesterol synthesis (Francesco et al., 2007). This lowers the level of fatty acid formation consequently; cholesterol and triglyceride levels are decreased hence lowering the risk of heart disease to consumers (Grag et al., 2003; Salmolin and Grosvenor, 2000). The large amount of double bonds in macadamia fatty acid makes them highly susceptible to lipid peroxidation (rancidity). Hence the relationship between drying process and possible changes of lipid composition should be investigated (Warangkana, 2012).

2.2 Dryers for Macadamia

2.2.1 Tent Dryer

Tent drying technology concentrates the sunlight on the materials to be dried. It is simple, cheap and can heat the drying material to over 25°C above ambient temperature (Esper, 1998; Weiss and Buchinger, 2001; Fadhel et al., 2005; Forson et al., 2007; Hassanain, 2011; Almuhana, 2012). This dryer works by generating higher temperatures when the shortwaves radiation is turned to longwave radiation, hence lowering relative humidity inside the tent dryer (Thant, Nwe, & Zaw, 2019). Drying and curing of macadamia nuts is accomplished by heating the nuts to 40°C-60°C. The temperature inside the dryer tents tend to vary from 35°C to 60°C due to variation in solar intensity. This method is effective since several tones of nuts can be dried in one instant. The drying efficiency of this type of a dryer depends on the relative humidity (RH) and the velocity of air (Warangkana, 2012). However, this dryer is highly weather dependent and the air flow rate inside the dryer is low due to low buoyance (Bala & Mondol, 2001).

2.2.2 Hot-air Convectional Method

For effective drying of nuts, the air used for drying should be hot, dry and moving. This ensures that drying takes shorter time unlike the direct solar drying. In Kenya most processors use this method for drying macadamia nuts. Air is blown past a heat exchanger that is heated with steam to the dryer. It is regulated to a temperature of 40-50°C.The drying process takes between 31-270 hours, depending on the temperature used. The drying continues until the nuts attain a moisture content of 1.5% (d.b.) moisture content, wet basis.

2.2.3 Hybrid Drying

This is a process that uses heat pump to dry macadamia nuts in two stages and takes a period of 15-52h in the second stage, depending on the moisture content of the first stage drying and the temperature used in second stage (Borompichaichartkul et al., 2009). The first stage uses a heat pump with 40°C temperature, while the second stage uses air heated at between 50-70°C. Using heat pump, the drying temperature and the initial moisture content of the macadamia nuts have a significant effect on the percentage of change of peroxide value. As the temperature for drying in the second stage, peroxide value increased. It was evident that the internal change in colour was more pronounced than the external change in colour as air temperature increased (Borompichaichartkul et al, 2009). They reported that drying macadamia nuts with the intermediate moisture content (IMC) of 11.1% (d.b.), the moisture content at the end of the first stage, using heat pump dryer followed by hot air drying gave a drying time of between 15–45.5 hrs, depending on the temperature used.

2.2.4 Microwave Dryer

Microwave provides the advantages of achieving fast drying rates (due to higher dialectic losses of water as compared to the product being dried) and at the same time improving the quality of some food products. The absorption of this energy is controlled by the level of wetness of products, which can be used for selective heating of interior parts of the sample containing moisture and without affecting the exterior parts. Microwave drying is considered very useful during a falling rate period due to volumetric, as heating generates the vapours are inside and an internal pressure gradient is developed which forces the water outside; temperature inside become higher than the outside thereby giving rise to a greater partial pressure forcing evaporating water to the surface. This prevents shrinkage of food materials (Chandrasekaran *et al.*, 2013). If microwave energy is combined with other drying methods, this can improve the drying efficiency as well as the quality of food products. This is far better than that achievable by microwave drying only or by other conventional methods only (Zhang *et al.*, 2006).

Silva et al. (2006) carried out research to dry macadamia *integrifolia* using a microwave assisted dryer with a nominal power of 900 W. They concluded that it was perfectly possible to dry macadamia nuts by applying microwave energy within 4.5–5.5 h, which is much shorter than those required in the conventional hot air-drying process (about 144 h). The method of applying microwaves in drying proved to be efficient in preserving the natural quality of the nuts. This means that it can be adopted for drying purpose of these nuts. Care should be taken since each variety macadamia nuts have different oil and sucrose content. This is because oil and sugar content have effect on dielectric properties of the products being dried. When drying macadamia nut using microwave assisted dryer, it was reported that it produced brighter kernels which were suitable for longer storage time. However, the kernels were very hard, which became tender when the microwave power was increased. The use of this type of dryer requires very expensive equipment which makes the capital investment to be very high. In addition, the energy efficiency of this type of dryer decreases with time as the dried products tend to reflect most of the power away due to reduced moisture when drying continues (Zarein et. al., 2013).

2.2.5 Radio Frequency-Assisted Drying

The radio frequency assisted dryer uses two parallel plate electrodes for radio frequency heating and has electrical heater and fan for hot air injection. This equipment uses a 6kW, 27MHz free-running oscillator type-scale radio frequency system. The Gap of electrodes played an important role in the heating rate. The optimal combination of gap and hot air temperature were 15.5cm and 50°C respectively. Radio frequency assisted dryer requires an average of 360 min to achieve the final moisture content of 3.0% wet basis (Wang et al., 2012). This drying system is fast and dries product uniformly unlike the above dryers (Wang et al., 2004). The only disadvantage is that these types of dryers are capital intensive.

2.2.6 Drying Models

In the drying of agricultural product, the behaviour of moisture loss with time in drying is described by an exponential relationship. In this study, moisture ratio versus drying time was fitted with the kinetic drying model. Seven of these kinetic models are proposed to describe the rate of moisture loss during thin layer drying rewrite correctly. These are called empirical models since the compromise between theory and the ease of use. They are generated by simplifying Fick's second law and are valid within the environment they were developed; temperature, air velocity, moisture content and the relative humidity Murat *et al.* (1999). The seven selected thin-layer drying models, which might be adequate to describe thin-layer drying data for the macadamia nuts are in Table 2.1.

Table 0.1: Thin layer drying models

Model	Equation	Reference
Newton	MR = exp(−kt)	Liu and Bakker
Page	MR = exp (−ktn)	Zhang and Litchfield
Logarithmic	MR = a exp (−kt) + c	Yagcioglu et al. (1999)
midilli	MR = a exp (−ktn) + bt	Midilli et al. (2002)
Approximation of diffusion	MR= a exp (−ktn) + (1− a) exp(−kbt)	Yaldiz and Erdekin (2001)
Two term	MR=a exp(-kt) +b exp(-gt)	Togrul and Pehlivan (2004)
Modified Handerson and Pabis	MR=a exp(-kt) +b exp(-gt)+c exp(-pt)	Karathanos and Belessiotis (1999)

In the thin layer drying models in Table 2.1, MR is the moisture ratio, which is evaluated as described in Equation 2.1.

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

(0.1)

In the equation, MR is moisture ratio, M is moisture content (% db.) at time t, M_e is equilibrium moisture content (% db.), M_i is initial moisture content (% db.), K is constant and t is time (min). In the tent dryer, the value of Me is relatively small compared to both M and M_i because of continuous fluctuation of relative humidity, hence for tent dryer, Equation 2.1 can be simplified to Equation 2.2 (Wang et al. (2004).

$$MR = \frac{M}{M_i} = \exp(-kt^n)$$

(0.2)

2.3 Temperature and Browning of Macadamia Nuts

A Maillard reaction is a form of non-enzymatic browning of food products during processing. It is a complex process that has many pathways and reactions that are unknown. This complex reaction is between amino-acid and reducing sugars, which occurs at increasing temperature. The factors that play role in the Maillard reaction include pH (acidity), types of amino acids and sugars, temperature, time, presence of oxygen, water, and water activity (a_w). Browning of macadamia nuts occur in three different pathways (Warangkana, 2012) among them Enzymic browning reaction, micro-organisms' infection and Maillard reaction. Maillard reaction in macadamia nuts is a result of reaction between reducing sugars and amines in the kernel. The browning becomes more as the temperature of drying increases (Borompichaichartkul, 2009). Macadamia nuts have a protein content of 7.8-9.2g per 100g kernel, according to Weinert (1993). Brown macadamia nuts have high level of phenolic acid compared to the white section of the same nuts (Warangkana, 2012). Phenolic acid is known to be responsible for the coloration of nuts when it is being processed. The two common phenolic acids found in macadamia nuts are Gallic acid and chlorogenic acid (Bolling, 2017). In addition, macadamia nuts infected by microorganism are brownish in colour, due to the utilization of phenols by the moulds. Immature kernels have higher sucrose and reducing sugar contents and more browning than mature kernels (Wall & Gentry, 2007).

2.4 Digital Image Analysis-Colour and Quality of Foods and Agro-products

In agricultural processing, colour is considered a fundamental physical property of agricultural products and foods. This is because colour correlates well with other physical, chemical, and sensorial indicators of product quality. As a result, colour plays a major role in the assessment of external quality in both food industries and food engineering research (Segnini et al., 1999 and Abdullah et al., 2001), since consumer purchase power is governing by what they see.

There are three colour modes that are used in image colour analysis. These include: RGB (red, green, and blue) scheme, CMYK (cyan, magenta, yellow, black) scheme, and L.a.b scheme. Of the three, the L.a.b model has the largest gamut as it encompasses all colours in the RGB and CMYK gamut's (Adobe Systems, 2002). The RGB model is an additive colour model based on the tri-chromatic theory, which uses transmitted light to display colours (Wikimedia Foundation I. , 2015). It is the colour space that is produced on the CRT display like computers screens, television etc. Cyan, magenta, and yellow are created when the various proportion and intensities of three primary colours are combined. The advantage of using RGB is that it is easy to implement, but it has the disadvantage of a non-linear visual perception. It is also device dependent and colour specification is semi-intuitive.

The L.a.b model is used as an abbreviation for the CIE (L*, a*, b*) colour space, developed in 1976. It is attributed to be device independent. The displayed colour is not defined by the output of the device unlike other models. The lab model has been designed to approximate human perception, as L* parameter closely correlates well with the human perception of lightness. Unlike L.a.b colour model, RGB and CMYK space output is dependent on the physical device such as digital camera, scanner, monitor, and printer. The Lab colour consists of a luminance or lightness component (L value, ranging from 0 to 100), along with two chromatic components (ranging from) -120 to +120): a* the component (from green to red) and the b* component (from blue to yellow).

2.4.1 Lighting System

When capturing colour images, proper light source is important since the colour of the food sample depends on the part of spectrum reflected from it (Francis and Clydesdale, 1975). The standard illuminants commonly used in food research are A (2856K), C (6774 K), D65 (6500 K), and D (7500 K). The light sources C, D65, and D are designed to mimic variations of daylight (Lawless and Heymann, 1998). Most of the solid agricultural products are opaque in nature. This opaque material reflects most of the incident light that strikes it. There are two general categories of instrumental geometries: 45º/0º or 0º/45º geometry. The 45º/0º is illustrated in Figure 2.1; excludes the specular reflection in the measurement. This corresponds to the visual changes in appearance of the sample due to both changes in pigment colour and surface texture.

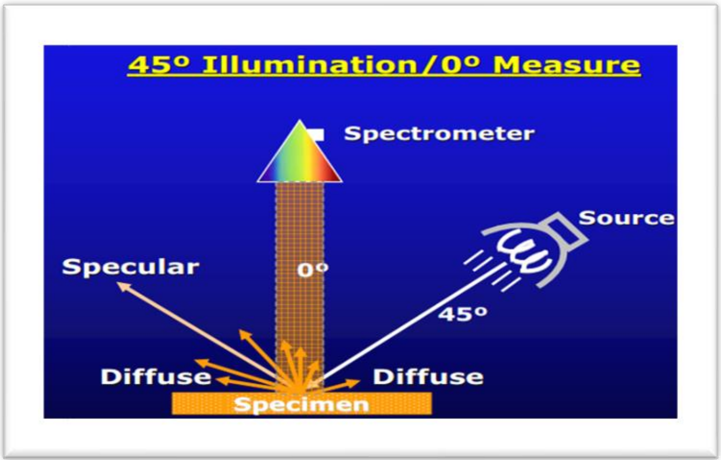

Figure 0.1: The 0º/45º geometry.

Gordon (2015)

The angle between the camera lens axis and the lighting source axis should be around 45, because the diffuse reflection responsible for the colour occurs at 45 from the incident light (Francis & Clydesdale, 1975). Furthermore, the light intensity over the food sample should be uniform. This can be achieved through experimenting with various lighting arrangements (such as varying the distance between the light source and the food sample, taking the pictures in a dark room) and checking the results with a light meter.

2.4.2 Colour Differences

The hunter L*, a* and b* system was used for the total color change (ΔE), chroma, hue angle and browning index (BI) were calculated by using these values. The hunter L*a*b* total colour difference (E*) is the distance between the colour locations in space. This distance can be expressed as in Equation 2.3 to 2.4 and L^*_o, a^*_o and b^*_o

refer to the colour characteristics of dried macadamia nuts. The L* value represents luminance channel which range from 0 (light) to 100 (dark)., while the chromaticity channels a* value represents green-red spectrum which range from −60 (green) to +60 (red) and b* value represents blue-yellow spectrum which range from −60 (blue) to +60 (yellow). The ΔE value indicates the total colour difference and is obtained using Equations 2.3 and 2.4 for CIE-L*a*b* and RGB data, respectively.

$$\Delta E_{L^*a^*b^*} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{0.3}$$

$$\Delta E_{RGB} = \sqrt{(\Delta R)^2 + (\Delta G)^2 + (\Delta B)}^2 \tag{0.4}$$

In the equation, ΔL∗is the lightness difference given by Equation 2.5,

$$L^* - L^*_o \tag{0.5}$$

Δa∗ is the red/green difference determined using Equation 2.6.

$$a^* - a^*_o \tag{0.6}$$

and Δb∗ is the yellow/blue difference which can be computed using :

$$b^* - b^*_o \tag{0.7}$$

ΔE* represents the magnitude of the difference in colour though it does not indicate the direction of the colour difference. Colour of the drying product becomes darker when the value of ΔE increases. The Chroma and the hue angle for the drying material are evaluated as in Equations 2.8 and 2.9, respectively.

$$\text{Chroma value} = \sqrt{(a*2 + b^{*2})}$$

(0.8)

$$H^* = \tan^{-1}\left\{\frac{b^*}{a^*}\right\} \text{ for } a>0,\ b>0,$$
$$= \left(180 + \tan^{-1}\left\{\frac{b^*}{a^*}\right\}\right),\ \text{for } a<0,\ b>0;\ \text{and for } a<0,\ b<0,$$
$$= \left(360 + \tan^{-1}\left\{\frac{b^*}{a^*}\right\}\right),\ \text{for } a>0,\ b<0,$$

(0.9)

In the equation, H* is the hue angle, which is the attribute of a visual sensation according to which an area appears to be similar to one of the perceived colors: red, yellow, green, and blue, or a combination of the two colours (Wikimedia Foundation I. , 2017). Figure 2.2 shows the sequence of color corresponding to Hue angle.

Radian is a measure of the arc on a circle corresponding to a given value of tangent on the colour chart. $L^*C^*h_o$ space is preferred for the specification of colour of the initial and the final dried product. This is because the concept of hue and Chroma agree well with the perception of the product, product acceptability by sight.

Figure 0.2: Hue angle chart.

Phloxbox (2007)

The effect of heat in the dryer to the browning of nuts are assessed using Equations 2.10- 2.12.

$$WI = 100 - ((100 - L)^2 + a^2 + b^2))^{1/2} \qquad (0.10)$$

Browning Index

$$BI = 100 \times \left(\frac{x-0.31}{0.172}\right) \quad (0.11)$$

In which,

$$x = \frac{(a+1.75L)}{5.645L+a-3.012b)} \quad (0.12)$$

2.4.3 Image Texture Analysis

Texture refers to the properties of material that defines the appearance of the surface of an object (Gebejes, Master, & Samples, 2013), and is defined as something consisting of mutually related elements (Thomas et al. 2010). According to Wirth (2004), texture feature is used to partition images into regions of interest and to classify those regions by providing information in the spatial arrangement of colours or intensities in an image. This is characterized by the spatial distribution of intensity levels in a neighbourhood and this occurs when the pattern of local variations in image intensity is repeated. Texture can therefore be described as fine, coarse, grained or smooth among others.

Texture analysis is the quantification and the use of image texture properties (Ondimu S.; Murase H., 2008). Therefore, an image texture is a set of matrices that is calculated during image processing that quantify the perceived texture of an image. This is used in aerial photographs, camera-based industrial inspection systems, shape analysis, satellite imaging and medical diagnosis (Nailon, 2010). There are four ways of analysis texture; structural, statistical, model based and transform based approach (Nailon, 2010). Of the four, texture characterization that is made through second order statistical measurement based on Gray Level Co-occurrence Matrix (GLCM) is preferred since it gives better result.

GLCM is a measurable system for looking at pixel composition that regards the spatial association of pixel (Che et *al*. 2015). Features computed that are from GLCM assume that the texture information in an image is contained in the overall spatial relationship. The neighbouring pixels are separated by a certain distant (d=l)in a given direction (0, 45, 90, or 135) ElMasry et *al* 2007). The main GLCM features used in this study are contrast, energy, homogeneity, and correlation. Contrast also called ‘sum of squares variance’, is a measure of the intensity contrast between a defined pixel and its neighbour over the whole image while correlation is a measure of how a pixel correlate to its neighbour over the entire image (Santoni *et al*., 2015).

I. Contrast also called "sum of squares variance" which measures the local variations that is present in an image; variation between the reference pixel and neighbour pixel. It is computed using Equation 2.13

$$Contrast = \sum_{i,j=0}^{N-1} p_{i,j}(i-j)^2 \tag{0.13}$$

II. Energy measures the orderliness in an image. It is computed using Equation 2.14

$$Energy = \sum_{i,j=0}^{N-1} P(i,j)^2 \tag{0.14}$$

III. A homogeneity measures the closeness of the distribution of pixel element in the GLCM to the GLCM diagonal. It is computed using Equation 2.15

$$Homogenity = \sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2} \tag{0.15}$$

IV. Correlation measures is a measure of image linearity; how the reference pixel is related to its neighbour pixel. This is computed using Equation 2.16

$$Correlation = \frac{\sum_{i,j=0}^{N-1} (i,j) P_{i,j} - \mu_x \mu_y}{\sigma_x \sigma_y} \tag{0.16}$$

2.5 Colour Development during Drying

The quality of dried macadamia nuts is evaluated in terms of the moisture content, colour of the kernel, peroxide value, and the reducing sugar content (Wall & Gentry, 2007). When these nuts are dried, the reducing sugar tends to decrease while the centres of the nuts darken slightly. These darkening of the kernels is due to exposure of enzymes in cell membrane and or incorrect nuts-in-shell drying regimes. (Lagadec, 2009). Colour indices (L∗, a∗, b∗) of the nuts and their relationships with moisture content has been used when sorting nuts utilized to design sorting facilities (Ragab Khir, Pan, & James F. Thompson, 2004). They reported that the above colour indices apart from a* had no relationship with the moisture content of the walnuts before drying. Ragab et *al.* (2004) concluded that the relationship between colour indices of L* or ΔE and walnuts shell moisture content to sort walnuts before drying.

In the commercial sector, companies set their own quality standard. However, the United Nations Economic Commission for Europe (UNECE) developed two standards, namely DDP-22 and DDP-23 for define both the marketing and commercial quality control of nut-in-shell macadamia nuts and macadamia kernels (Council, 2018). The use of these standards is voluntary and each company is free to choose which standards to adopt subject to national regulations. The standard grading of macadamia nuts has been set up on the size and the appearance of the unshelled nuts, the relative wholeness of the kernel after shelling, the colour of the kernel, texture and the condition of the kernel with respect to insect damage (Ripperton *et al.*, 1938). The kernel of sizable nuts is graded based on the specific gravity method and the percentage of kernel that are grade 1 determined. However, acceptable colour standards for grading macadamia nuts have not been developed (Ripperton et al., 1938).

2.6 Summary of Literature Review and Research Gap

Author/s	Context	Reported Findings	Research gap
Silva et al., 2006	Sought to produce dried macadamia nuts by applying microwaves to assist the hot air-drying process, thus reducing the drying time, and increasing the industrial yield and quality of the kernels as compared to those from conventional processes.	Reported that peroxide values, free fatty acid percentages and sensory acceptance evaluations for a period of six months after processing using microwave assisted dryer was well below the limit stipulated by the Brazilian legislation	• focused on two types of drying methods • Image analysis was never used to identify the quality of these nuts
Wang et al., 2012	Studied on the application of radio frequency (RF) energy in dehydration of in-shell Macadamia nuts	The drying kinetics of the nuts were described well by the Page model for hot air drying, but a logarithmic model was more suited for RF/hot air drying.	• Lack of information on Approximation of Diffusion and Modified Handerson and Pabis models
Borompichaichartkul et al., 2009	Sought to improve the quality of macadamia nuts	The interaction between the drying temperature and the intermediate	• Focused only on two types of dryer

Author/s	Context	Reported Findings	Research gap
	using hybrid pump drying process	moisture content (IMC) had no effect on the internal and external total color changes	• Lack of study on the effect of these dryers on the various variety of these nuts

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The macadamia nuts samples MRG-20 and KRG-15 used in this research were collected from the KALRO-Practical Training Centre (PTC) in Thika and from a farmer in Embu. These Nuts-in-shell were air dried during the pre-drying stage in a Solar Tent Dryer (STD), which was open to allow flow of air. These Nuts-in-shell were air dried to an average moisture content of 10.62 and 12.98% wet basis (w.b.) for MRG-20 and KRG-15 respectively for a period of two weeks (Robin & Robin, n.d.). Borompichaichartkul et al. (2009) reported that the interaction between the drying temperature and the intermediate moisture content (IMC) has no effect on the internal and external total color changes.

3.2 Development of Colour Index for Evaluating Quality of Macadamia Nuts

3.2.1 Experimental Set up

A Colour Digital Camera, CDC, (Samsung WB150F, Samsung, South Korea), with a wide-angle lens 24 mm and high resolution of 14.2 megapixel was located vertically 30 cm over the background. The camera was fixed on a static table. The adjustment of the camera was standardized in manual mode with the lens aperture at *f* = 4.5 and speed of 1/80, with no zoom and no flash. The intermediate resolution of the CDC was 1280×720 pixels, and images storage was in JPEG format. The camera was connected to the USB port of a PC for downloading. The angle between the camera lens and the lighting source was 45°. Sample illuminators (Bulb light D65000K) and the CDC was placed in a dark room to avoid the external light and reflections as illustrated in Figure 3.1.

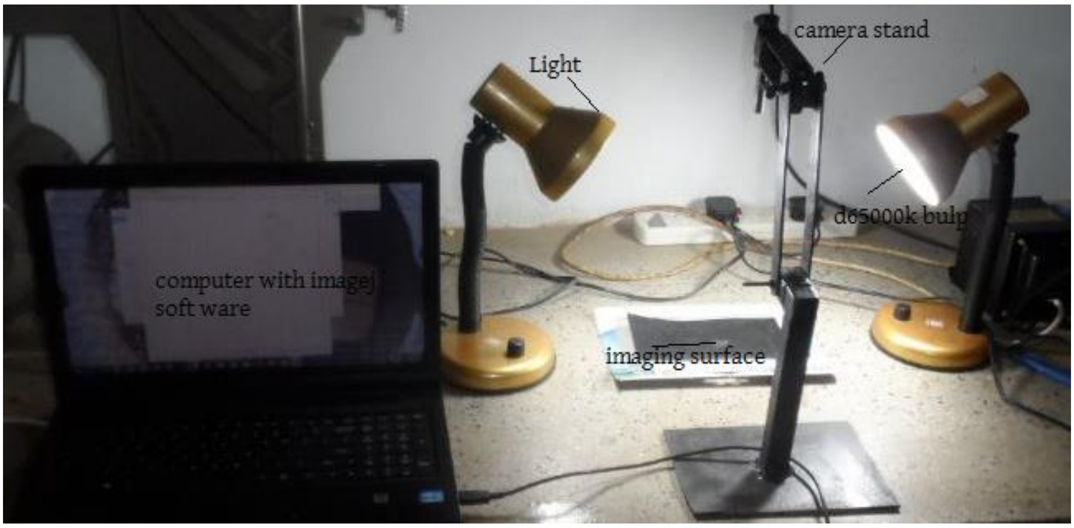

Figure 0.1: A photographic presentation of the experiment and computer vision system.

3.2.2 Experimental Design

The nuts were dried using air drying at 50℃, 60℃ and 50-60℃ and also dried using solar tent dryer, solar tent- oven (60ºC), and solar tent-MW. 3 nuts samples for each variety dried using the different methods were randomly collected after every 60 minutes. This was repeated in triplicate. This was done till the nuts attained a moisture content of 4% (w.b.). Colour of dried macadamia nuts were determined by the digital image analysis. This was done by taking images for the two varieties before and after every time of drying. The images were downloaded to a PC from the CDC using a USB cable (model CB5MU05E). These images were uploaded to the Imagej software. A plugin called RGB-Measure.Java was downloaded to the plugins folder. The images were then run and analysed using this plugin for quantification of the colour quality of macadamia nuts. Colour parameters were reported in RGB (red, green, and blue). This was followed by taking images of the samples using Minolta CR-200 and the result reported using CIE-Lab scale as L^*, a^*, and b^*.

3.2.3 Development of a New Methodology for Object Recognition

This involved the comparison of the true colour of current image pixel and the predefined colour index of macadamia nuts. The distance between the image pixel colour and the predefined object colour was determined using Equation 3.1. The similarity was defined by the distance, d.

$$d = \sqrt{(c.r_o - c.r)^2 + (c.g_o - c.g)^2 + (c.b_o - c.b)^2} \quad (0.1)$$

In the equation, $C.r_o$, $C.g_o$, $C.b_o$ are the initial colours extracted from Imagej representing red, green and blue respectively while C.r, C.g, C.b are the RGB colours at time t.

Direct colour comparison can lead to error due to brightness of image. To avoid this error during object identification, the original colours were converted to normalized colours using Equations 3.2-3.4.

$$C'r = \frac{C.r}{C.r+C.g+C.b}.100\% \quad (0.2)$$

$$C'g = \frac{C.g}{C.r+C.g+C.b}.100\% \quad (0.3)$$

$$C'b = \frac{C.b}{C.r+C.g+C.b}.100\% \quad (0.4)$$

These colours show how much each component contained in colour (%). Saturation colour for the dried nuts was determined using Equation 3.5.

$$S(\mathrm{C.r, C.g, C.b}) = 1 - \frac{min(\mathrm{C.r,C.g,C.b})}{\mathrm{C.r+ C.g+ C.b}} \quad (0.5)$$

3.2.4 Texture Features Extraction

This process involved several steps in order to determine the GLCM for both KRG-15 and MRG-20 nuts. First, the Texture analysis plugin called GLCM Texture

Analyzer12 was downloaded and installed in Imagej. The digital image was then pre-processing and resized to 8-bit. Then, the algorithm counted the number of cooccurrences of two neighbouring pixels of a specified distance and spatial relationship. The elements were then transposed and normalized to represent probabilities of cooccurrence. The texture measures were derived from GLCM. These yielded the result in the direction of the steps of 0, 90,180 and 270-degree angle with a distance of step1. Four texture features were computed namely: angular second moment (ASM), contrast, correlation, inverse difference moment and homogeneity.

3.3 Determination of Effect of Temperature on Quality of Different Varieties of Macadamia Nuts

Oven drying was carried out at a constant temperature of 50°C for KRG-15 and MRG-20 until a desired moisture content of 4.0% w.b. was achieved. This was achieved by setting the drying temperature of the dryer at 50℃. A sample size of 700gms was used for all the experiments. The weight of the nuts was measured after every 60 minutes. Six nuts were randomly selected after every 60 minutes until the desired MC was achieved and the kernel extracted. The images were taken using the CDC set-up and Minolta CR200. This was repeated three times. The experiment was then repeated using air temperature of 60°C, which involved the step of setting the drying temperature of the dryer to 60℃.This was done in triplicate for both temperatures. Oven drying was necessary in identification of the effect of temperatures on the quality of macadamia nuts. The images taken were then uploaded to Imagej and RGB data extracted. The Minolta CR-200 gave CIE Lab results as L*a* and b*. The browning index for the above result were calculated using the Equation 2.11 and the effect of air-drying temperature on KRG-15 and MRG-20 evaluated using the classification developed.

3.4 Evaluation of the Performance of Different Dryers when Drying KRG-15 and MRG-20 Nuts

3.4.1 The Solar Tent Dryer

Figure 3.2 shows a solar tent dryer that comprised of two chambers: pre-drying for reducing the moisture content of macadamia nuts to about 10-14% MC (w.b) and drying chamber. This Structure was contracted at the Agricultural and Biosystems Engineering Department of Jomo Kenyatta University of Agriculture and Technology (JKUAT), which is located at Juja (37.05°E longitude, 1.19°S latitude and at an altitude of 1550m above sea level). Four data loggers (Hobo MX1101, Onset) sensors were placed inside the dryer to record both temperature and relative humidity in the dryer. The data loggers namely SN-12, SN-13, SN-15 and SN-16 were places as shown in Figure 3.1 to record temperature and relative humidity (include a schematic drawing of the inside on the dryer to show the arrangement of the trays and placement of the sensors. The fans in the tent dryer were powered by -solar panels. Thus, their speed was dependent on the solar irradiance.

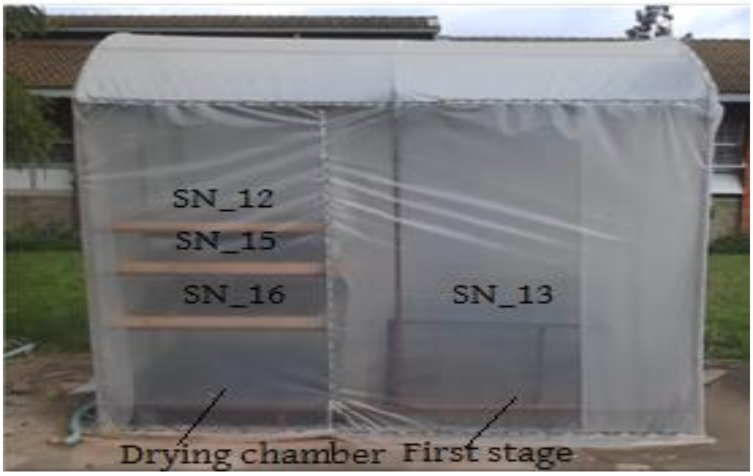

Figure 0.2: Solar dryer used in the study.

3.4.2 Pre-drying of Nuts-in-shell Macadamia Nuts

The macadamia nuts samples MRG-20 and KRG-15 used in this research were collected from the Practical Training Centre (PTC) in Thika and from a farmer in Embu. This was because PTC did not have MRG-20 at the time of collection, hence they referred the researcher to a farmer in Embu. The first stage involved Pre-drying the Nuts-in-shell macadamia nuts. This was carried out in a Solar Tent Dryer (STD) shown in Figure. 3.3 by placing the nuts in large trays inside the dryer. These nuts were air dried to an average moisture content of 10.62 and 12.98% wet basis (w.b.) for MRG-20 and KRG-15 respectively for a period of two weeks (Robin & Robin, 2016) Borompichaichartkul et *al*. (2009) reported that the interaction between the drying temperature and the intermediate moisture content (IMC) has no effect on the internal and external total color changes. Hence, the variation of moisture content at the pre-drying stage does not inform the final quality of macadamia nuts.

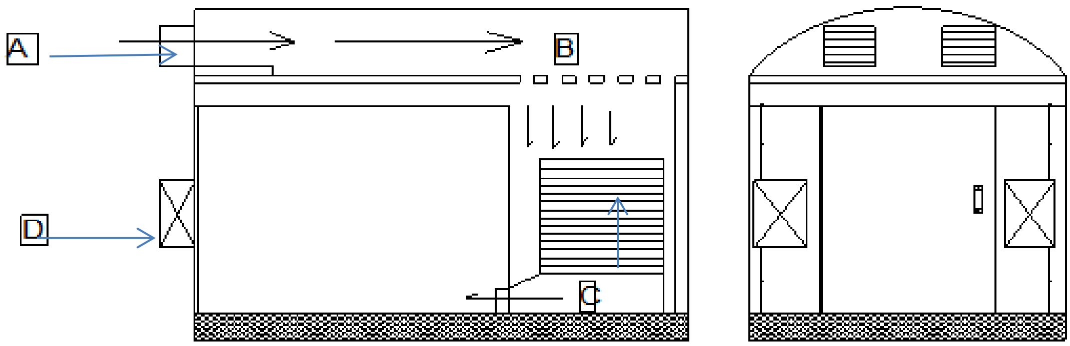

Figure 0.3: Schematic diagram of solar tent dryer.

In the figure: A is the air inlets; B is the black mild steel plate collector; C is the drying chamber; D is the exhaust fan

3.4.3 Second Stage Drying

The second stage drying involved drying both KRG-15 and MRG-20 to a moisture content of about 4.0 % d.b except for the solar tent dryer which managed 4 % d.b due to change of weather that resulted to high relative humidity. The dry matter content and colour of all samples was measured before and after drying. Moisture content was determined using oven drying at 105˚C for 24 hours. Images were taken for the two varieties before and after drying. Colour and colour difference was measured with the help of Minolta colour meter (Minolta CR-200, Osaka, Japan) standardized on a white plate No. 11933069. The result was recorded as lightness, L^*, a^* and b^*.

3.4.3.1 Solar Tent Dryer

Five samples of seven hundred grams each were randomly selected for both KRG-15 and MRG-20, during the second stage set up. The weight of the samples was recorded after every 60 minutes until a moisture content of 4.0 % (w.b) was achieved. The fan was set at a velocity of 3.5m/s. This procedure was repeated in triplicate for both varieties.

3.4.3.2 Solar tent - Microwave Drying

The nuts were first dried using the solar tent dryer to a moisture content of 5% w.b. These were further dried using a microwave to the required moisture content of 4% w.b. A power setting of 420 watts was applied for microwave drying. The weight of the nuts was recorded after every 2 minutes till they reached a moisture content of 4.0 % w.b. This procedure was repeated in triplicate for both varieties.

3.4.4 Determining the Chemical Composition

3.4.4.1 Determination of Peroxide Value

The peroxide value (PV) of the macadamia oil of the two varieties was determined using a titration method according to AOAC Official method Cd8-53 (1998). Peroxide value analysis test was carried out by extracting macadamia nuts oil from 50g of KRG-15 and MRG-20 samples using petroleum ether as a solvent for 4h Oil was concentrated by eliminating excess solvent using a rotary evaporator at 45°C for 45 min. The experiment was replicated in triplicate for both varieties.

3.4.4.2 Determination of Free Fatty Acid Value

The FFA content (as oleic) of the crude oil of the macadamia oil of the two varieties was determined using a titration method according to AOAC method 940.28. Six grams of macadamia oil was weighed into a 250 ml conical flask. In a second 250ml conical flask, 100 ml of 95% ethanol was heated and neutralized with 1-2 drops of 0.1 M KOH, 0.5 ml of 1% phenolphthalein indicator was then added. The hot neutralized alcohol (50 ml) was added to the oil, and this was boiled and titrated with 0.1M KOH (from 1 10 ml burette) while stirring until a definite pink colour persists for 15 s. The experiment was replicated for triplicate for both KRG-15 and MRG-20 varieties.

3.4.4.3 Determination of Free Fatty Acid Composition

This test was carried out using the gas chromatography method. The extraction of the lipids was done by a modification of the Bligh and Dyer method (1959). Three milligram of macadamia oil was weighed into the conical flask. Eight milligrams of Methanolic HCl solution were added. Heat was applied under reflux for an hour and cooled under tap water. Methyl esters was then extracted by transferring the solution into a separating funnel and adding 8 ml of hexane. This was Shaken vigorously and allowed stand. The hexane layer was collected, and the aqueous layer returned. The extraction was repeated one more time. The hexane fractions were combined and washed with 3 portions of distilled water to remove the acid. Filtration was achieved using defatted cotton wool and anhydrous Sodium Sulphate (enough sodium Sulphate was added to remove water). The filtrate was concentrated using rotary evaporator at 40°C to about 0.5-1ml. The sample was then injected into the GC (Shimadzu GC-9A). Using the standard reference spectrum determined sing the same GC condition, the spectrum of each sample was noted, and the fatty acid represented by the peak identified. The experiment was replicated thrice.

3.4.4.4 Determination of Rancidity Development

Thiobarbituric acid reactive substance (TBARS) test was used to assess the degree of rancidity development in the macadamia nuts sample after drying. This method was carried out using TBA spectrophotometric methods (MDA-TBA). The method of Tarladgis et *al.* (1960) as modified by Izumimoto et *al.* (1990) was applied. This involved mixing 10 g sample with distilled water and extracting with 20% trichloacetic acid (TCA). After 30 minutes, 5 ml aliquot of the filtrates was pipetted, and 5 ml (TBA) reagent added. The mixture was then stirred and heated in boiling water for 30 minutes. The absorbance of the pinkish colour formed was measured using spectrophotometer at 532nm. A blank was prepared using 20% TCA and TBA solution. The experiment was replicated thrice. TBARS was calculated as Malonaldehyde (MA, mg/kg) was calculated using Equation 3.6, in which E was the extinction value at 532nm:

$$MA = E532^{*}12.9$$

(0.6)

3.4.5 Data Analysis

In order to develop a thin layer mathematical model for the drying of macadamia nuts in different drying condition, the data acquired was used to plot graphs relating to temperature and relative humidity for tent dryer, moisture content and moisture ration with regard to time.

The drying data was fitted into equations in Table 2.1 and the best model for describing drying characteristics of macadamia nuts in different drying conditions determined. This required the use of statistical tools. That involved the determination of coefficient of determination (R^2), Chi square (x^2) and Root Mean Square Error (RMSE) using Equations 3.7-3.9, respectively. The drying rate was determined using Equation 3.10 These analyses were done using Microsoft 2013 Excel.

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} \left(MR_{pre,1} - MR_{exp,i} \right)^2}{\sum_{i=1}^{N} \left(MR_{pred} \bar{-} MR_{pre,i} \right)^2} \right)$$

(0.7)

$$x^2 = \sum_{i=1}^{N} \frac{\left(MR_{experimental\ \ value} - MR_{predicted\ \text{value}} \right)}{\text{N-n}}$$

(0.8)

$$RMSE = \sum_{i=1}^{N} \sqrt{\frac{\left(MR_{experimental\ \ value} - MR_{predicted\ \ value} \right)^2}{N}}$$

(0.9)

$$Drying\ rate = \frac{M_{t+dt} + M_t}{dt}$$

(0.10)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The results of the study are presented and discussed in this chapter with the focus on the main objective of the study, which was to evaluate the effect of drying methods on the quality of dried macadamia nuts by using colour imaging analysis techniques. The three specific objectives were: first, to develop colour index using imaging technique for evaluating quality of macadamia nuts second, to establish the effect of temperature on the quality of different species of macadamia nuts, and finally to evaluate the performance of the different dryers on KRG-15, and MRG-20 macadamia nuts.

4.2 Macadamia Quality Evaluation Using Colour Index and the Other Image Features

Colour index was determined for both KRG-15 and MRG-20 macadamia nuts dried at different temperature using different methods. These included, air drying at 50℃, 60℃ and 50-60℃, and solar tent drying, solar tent 60℃, and solar tent-MW. Three samples were randomly collected for KRG-15 and MRG-20 dried using the different methods. This was repeated in triplicate. The imaging data were obtained by using CDC and Minolta CR-200. The CDC images were then taken and uploaded to the PC with Imagej software, at the mean tabulated as shown in plate B1 and B2 in appendix B for KRG-15 and MRG-20 respectively. RGB values were collected and normalized using Equations 3.2-3.4 above. In addition, RGB colour change, browning index, White index, Lightness L^*, hue angle and saturation colour were determined.

The study showed that there was significant level of correlation ($P<0.05$, $R^2=0.9993$) between normalized colour of the KRG-15 and the colour difference calculated using the RGB extraction. The RGB colour change of the dried KRG-15 nuts was expressed (P<0.05) as a function of normalized colours C'b and C'r using Equation 4.1.

$$\Delta E_{RGB} = 44.73 - 10.33\ C'b + 8.20\ C'r \quad (0.1)$$

Similarly, regression analysis relating both hue angle and saturation colour of the dried KRG-15 nuts with normalized colour C'b and C'r yielded Equations 4.2 and 4.3 respectively with a linear relationship

$$Hue = 930.78 - 9.78\ C'b - 16.54\ C'r \quad (4.2)$$

$$Sat = 1 - 0.01\ C'b - 1.5E^{-16}\ C'r \quad (0.2)$$

As for MRG-20, the study showed that there was significant level of correlation (P<0.05) between normalized colours and the colour difference. This was same for both hue angle and saturation colour. The colour change of the dried MRG-20 nuts was expressed as a function of normalized colours of same dried nuts (Equation 4.4). Regression analysis relating both hue angle and saturation colour of the dried MRG-20 nuts with normalized colour of blue and red yielded Equations 4.5 and 4.6 respectively with a linear relationship.

$$\Delta E_{RGB} = 18.29\ C'b - 38.51\ C'r - 1898.41 \quad (0.3)$$

$$Hue = 311.37 - 1.70\ C'b - 5.89\ C'r \quad (0.4)$$

$$Sat = 1 - 0.01\ C'b - 2.13E^{-16}\ C'r \quad (0.5)$$

It was observed as shown in Figure 4.1 that colour blue value of dried KRG-15 gave better prediction of the ΔE_{RGB} during drying. This is because it consistently decreased as the ΔE_{RGB} increased. It was also observed in Figure 4.2 that the change in colour blue (ΔC'.b) increased with increase in total colour change ΔE_{RGB} unlike the change observed in green and red which decreased at some point. Shen (2003) also reported that colours of vegetables are classified to represent different qualities using colour difference. Similar result was observed when drying MRG-20 nuts as shown in Figure 4.3. This indicate that colour blue (c'b) of the macadamia nuts can be used to predict the colour of the dried nuts.

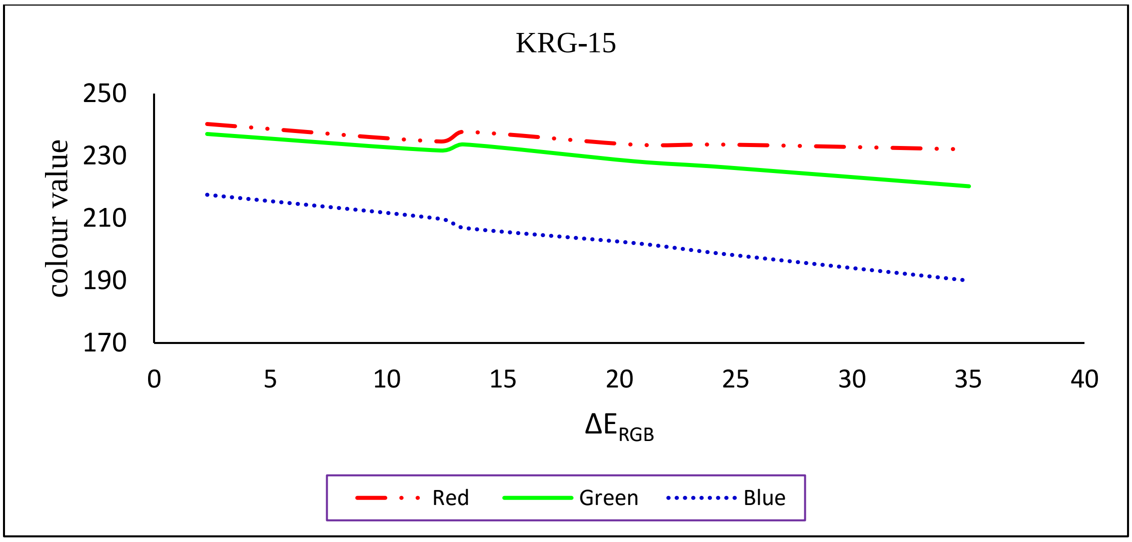

Figure 0.1: Relation between colour value and colour difference in RGB for KRG-15.

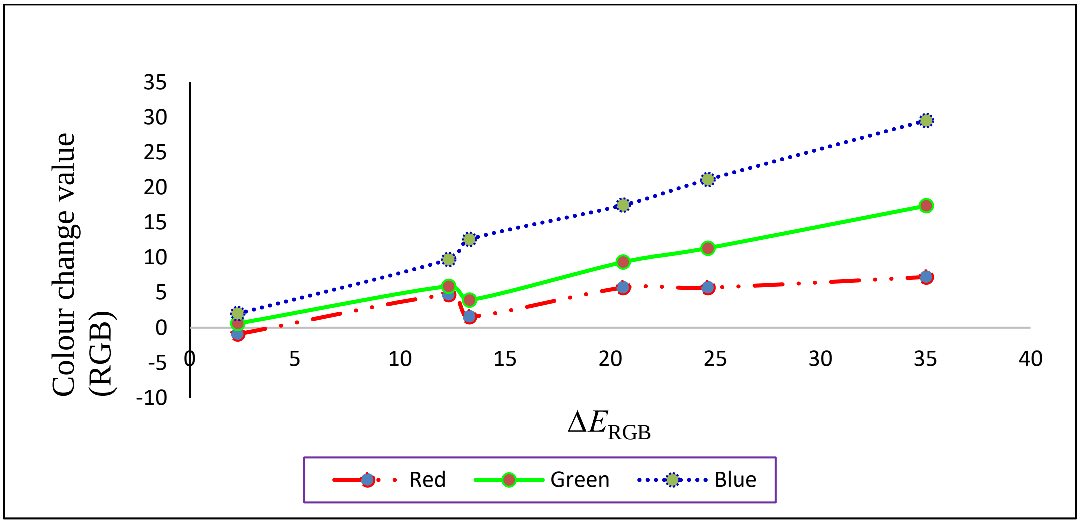

Figure 0.2: Relation between colour change and colour distance in RGB for KRG-15.

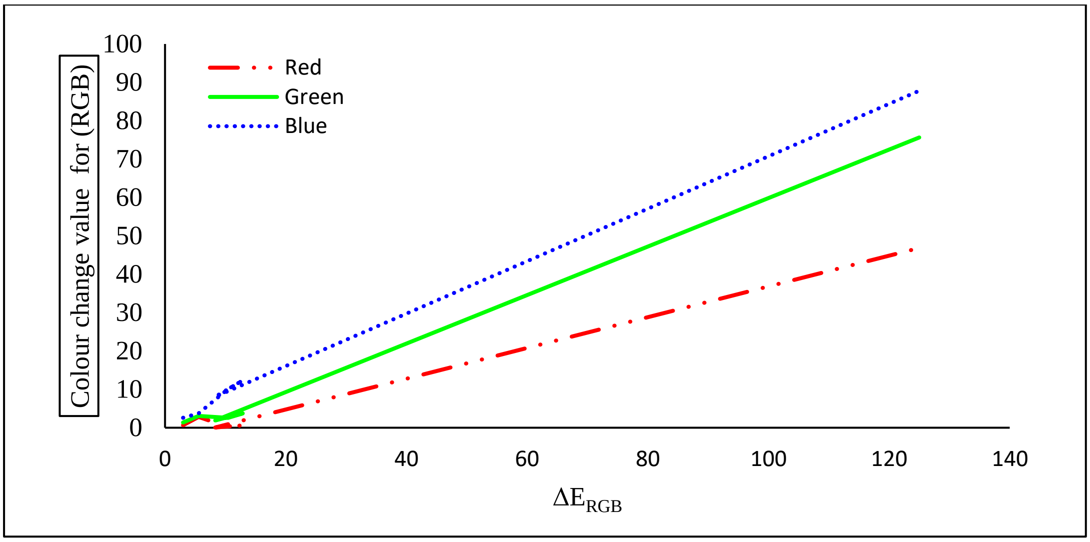

Figure 0.3: Relation between colour change and colour distance in RGB for MRG-20.

Similarly, the lightness L^* for the nuts was further expressed as a function of normalised colour blue (Equation 4.7) with a regression coefficient of 0.9118. The predicted value for the L^* was plotted against the observed value as shown in Figure 4.4.

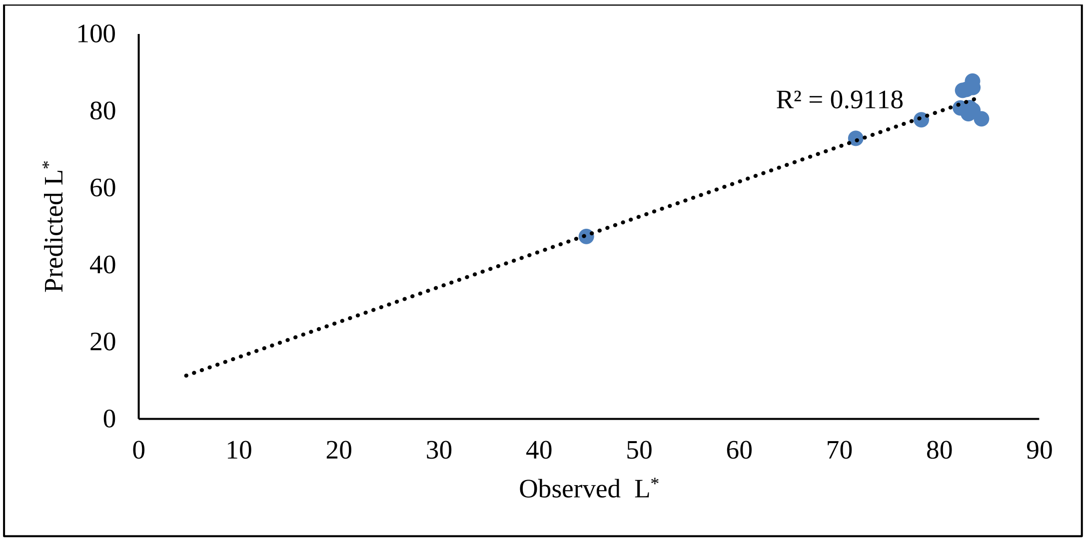

Figure 0.4: Comparison between the predicted Lightness with experimental Lightness values for the macadamia nuts.

$$L = 8.5933C'b - 181.289 \quad (0.6)$$

To assess the effect of heat on the browning of nuts, the browning index method was employed. The dryer with the least browning index was preferred. Hence the BI was also expressed as a function of normalised colour blue (Equation 4.8) with R^2 of 0.9238. The predicted value for the BI was plotted against the observed value as shown in Figure 4.5.

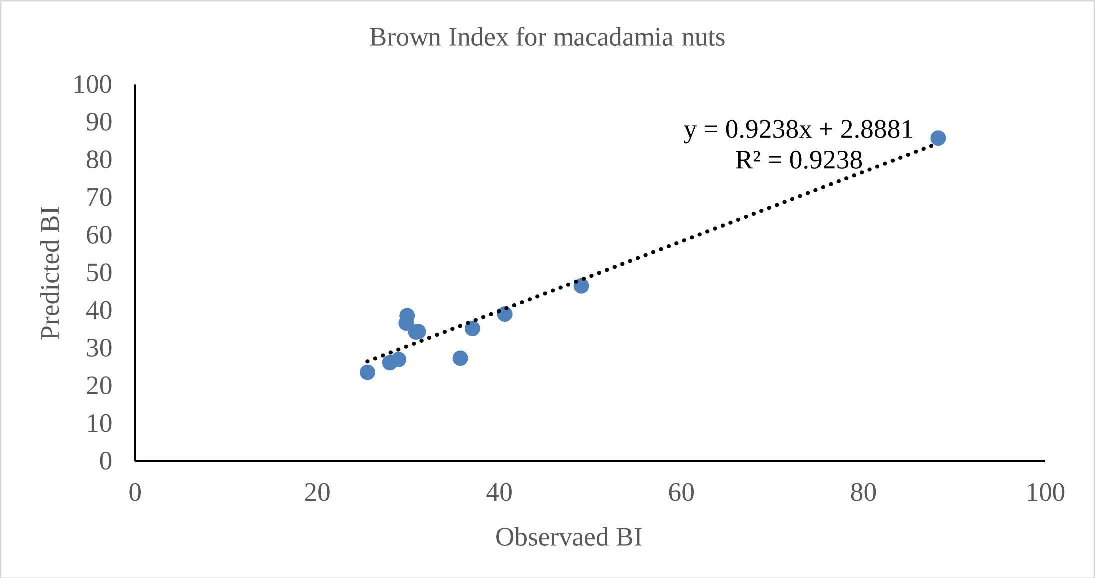

Figure 0.5: Comparison between the predicted Browning Index with experimental BI values for the macadamia nuts.

$$BI = 438.3975 - 13.2481C'b \qquad (0.7)$$

To classify the quality of macadamia nuts, BI was expressed in terms of White Index (WI) (Equation 4.9, R^2=0.9464). WI gave the human perception of macadamia nuts. Table 4.1 shows the grading of macadamia nuts based on BI developed from imaging analysis.

$$BI = 159.361 - 1.820WI \qquad (0.9)$$

Table 0.1: Grading of macadamia nuts using browning index

Browning index	Grade
25-31	1st grade
31-40	2nd grade
40-49	3rd grade
49-above	Reject

The results revealed that colour parameters could be used to monitor the browning of the KRG-15 and MRG-20 nuts dried using the various drying methods as was observed above by (Subhashree, Sunoj, Xue, & Bora, 2017). This is important since it can be used for grading nuts irrespective of the drying method. The application of this grading index can be used to describe the total acceptance colour standard for classification of the nuts when combined with the United Nations Economic Commission for Europe (UNECE) standards.

4.3 Effect of Drying Temperature on Quality of Different Species of Macadamia Nuts

4.3.1 Drying Kinetics

The two varieties were dried from a moisture content of 12.98 and 10.62% wet basis (w.b) for KRG-15 and MRG-20 respectively, to a moisture content of between 3.0-3.5% w.b. as shown in Figure 4.6. This variation was due to the difference in the moisture content at the farm level, since they were collected at different locations. The nuts were dried at a temperature of 50°C and 60°C with a constant air velocity of the dryer. At the initial drying period, the rate of moisture removal was high for both KRG-15 and MRG-20 for both temperatures as shown in Figure 4.7. From the same figure, it was observed that the drying rate was highest after 72 minutes of the continuous drying for all varieties and drying temperatures, but it slowed thereafter. Similar observations were made by Ndukwu (2009) when drying cocoa beans. This is because after the 72 minutes, it required more energy to break the molecular bond hence decrease in drying rate for both KRG-15 and MRG-20 nuts. It was also observed that the drying rate increases as the temperature increases.

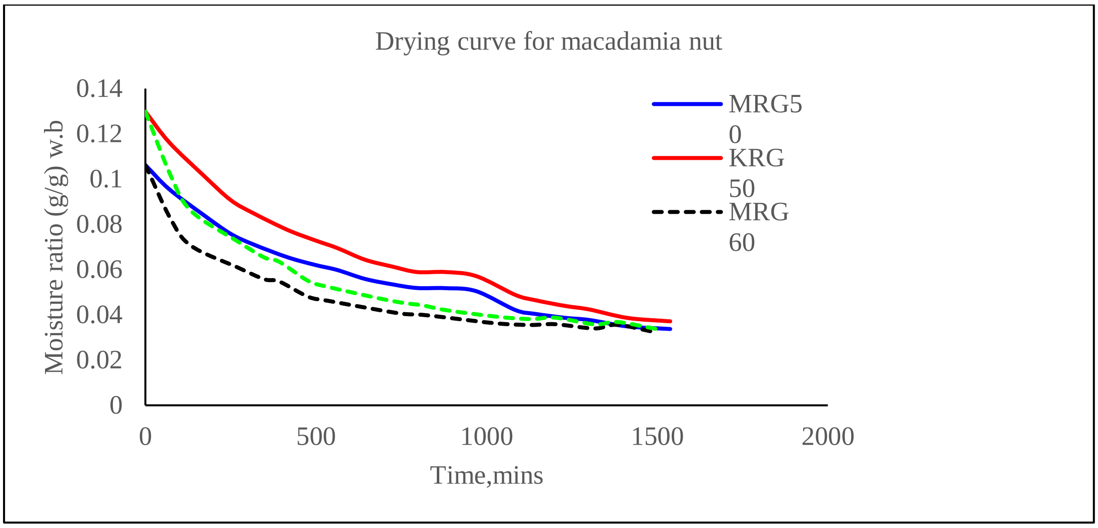

Figure 0.6: Drying curve for KRG-15 and MRG-20.

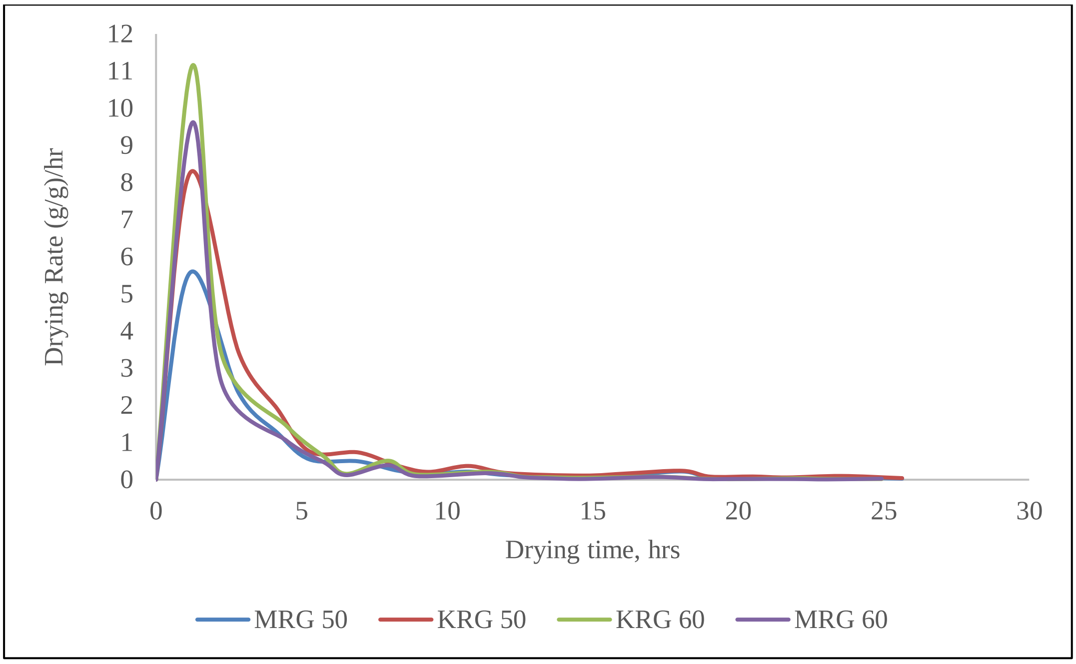

Figure 0.7: Drying rate curve.

4.3.1.1 Effective moisture diffusivity

The effective moisture diffusivity (D_{eff}) values evaluated during the drying of KRG-15, and MRG-20 dried at the temperatures of 50˚C, and 60˚C are summarized in Table 4.2. The computed D_{eff} for each variety represented the overall mass transport property of moisture in the material, which included liquid diffusion, vapour diffusion and other possible mass transfer mechanisms. Effective diffusivities found in this study were within the reported diffusivities for food materials during drying, which was 10^{-9} and 10^{-11} m^2/s. similar results have been reported by Kamwere et., al (2015) when drying kales, stinging nettle, cabbage and cowpea. The D_{eff} values for the oven dried samples at 60˚C were found to be higher compared to those of oven drying at 50˚C for the two varieties in the experiment. This is because effective diffusivity increases with the increase in temperature (Rafiee, et al., 2010). The D_{eff} for KRG-15 was higher than that of MRG-20 at all temperatures due to the difference in the initial moisture content at the time of drying.

Table 0.2: Comparison of effective moisture diffusivity for the KRG-15 and MRG-20 dried at temperatures of 50 and 60˚C

Varieties	Effective moisture diffusivity m^2/s	
	Temperature	
	50˚C	60˚C
KRG-15	2.46E-10	2.64E-10
MRG-20	2.05E-10	2.23E-10

4.3.1.2 Activation energy

The energy of activation for the macadamia nuts was calculated by using an Arrhenius Equation 4.10 (Garavand et. al. 2011), which represented the mass transportation of moisture in the nuts. These includes liquid diffusion, vapour diffusion or among others. Where E_a is the energy of activation (kJ/mol), R is universal gas constant (8.3143 kJ/mol), T_o is absolute air temperature (K), and D_0 is the pre-exponential factor of the Arrhenius equation ($m2s^{-1}$).

$$D = D_o\, exp(-\frac{E_a}{RT_o}) \quad (4.10)$$

Figure 4.8 shows the activation energy, which was determined by the plot of natural logarithm of effective diffusivity (ln D_{eff}) against the inverse of absolute temperature (1/T) The gradient of the curve gave the value of activation energy (E_a) to be 6.39 and 7.78 kJ/kg and diffusivity coefficient (D_o) to be 2.65E-09 m2/s and 3.72E-09m2/s for

KRG-15 and MRG-20 respectively. This difference may be attributed to the difference in the nature and structure of KRG-15 and MRG-20.

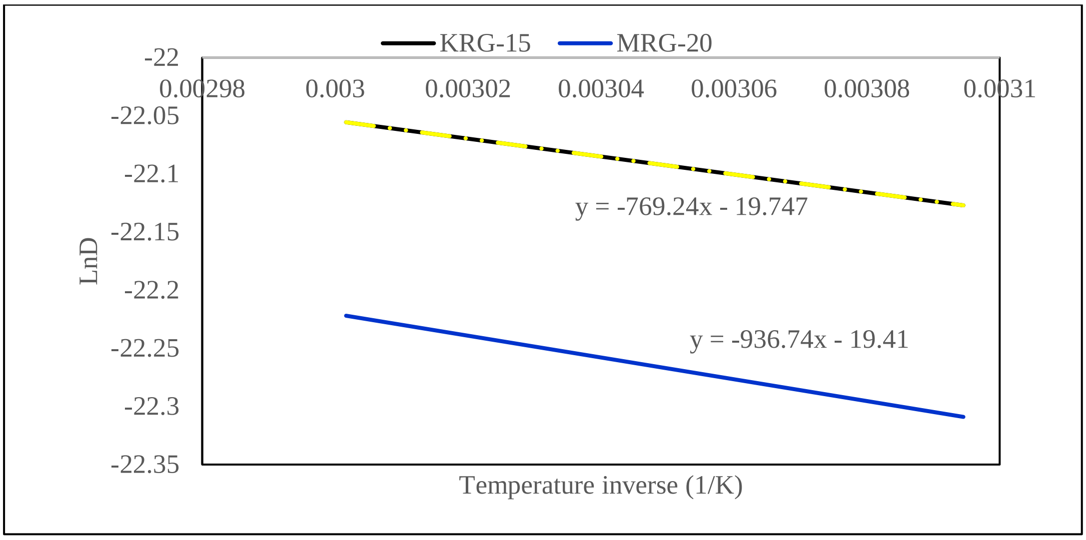

Figure 0.8: Relation between natural logarithm of effective diffusivity and temperature inverse.

4.3.2 Influence of Hot Air Temperature on Non-Enzymatic Browning

The browning index was generated using results shown in Table A1 and Table A2. From Table 4.3, MRG-20 nuts had the lowest browning index (BI) compared to KRG-15 nuts after drying. It was also observed that oven drying at 50˚C produced nuts with lower BI compared to nuts dried at the temperature of 60˚C. However, oven drying at both temperatures produced grade two nuts except when oven drying MRG-20 nuts at 50˚C, which produced grade one nuts. This classification was achieved using the grading system in Table 4.1 above. Increasing temperature results to nuts with high BI as shown in Table 4.3. Similar observations were made by GÖĞÜŞ & EREN (1998) when drying pepper.

Table 0.3: Brown Index of macadamia nuts after drying

Temperature	Browning index	
	KRG-15	MRG-20
50˚C	35.7173	28.01783
60˚C	40.58541	31.12226

4.4 Effect of other drying methods on quality of macadamia

4.4.1 Performance of Solar Tent Dryer at no Load

Figure 4.9 shows the mean temperatures for the four different sections in the dryer, the ambient and the solar radiation recorded between 25th to 29th February 2016.The results showed the maximum temperatures were recorded at 15:20 pm while maximum solar radiation occurred at 12:30 pm. The difference in time was due to the time required to heat the gauge 16 black mild sheet metal for heat transmission inside the dryer. Comparison between solar tent dryer and open sun drying temperature is shown in Table 4.4. It is apparent that the solar tent dryer temperature was significantly higher (p-value = 2.85E-14, F_{crit}, 5% = 4.196, $F_{computed}$, = 42.340). This indicates that the use of solar tent dryer is more efficient and reliable in comparison to open sun drying. Similar results were reported by Ojutiku, Kolo, & Mohammed (2009), Arun, Ayyappan, & Sreenarayanan (2014) and Arun, Balaji, & Selvan (2014).

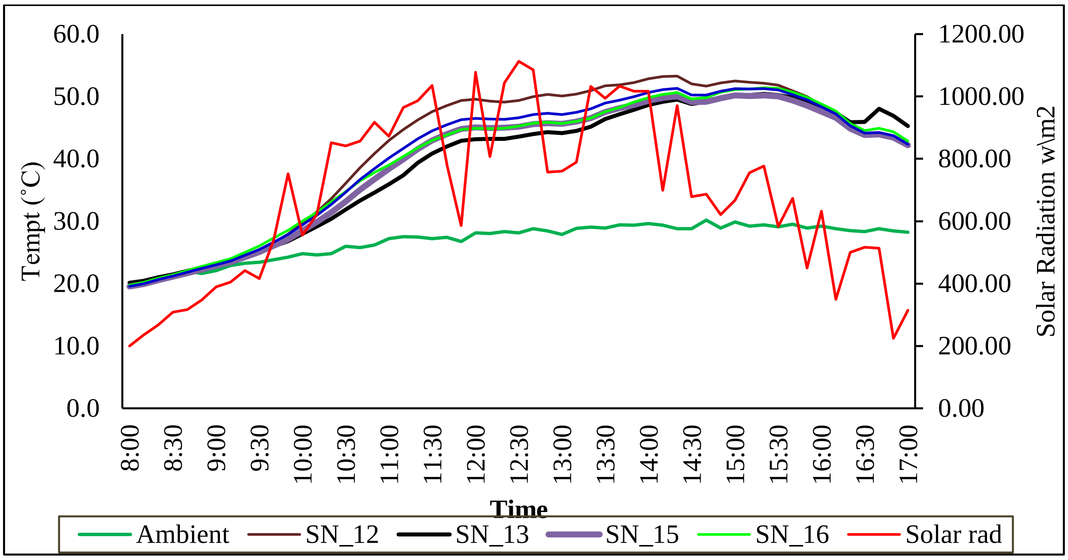

Figure 0.9: Temperature curve in the solar tent dryer.

Table 0.4: Anova for temperatures in solar tent dryer

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Between Groups	5250.0	2	2625.0	42.3	2.9E-14	3.081
Within Groups	6634.2	107	62.0			
Total	11884.2	109				

Figure 4.10 shows the mean relative humidity for the four different sections in the dryer, the ambient and the solar radiation. The results show that the minimum relative humidity was observed at 15:20 pm. Similarly, the results in Table 4.5 (p-value = 9.38E-11, F_{crit}, 5%, =3.93, $F_{computed}$ =51.5) show that there was significant difference in the relative humidity for ambient and solar tent dryer and open sun. The four different sections in the dryer have lower relative humidity than the ambient environment. This provided a conducive environment for drying macadamia nuts.

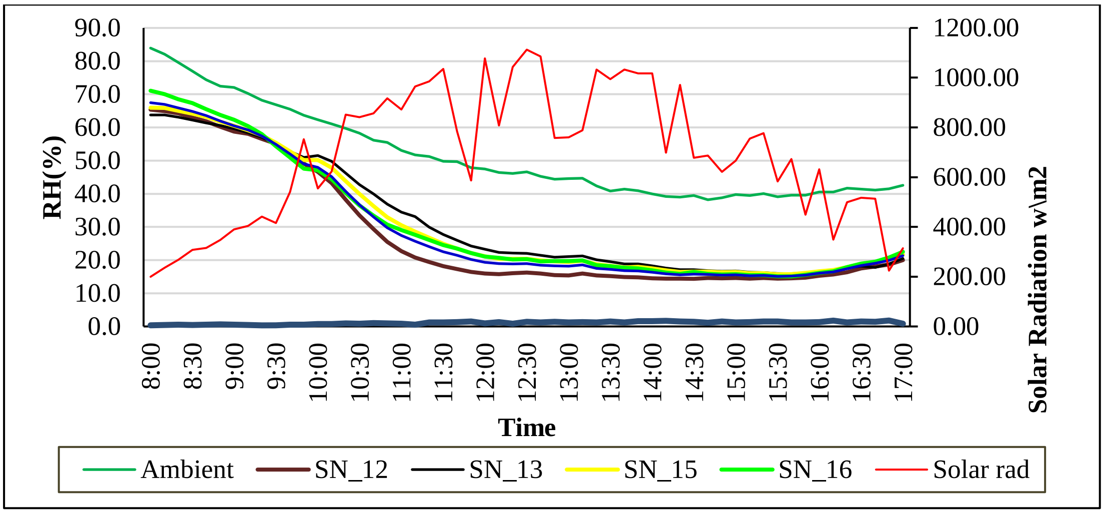

Figure 0.10: Relative humidity curve under solar tent dryer.

Table 0.5: ANOVA results for relative humidity distribution at inlet and solar tent dryer

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Between Groups	12957.2	1	12957.2	51.5	9.38E-11	3.93
Within Groups	27153.3	108	251.4			
Total	40110.6	109				

Where are the other subsections related to this i.e., 4.4.2, 4.4.3, among others.

4.4.2 Performance of Dryers under Load based on Drying Kinetics

4.4.2.1 Moisture Content

The two varieties were dried from an initial moisture content of 12.98 and 10.62% wet basis (w.b) for KRG-15 and MRG-20 respectively, to a moisture content of between 3.0-3.5% w.b. The drying curves for KRG-15 macadamia nuts dried using oven drying 50-60[1], solar tent dryer, solar tent-MW[2] dryer, and solar tent – oven 60[3] dryer is shown in Figure 4.11. The results revealed that the rate of moisture removal was high at initial drying stage which had steeper slope for all the drying methods but slowed thereafter except for solar tent-MW. At this stage, the free moisture is at the surface of the nuts which does not require long heating to be evaporated. The introduction of microwave when drying KRG-15 nuts resulted in increase in the rate of moisture removal and shortened drying time. This is because the introduction of microwave vibrates the polar molecules thereby resulting in localized heat within the KRG-15 nut water molecules, as observed by (Çelen, 2019) . Similar result was observed using MRG-20 as shown in Figure 4.12.

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[1] Oven 50-60 means nuts where air dried at 50^{o}C to 5% MC then air dried at 60^{o}C to 3-3.5% MC

[2] Solar tent-MW means nuts were dried in solar tent dyer to 5% MC then microwave dried to 3-3.5% MC

[3] Solar tent-60 means nuts where dried in solar tent dryer to 5% MC then air dried at 60^{o}C to 3-3.5% MC

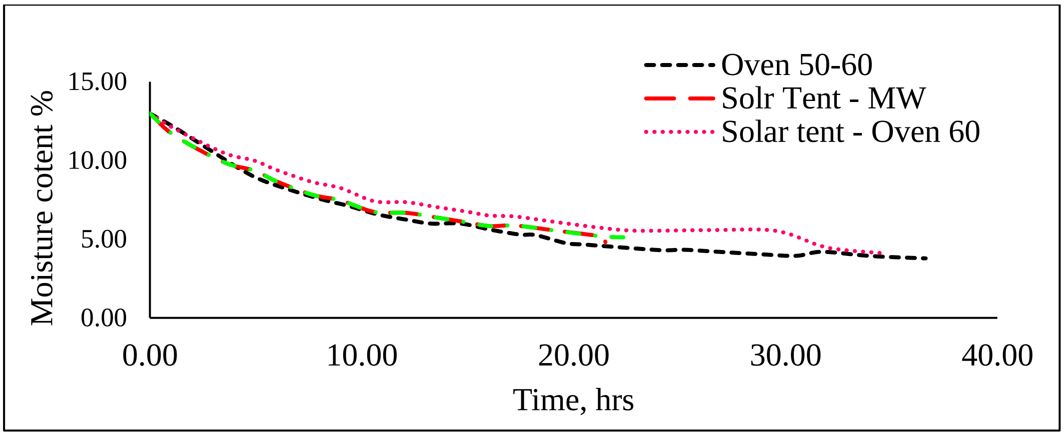

Figure 0.11: Drying curve for KRG-15.

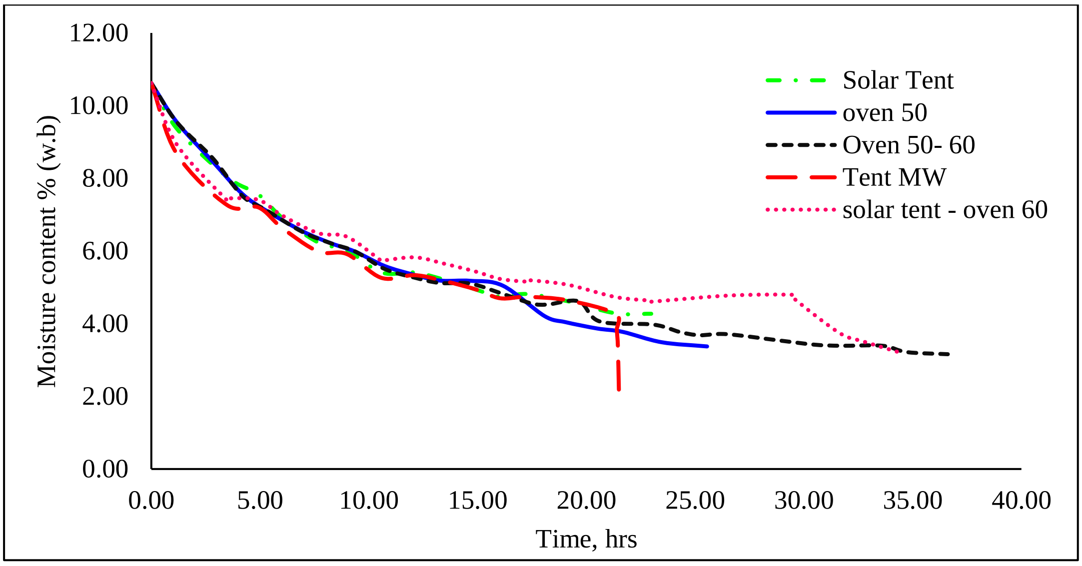

Figure 0.12: Drying curve for MRG-20.

4.4.2.2 Drying Rate

From Figures 4.13 and 4.14, the initial drying rate was high for all the drying processes but slowed down later. The falling rate of oven drying at 60°C was the highest with a drying rate of 2.4 (g/g)/hrs and 1.9 (g/g)/hrs for KRG-20 and MRG-20, respectively. The introduction of microwave dryer after solar tent drying increased the drying rate to 2.2 (g/g)/hrs and 2.3 (g/g)/hrs for KRG-20 and MRG-20, respectively. This is because the introduction of microwave power generated more heat within the nuts samples thereby creating a large vapour pressure difference between the centre of the nuts and the surface of the nuts (Zarein et. al. 2015). Similar result was observed when subjecting both KRG-15 and MRG-20 to oven drying at 60°C after drying the nuts using solar tent dryer since the nuts were further air heated at 60°C. The drying rate curve for solar tent dryer was not consistent due to unstable ambient temperature which influences relative humidity and temperature inside the dryer as was shown in Figures 4.9 and 4.10 above.

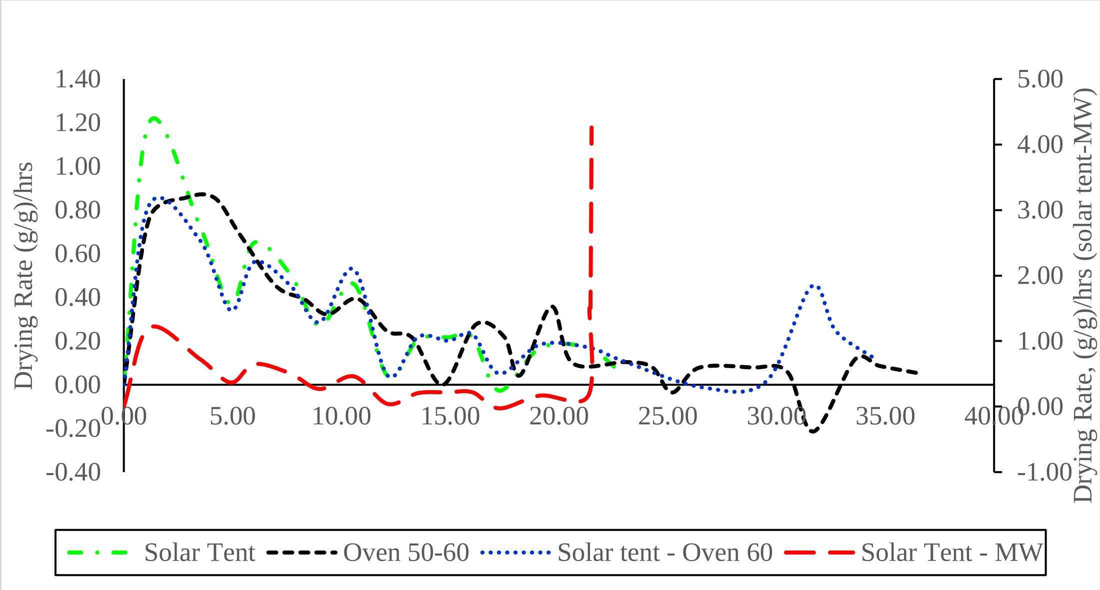

Figure 0.13: Drying rate curve for KRG-15.

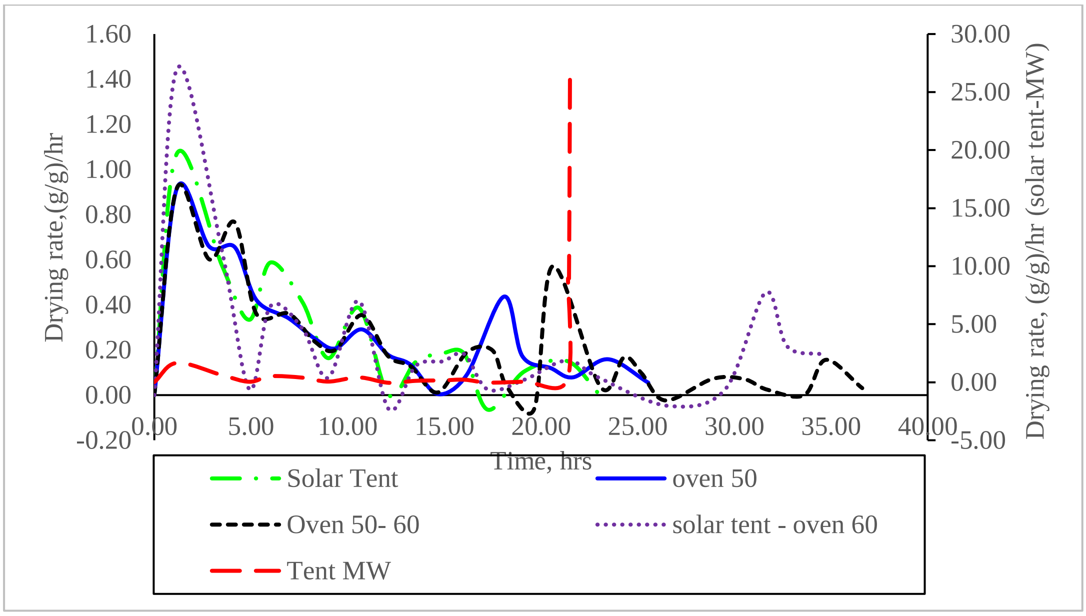

Figure 0.14: Drying rate curve for MRG-20.

4.4.2.3 Evaluation of thin layer drying models in drying of KRG-15 and MRG-20

The moisture ratio was obtained from the data obtained on moisture content (w.b.) versus drying time so as to enable the drying curve to be normalized using Equations 2.1 and 2.2. The curve fitting computations were carried out on the kinetic drying models listed above in Table 2.1. The models were evaluated based on their statistical indicators of R^2, RSME and χ^2 as listed in Tables 4.6 and 4.7 for KRG-15 and MRG-20, respectively

They were fitted for both KRG-15 and MRG-20 using Microsoft 2013 Excel solver. The best model of fit describing the thin layer drying parameter for both varieties were chosen as the ones with the highest R^2 and the lowest RSME and χ^2 value. Only seven of the eight models showed the goodness of fit with R^2 ranging from 0.9978-0.9585, RMSE; 0.0089-0.0755 and χ^2; 0.0001 – 0.0060 for KRG-15 and R^2 ranging from 0.8830 to 0.9973, RMSE; 0.0082-0.1595 and χ^2; 8.19E-05 – 0.026782 for MRG-20.

It was observed that Approximation of Diffusion and Modified Handerson and Pabis models were the best descriptive model as shown in Table 4.8 and cut across all the drying method. They had the highest R^2 values vary from 0.9835 – 0.09978 and 0.9369 – 0.9973 for KRG-15 and MRG-20 respectively for Approximation of Diffusion model and 0.9816 – 0.09976 and 0.9171 – 0.9968 for KRG-15 and MRG-20 respectively for Modified Handerson and Pabis model and, the lowest RSME and χ^2 value as indicated in Table 4.6 and 4.7. Hence, Approximation of Diffusion and Modified Handerson and Pabis models were the best of fit models which gave better prediction than other models and best described the drying characteristics of both KRG-15 and MRG-20 varieties on macadamia nut. Phusampao et al. (2014) and Aregbesola, et al. (2015) reported that Modified Handerson and Pabis model was the best fit model to describe the drying characteristic of macadamia nuts and dika nuts respectively.

Table 0.6: Coefficients and constants for different models for KRG-15

Drying Method	Model	Parameters	SSD	Rsq	Chi sq.	RSME
Solar tent dryer	1[4]	k=0.0009	0.0538	0.9585	0.0030	0.0532
	2[5]	k=0.0082, n=0.6644	0.0052	0.9906	0.0003	0.0165
	3[6]	a=0.6239, c=0.3653, k=0.0021	0.0018	0.9967	0.0001	0.0098
	4[7]	a=0 b=0	1.2337	0.6598	0.0726	0.2548
	5[8]	a=0.9993, b=0.0001, k=0.0030, n=0.8657	0.0017	0.9969	0.0001	0.0095
	6[9]	a=0.3, b=0.0335, k=0.0582, n=0.0487	0.0015	0.9972	0.0001	0.0089
	7[10]	a=0.8702, b=0.1298, k=0.007, g=0.5773	0.0167	0.9697	0.0011	0.0296
	8[11]	a=0.02223, b=0.3763, c=0.6011, k=0.4603, g=0.0000, p=0.0020	0.0015	0.9972	0.0001	0.0089
Oven at 50 degrees	1	k=0.013	0.0369	0.9877	0.0016	0.0392
	2	k=0.0050, n=0.7937	0.0056	0.9955	0.0003	0.0152
	3	a=0.8438, c=0.1177, k=0.0016	0.0113	0.9909	0.0005	0.0217
	4	a=0.0000, b=0.0000	2.7155	0.6996	0.1234	0.3364
	5	a=1.0040, b=0.0000, k=0.0052, n=0.7890	0.0055	0.9955	0.0003	0.0152
	6	a=0.4940, b=1034.9097, k=0.0000, n=1.7085	0.0035	0.9972	0.0002	0.0120
	7	a=0.8913, b=0.1087, k=0.0011, g=0.5773	0.0113	0.9910	0.0006	0.0217
	8	a=0.0000, b=0.7883, c=0.2166, k=0.4603, g=0.0010, p=0.0065	0.0043	0.9965	0.0002	0.0134
Oven at 60 degrees	1	k=0.0020	0.1197	0.9594	0.0060	0.0755
	2	k=0.0253, n=0.6015	0.0048	0.9951	0.0003	0.0152
	3	a=0.7844, c=0.1634, k=0.0032	0.0107	0.9889	0.0006	0.0226
	4	a=0.0000, b=0.0000	4.6028	0.5078	0.2423	0.4682
	5	a=0.9408, b=0.0001, k=0034, n=0.9460	0.0122	0.9875	0.0007	0.0241
	6	a=0.5672, b=0.0539, k=0.0579, n=0.4325	0.0022	0.9978	0.0001	0.0101
	7	a=0.7265, 0.2735, k=0.0014, g=0.5773	0.0262	0.9743	0.0015	0.0353
	8	a=0.1316, b=0.2581, c=0.6103, k=0.5194, g=0.0004, p=0.0033	0.0024	0.9976	0.0002	0.0106
solar tent dryer-oven at 60	1	k=0.0007	0.0668	0.9641	0.0027	0.0507
	2	k=0.0043, n=0.7377	0.0194	0.9795	0.0008	0.0273
	3	a=0.7258, c=0.2435, k=0.0011	0.0246	0.9738	0.0011	0.0308
	4	a=0.0000, b=0.0000	6.1391	0.0000	0.2558	0.4859
	5	a=1.0049, b=0.0000, k=0.0043, n=0.7376	0.0193	0.9795	0.0009	0.0272

[4] 1- Newton model

[5] 2- Page model

[6] 3- Logarithmic

[7] 4- Wang and Singh

[8] 5- Midilli

[9] 6- Approximation of diffusion

[10] 7- Two term

[11] 8- Modified Handerson and Pabis

	6	a=0.5663, b=2706.0676, k=0.0000, n=1.7555	0.0155	0.9835	0.0007	0.0244
	7	a=0.8931, b=0.1069, k=0.0006, g=0.5773	0.0300	0.9683	0.0014	0.0340
	8	a=0.0000, b=0.7717, c=0.2346, k=0.4603, g=0.0005, p=0.0038	0.0173	0.9816	0.0009	0.0258
oven 50-60 degrees	1	k=0.0010	0.0414	0.9836	0.0013	0.0354
	2	k=0.0024, n=0.8741	0.0265	0.9858	0.0009	0.0284
	3	a=0.8925, c=0.1071, k=0.0013	0.0210	0.9887	0.0007	0.0252
	4	a=0.0000, b=0.0000	12.9700	0/0000	0.4184	0.6269
	5	a=0.9880, b=0.00005, k=0.0009, n=1.0385	0.0201	0.9892	0.0007	0.0247
	6	a=0.9030, b=0.0528, k=0015, n=0.9716	0.0214	0.9885	0.0007	0.0255
	7	a=0.9472, b=0.0528, k=0.0009, g=0.5773	0.0335	0.9825	0.0012	0.0319
	8	a=0.0442, b=0.0978, c=0.8842, k=0.4603, g=0.0000, p=0.0012	0.0222	0.9881	0.0008	0.0259
Solar tent dryer-MW	1	k=0.0008	0.0451	0.9657	0.0027	0.0500
	2	k=0.0077, n=0.6740	0.0033	0.9942	0.0002	0.0135
	3	a=0.6451, c=0.3394, k=0.0019	0.0027	0.9951	0.0002	0.0123
	4	a=-0.0005, b=0.0000	0.0112	0.9848	0.0007	0.0249
	5	a=1.0109, b=0.0001, k=0.0066, n=0.7537	0.0112	0.9848	0.0008	0.0249
	6	a=0.7029, b=0.6678, k=0.0039, n=0.7044	0.0019	0.9966	0.0001	0.0102
	7	a=0.8706, b=0.1294, k=0.0007, g=0.5773	0.0126	0.9778	0.0009	0.0264
	8	a=0.0459, b=0.3228, c=0.6339, k=0.4603, g=0.000001, p=0.0017	0.0021	0.9962	0.0002	0.0109

Table 0.7: Coefficients and constants for different models for MRG-20

Dryer type	model	Parameters	SSD	Rsq	Chi sq.	RSME
Solar tent dryer	1	k=0.0009	0.069385	0.944668	0.003855	0.06043
	2	k=0.01057, n=0.6274	0.006946	0.986886	0.000409	0.019119
	3	a=0.6055, c=0.3833, k=0.0023	0.002254	0.995707	0.000141	0.010891
	4	a=0.0000, b=0.0000	-	-	-	-
	5	a=9986, b=0.0002, k=0.0033, n=0.8571	0.002188	0.995832	0.000146	0.010732
	6	a=11.9163, b=0.4392, k=0.0006, n=0.8997	0.002757	0.994892	0.000184	0.012047
	7	a=0.8517, b=0.1483, k=0.0007, g=0.5773	0.021059	0.960237	0.001404	0.033292
	8	a=0.0476, b=0.3689, c=0.5899, k=0.4603, g=7.5E-07, p=0.0020	0.002073	0.996053	0.000159	0.010446
Oven at 50 degrees	1	k=0.0012	0.037882	0.974669	0.001722	0.040584
	2	k=0.0050, n=0.7910	0.008152	0.993725	0.000388	0.018827
	3	a=0.8353, c=0.1233, k=0.0016	0.014302	0.984872	0.000715	0.024937
	4	a=-0.0005, b=0.0000	1.429083	0.837531	0.109929	0.308662
	5	a=1.0011, b=0.0002, k=0.0051, n=0.7897	0.008151	0.993805	0.000429	0.018825
	6	a=7.6048, b=0.5957, k=0.0011, n=0.9347	0.001556	0.99733	8.19E-05	0.008225
	7	a=0.8912, b=0.1080, k=0.0011, g=0.5773	0.012371	0.989149	0.000651	0.023192
	8	a=0.0000, b=0.8100, c=0.1951, k=0.3475, g=0.0010, p=0.0074	0.00662	0.994178	0.000389	0.016966
Oven at 60 degrees	1	k=0.0019	0.15533	0.943771	0.007767	0.086004
	2	k=0.0331, n=0.5546	0.005493	0.993845	0.000289	0.016174
	3	a=0.7527, c=0.1877, k=0.0034, n=0.5546	0.013837	0.984433	0.000769	0.025669
	4	a=0, b=0	1.851588	0.615826	0.097452	0.296936
	5	a=0.8900, b=2.2E-5, k=0.0230, n=0.6045	0.02232	0.994051	0.001313	0.032602
	6	a=4.9218, b=0.0354, k=0.0051, n=0.6096	0.002494	0.997195	0.000147	0.010897
	7	a=0.6937, b=0.3063, k=0.0012, g=0.5773	0.028657	0.968921	0.001686	0.036941
	8	a=0.1644, b=0.2318, c=0.6039, k=0.4603, g=0.0002, p=0.0030	0.002834	0.996811	0.000189	0.011618
solar tent dryer-oven at 60	1	k=0.0007	0.196422	0.883012	0.007857	0.086918
	2	k=0.0114, n=0.6090	0.08282	0.904322	0.003451	0.056439
	3	a=0.7877, c=0.0694, k=0.0007	0.100831	0.883286	0.004384	0.062275
	4	a=-0.0005, b=3E-07	0.599115	0.864586	0.024963	0.151799
	5	a=0.9652, b=0.0000, k=0.0079, n=0.6546	0.081628	0.905656	0.00371	0.056032
	6	a=10.3117, b=0.7236, k=0.0020, n=0.9429	0.054866	0.93688	0.002494	0.045937
	7	a=0.8063, b=0.1937, k=0.0005, g=0.5773	0.071722	0.917066	0.00326	0.052522

	8	a=0.1937, b=0.6759, c=0.1303, k=0.4603, g=0.0005, p=0.0005	0.071722	0.917066	0.003586	0.052522
oven 50-60 degrees	1	k=0.0018	0.83914	0.956149	0.026223	0.159463
	2	k=0.0029, n=0.9267	0.765485	0.956827	0.024693	0.152304
	3	a=0.9671, c=0.0000, k=0.0017	0.803451	0.960953	0.026782	0.156035
	4	a=-0.0005, b=-3E-07	2.848818	0.694762	0.091897	0.007452
	5	a=0.9857, b=0.0000, k=0.0024, n=0.9481	0.771642	0.958946	0.026608	0.152915
	6	a=0.0797, b=0.0012, k=0.8692, n=0.0223	0.028231	0.985132	0.000973	0.029249
	7	a=0.9401, b=0.0599, k=0.0010, g=0.5773	0.028814	0.98485	0.000994	0.029549
	8	a=0.0502, b=0.8281, c=0.1217, k=0.4603, g=0.0011, p=0.0005	0.028464	0.985012	0.001054	0.029369
Solar tent dryer-MW	1	k=0.0009	0.064035	0.930447	0.003767	0.059645
	2	k=0.0047, n=0.7590	0.041794	0.940741	0.002612	0.048186
	3	a=0.7613, c=0.2009, k=0.0013	0.046433	0.934153	0.003096	0.05079
	4	a=-0.0005, b=-3E-07	1.203344	0.756869	0.075209	0.258558
	5	a=0.9948, b=0.0000, k=0.0044, n=0.7670	0.041763	0.940786	0.002983	0.048168
	6	a=0.1525, b=0.0802, k=0.0089, n=0.9986	0.04051	0.942561	0.002894	0.04744
	7	a=0.8946, b=0.1054, k=0.0008, g=0.5773	0.043254	0.938666	0.00309	0.049021
	8	a=0.0071, b=0.8460, c=0.1469, k=0.4603, g=0.0007, 0.0083	0.040504	0.942571	0.003375	0.047437

From the results, Table 4.8 summarizes the drying model of best fit for KRG-15 and MRG -20 macadamia nuts varieties for the different drying methods.

Table 0.8: Summary of best of fit model for KRG-15 and MRG-20 for different drying method

Drying method	MRG-15	KRG-15
Solar tent dryer	log midilli Approximation of diffusion Modified Handerson and Pabis	Midilli Approximation of diffusion Modified Handerson and Pabis
Oven at 50 degrees	Page midilli Approximation of diffusion Modified Handerson and Pabis	Page Midilli Approximation of diffusion Modified Handerson and Pabis
Oven at 60 degrees	Page midilli Approximation of diffusion Modified Handerson and Pabis	Page Approximation of diffusion Modified Handerson and Pabis
solar tent dryer-oven at 60	Two term Approximation of diffusion Modified Handerson and Pabis	Approximation of diffusion Modified Handerson and Pabis
oven 50-60 degrees	Two term Approximation of diffusion Modified Handerson and Pabis	Midilli Log Approximation of diffusion Modified Handerson and Pabis
Solar tent dryer-MW	Approximation of diffusion Modified Handerson and Pabis	Page Approximation of diffusion Modified Handerson and Pabis

4.5 Effect of Drying Methods on Colour Parameters of KRG-15 and MRG-20 Nuts

4.5.1 L*C*h_o

4.5.1.1 Lightness (L*)

The L* value that indicates the degree of lightness of macadamia kernels, which ranged between 71.67 to 83.36 and between 44.75 to 84.21 for KRG-15 and MRG-20 respectively as shown in Table A5 and A6. Table 4.9 showed that the variety of macadamia nuts had no significant influence (P>0.05) on the lightness (L^*) parameter value of the dried nuts.

Table 0.9: An ANOVA showing the effect of both drying method and variety on lightness value

Source of Variation	SS	df	MS	F	P-value	F crit
Drying method	3199.99	6.00	533.33	14.02	1.5E-07	2.42
Variety	131.32	5.00	26.26	0.69	0.63	2.53
Error	1141.43	30.00	38.05			
Total	4472.73	41.00				

However, the drying method influenced the lightness (L^*) parameter value of the dried KRG-15 nuts and was statistically significant (p≤0.05) as shown in Table 4.10. Similarly, the drying methods also had a significant (p≤0.05) effect on lightness (L^*) parameter value of the dried MRG-20 nuts as shown in Table 4.11 (see Table A1 and A2 for the Lightness value for both KRG-15 and MRG-20, respectively). Thus, the L* value is a good parameter for monitoring the color change and thus can be used to selecting the drying method that produce good quality colour for the two varieties as observed by (Bagheri, Kashaninejad, Ziaiifar, & Aalami, 2019) when drying peanuts.

Table 0.10: An ANOVA showing effect of drying method on lightness of KRG-15 nuts

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	366.763	6	61.127	8.436	0.001	2.848
Within Groups	101.448	14	7.246			
Total	468.211	20				

Table 0.11: An ANOVA showing effect of drying method on lightness of MRG-20 nuts

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3849.984	6	641.664	154.941	5.549E-12	2.848
Within Groups	57.979	14	4.141			
Total	3907.963	20				

To determine which drying method resulted in this difference (L*), a Post-hoc test was carried out for both KRG-15 and MRG-20 nuts. Table 4.12 showed that the KRG-15 nuts varieties dried using Solar tent-MW were significantly different ($p \leq 0.05$) from those dried using solar tend dryer, oven drying at 50℃, solar tent-60℃ and oven drying 50-60℃. Similar result was observed when drying MRG-20 nuts as shown in Table 4.13. This is because solar tent-MW dryer produced dark nuts for both KRG-15 and MRG-20 nuts varieties. This means that solar tent-MW drying lowered the quality of the nuts for both varieties based on human perception.

Table 0.12: Post-hoc test on significance of drying method on lightness value for KRG-15 nuts

Comparison	absolute difference	critical range	Results
Initial to solar Tent	0.92	7.51	not significantly different
Initial to 50	1.90	7.51	not significantly different
Initial to solar Tent-60	1.21	7.51	not significantly different
Initial to 50-60	0.89	7.51	not significantly different
Initial to 60	6.04	7.51	not significantly different
Initial to solar Tent-MW	12.58	7.51	significantly different
Solar tent to 50	0.98	7.51	not significantly different
solar tent to solar tent-60	0.29	7.51	not significantly different
solar tent to 50-60	0.03	7.51	not significantly different
solar tent to 60	5.12	7.51	not significantly different
solar tent to solar tent-MW	11.65	7.51	significantly different
50 to solar tent-60	0.69	7.51	not significantly different
50 to 50-60	1.01	7.51	not significantly different
50 to 60	4.14	7.51	not significantly different
50 to solar tent-MW	10.68	7.51	significantly different
solar tent-60 to 50-60	-0.32	7.51	not significantly different
solar tent-60 to 60	4.83	7.51	not significantly different
solar tent-60 to solar tent-MW	11.37	7.51	significantly different

Comparison	absolute difference	critical range	Results
50-60 to 60	5.16	7.51	not significantly different
50-60 to solar tent-MW	11.69	7.51	significantly different
60 to solar tent-MW	-6.53	7.51	not significantly different

Table 0.13: Post-hoc test on significance of drying method on lightness value for MRG-20' lightness

Comparison	absolute difference	critical range	Results
Initial to solar Tent	2.16	5.67	not significantly different
Initial to 50	1.55	5.67	not significantly different
Initial to solar Tent-60	1.97	5.67	not significantly different
Initial to 50-60	0.68	5.67	not significantly different
Initial to 60	2.79	5.67	not significantly different
Initial to solar Tent-MW	40.14	5.67	*significantly different*
Solar tent to 50	0.61	5.67	not significantly different
solar tent to solar tent-60	0.18	5.67	not significantly different
solar tent to 50-60	1.48	5.67	not significantly different
solar tent to 60	0.63	5.67	not significantly different
solar tent to solar tent-MW	37.98	5.67	*significantly different*
50 to solar tent-60	0.42	5.67	not significantly different
50 to 50-60	0.87	5.67	not significantly different
50 to 60	1.24	5.67	not significantly different
50 to solar tent-MW	38.59	5.67	*significantly different*
solar tent-60 to 50-60	-1.29	5.67	not significantly different
solar tent-60 to 60	0.82	5.67	not significantly different
solar tent-60 to solar tent-MW	38.17	5.67	*significantly different*
50-60 to 60	2.11	5.67	not significantly different
50-60 to solar tent-MW	39.46	5.67	*significantly different*
60 to solar tent-MW	-37.35	5.67	not significantly different

4.5.1.2 Hue angle

The hue angle refers to a dominant colour or a specific wavelength of light in the light spectrum that is reflected when light falls on macadamia kernels. The hue angle parameter was calculated from the experimental data using Equation 2.9 above. The results of hue angle for both KRG-15 and MRG-20 nuts before and after drying using six different methods are presented in Table 4.14. The results show that the hue angle of the nuts dried using different drying methods increased compared to before drying (initial). However, the hue angle for MRG-20 dried using solar tent-MW dryer decreased compared to s before drying. This implies that the MRG-20 nuts became darker when dried using MRG-20.

An analysis of variance between the two varieties of macadamia nuts and the drying methods yielded the results shown in Table 4.15. From the result, it was observed that the variety of macadamia nuts had no significant influence (P>0.05) on the hue angle parameter of the dried nuts. However, the drying method influence on the hue angle parameter was statistically significant (p≤0.05). This led to a further analysis to see the effect of drying methods on both KRG-15 and MRG-20.

Table 0.14: Hue angle variation for both KRG-15 and MRG-20 from different drying method

Drying Method	KRG-15	MRG-20
Initial	263.4±1.01	262.35±0.61
Solar Tent	262.8±0.01	263.39±1.17
50	266.2±0.78	263.54±0.58
Solar Tent -60	267.4±2.68	265.82±0.30
50-60	266.3±0.36	265.02±1.01
60	269.5±2.63	265.73±1.99
Solar Tent-MW	267.9±4.98	67.83±0.90

Table 0.15: Two-way ANOVA of macadamia nuts for Hue angle data

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Drying method	50725.941	6	8454.323	5.208	0.001	2.421
Variety	8808.433	5	1761.687	1.085	0.389	2.534
Error	48702.463	30	1623.415			
Total	108236.836	41				

A further ANOVA test at 5% level of significance for the KRG-15 nuts shown in Table 4.16, shows that there was no significance difference (P<0.05) in the hue angle between the KRG-15 nuts dried using the different methods. However, the difference in hue angle between MRG-20 nuts was significant due to the method of drying used. Hence, the post-hoc was carried out see which drying methods resulted in this difference when drying MRG-20 nuts. From Table 4.17, it was shown that hue angle for MRG-20 nuts dried using solar tent-MW dryer triggered this difference when compared MRG-20 nuts dried with the other drying methods. It was also observed that MRG-20 nuts dried using solar tent-60 differed significantly from the initial condition of the nuts before drying. From the result, it is evident that solar tent-MW produces low quality MRG-20 nuts after drying as observe in Figure 4.18. Solar tent-60 dryer slightly affects the colour quality since the difference is observed when compared to the initial condition.

Table 0.16: An ANOVA showing effect of drying method on Hue angle for KRG-15 nuts

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	65.893	6	10.982	2.071	0.123	2.848
Within Groups	74.257	14	5.304			
Total	140.150	20				

Table 0.17: An ANOVA showing effect of drying method on Hue angle for MRG-20 nuts

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	99291.873	6	16548.646	15322.670	6.827E-26	2.848
Within Groups	15.120	14	1.080			
Total	99306.993	20				

Table 0.18: Post-hoc test for MRG-20 hue angle

Comparison	absolute difference	critical range	Results
Initial to solar Tent	1.04	2.90	not significantly different
Initial to 50	1.19	2.90	not significantly different
Initial to solar Tent-60	265.82	2.90	*significantly different*
Initial to 50-60	2.67	2.90	not significantly different
Initial to 60	3.38	2.90	*significantly different*
Initial to solar Tent-MW	194.51	2.90	*significantly different*
Solar tent to 50	0.16	2.90	not significantly different

Comparison	absolute difference	critical range	Results
solar tent to solar tent-60	2.43	2.90	not significantly different
solar tent to 50-60	1.63	2.90	not significantly different
solar tent to 60	2.34	2.90	not significantly different
solar tent to solar tent-MW	195.55	2.90	*significantly different*
50 to solar tent-60	2.28	2.90	not significantly different
50 to 50-60	1.48	2.90	not significantly different
50 to 60	2.19	2.90	not significantly different
50 to solar tent-MW	195.71	2.90	*significantly different*
solar tent-60 to 50-60	0.80	2.90	not significantly different
solar tent-60 to 60	0.09	2.90	not significantly different
solar tent-60 to solar tent-MW	197.98	2.90	*significantly different*
50-60 to 60	0.71	2.90	not significantly different
50-60 to solar tent-MW	197.19	2.90	*significantly different*
60 to solar tent-MW	-197.90	2.90	not significantly different

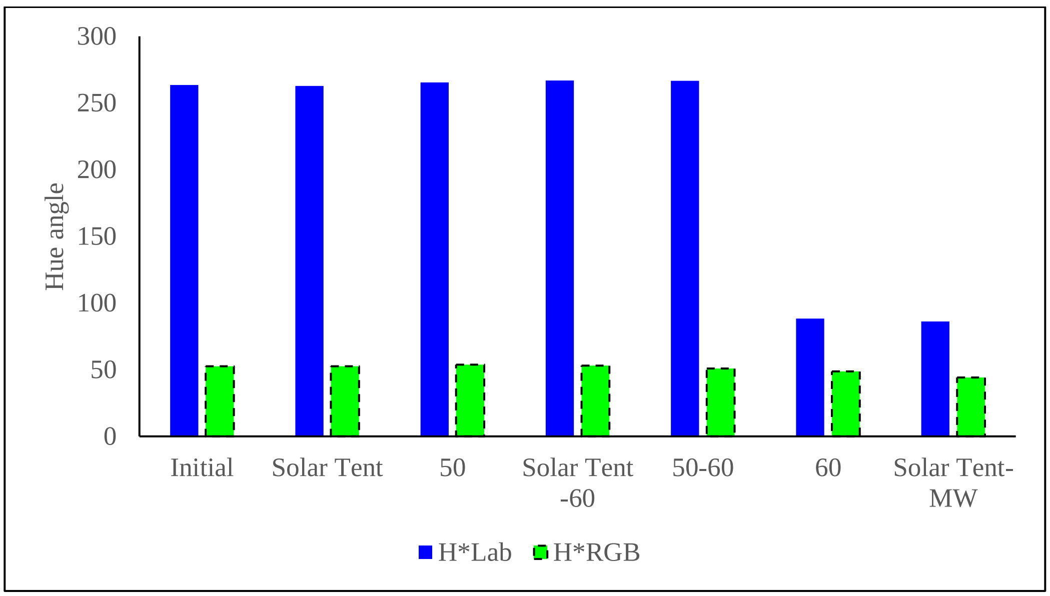

Figure 0.15: Hue angle graph for KRG-15.

Figure 4.15 shows that KRG-15 nuts dried using oven drying at 60˚C and solar tent-MW dryer had the greatest drop in hue angle value from the initial value for both colour models. This changed from the dominant colour type blue to yellow. This means that the nuts were browning due to drying the KRG-15 nuts using Oven drying at 60℃ and solar tent-MW.

The CIE hue value for the nuts is more conspicuous compared to RGB hue value. The correlation coefficient between hue angles for CIE_{Lab} and RGB was found to be 0.783 yielding Equation 4.11. This means that the hue angle obtained using the RGB values can be computed using this formula mimic human perception of the dried KRG-15 nuts.

$$H^*_{Lab} = 96.531 - 1.744H^*_{RGB} \quad (0.11)$$

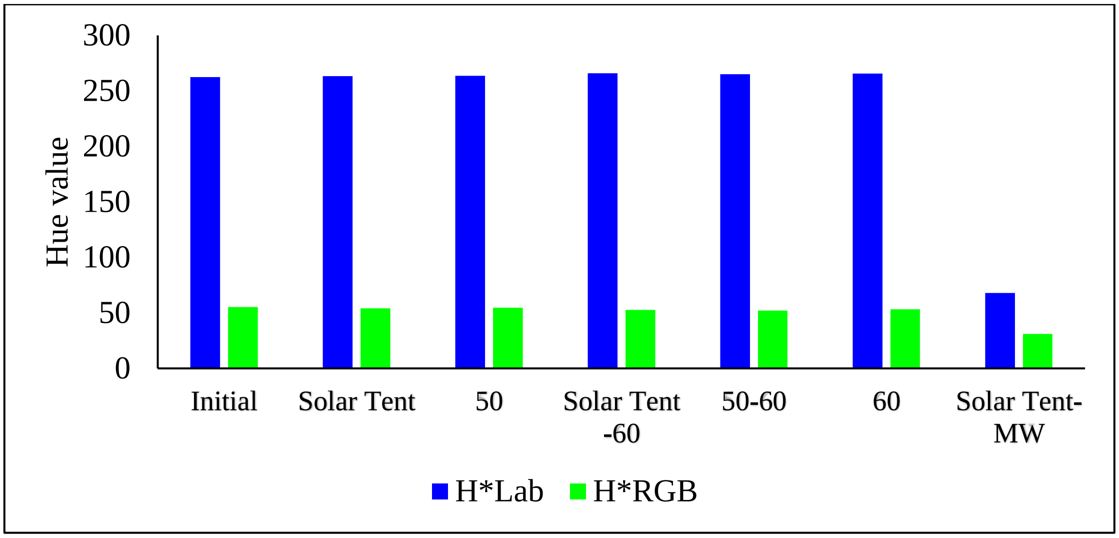

Figure 0.16: Hue angle graph for MRG-20.

Similarly, Figure 4.16 shows that MRG-20 nuts dried using a combination of solar tent-MW had the greatest change in hue angle value for both colour models. The correlation coefficient between hue angles for used colour models used was found to be 0.991 yielding Equation 4.12.

$$H^*_{Lab} = 22.526H^*_{RGB} - 932.1 \quad (0.12)$$

4.5.1.3 Chroma

The results of Chroma values for both KRG-15 and MRG-20 nuts before and after drying using six different methods are presented in Table 4.19. From the ANOVA analysis, shown in Table 4.20, it was observed that the variety of macadamia nuts had no significant influence (P>0.05) on the Chroma parameter of the dried nuts. In addition, it was also observed that the drying method had no influence (P>0.05) on the Chroma parameter of the dried nuts. This means that it differentiating KRG-15 from MRG-20 nuts after drying would occur by chance.

Table 0.19: Chroma variation for KRG-15 and MRG-20 from different dryers

Drying Method	KRG	MRG
Initial	21.2±2.1	21.39±3.23
Solar Tent	21.1±2.9	23.19±3.53
50	22.7±2.3	22.67±4.53
Solar Tent -60	23.5±2.7	23.10±3.58
50-60	23.6±3.0	23.76±2.98
60	28.1±2.8	23.75±3.40
Solar Tent-MW	27.8±1.0	25.76±1.90

Table 0.20: Two-way ANOVA of macadamia nuts' chroma da**ta**

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Drying method	52.759	6	8.793	2.288	0.081	2.661
Variety	3.896	3	1.299	0.338	0.798	3.160
Error	69.191	18	3.844			
Total	125.846	27				

4.5.2 RGB Total Colour Change (ΔE_{RGB})

From Table 4.21, it was observed that the variety of macadamia nuts had influence on the total colour difference parameter, which was statistically significant (p≤0.05). In addition, it was also observed that the drying method influence of the total colour change for both KRG-15 and MRG-20 was statistically significant (p≤0.05). This was the same when observing the difference (p≤0.05) between MRG-20 nuts. This difference was is shown in

Figures 4.17 and 4.18 when using either RGB or CIE_{Lab*} colour model. According to Srichamnong & Srzednicki, (2015), browning of macadamia nuts variety's kernel tend to differ and also influenced by temperature. The drying the KRG-15 and MRG-20, the reducing sugars reacted with the kernel proteins causing the formation of brown pigments, hence resulting in colour difference as observed.

Table 0.21: Two-way ANOVA for total colour chan**ge**

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Drying method	8380.583	6	1396.764	8.591	1.8E-05	2.421
Variety	8256.572	5	1651.314	10.156	9.1E-06	2.534
Error	4877.620	30	162.587			
Total	21514.775	41				

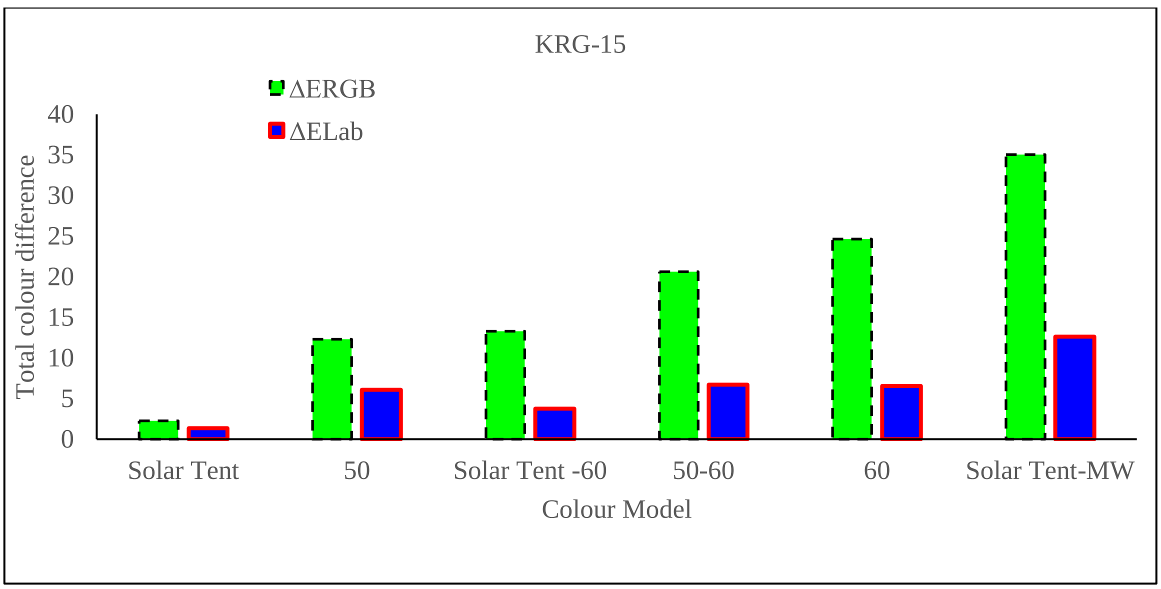

Figure 0.17: Total colour difference graph for KRG-15.

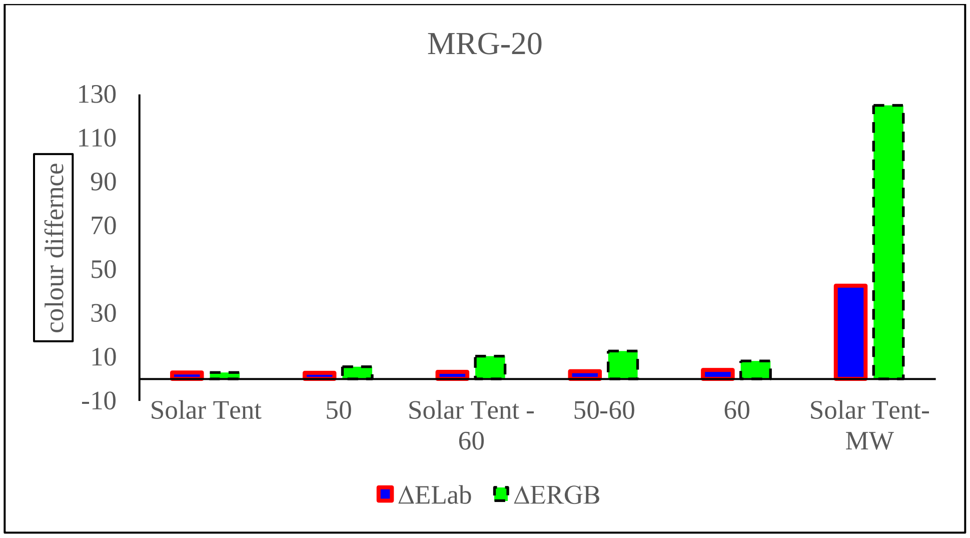

Figure 0.18: Total colour difference graph for MRG-20.

It was observed that it is easier to identify the effect of drying method using ΔE_{RGB} as compared to ΔE_{La*b*}. In the RGB colour model, the highest colour changes were observed on KRG-15 dried using both solar tent dryer and microwave oven (Solar-MW) and oven drying at 60°C. ΔE_{RGB} was more pronounced that ΔE_{La*b*}. hence giving better view for differentiating the nuts.

Since the CIE La^*b^* colour system mimics human vision, a regression model was developed to describe the relationship between CIE La^*b^* and RGB. From Table 4.22, there was a strong ($p \leq 0.05$) linear relationship between RGB colour change, ΔE_{RGB} of dried MRG-20 and CIE colour change the colour change, $\Delta E_{La^*b^*}$ determined using Minolta colorimeter. The regression analysis yielded Equation 4.13 with a correlation coefficient of 0.888. This means that it is possible to tabulate the values of $\Delta E_{La^*b^*}$ for MRG-20 nuts from the values of ΔE_{RGB} obtained using CCD in the lab.

Table 0.22: ANOVA for correlation of CIE colour difference with RGB colour distance in KRG-15 nuts

	df	SS	MS	F	Significance F
Regression	1	63.049	63.049	31.664	0.0049

Residual	4	7.965	1.991		
Total	5	71.014			

$$\Delta E_{Lab} = 0.313\Delta E_{RGB} + 0.531 \quad (0.8)$$

Similar observations were observed with MRG-20. Figure 4.17 shows the total colour change for both RGB and La*b* colour models. The highest colour changes for RGB model were observed on MRG-20 nuts dried using both solar tent dryer and microwave oven (Solar tent-MW). This was also observed when using La*b* colour model. The regression analysis yielded Equation 4.14 that was significant ($p \leq 0.05$) as shown in Table 4.23 with a correlation coefficient of 0.996 between colour changes for colour models used.

$$\Delta E_{Lab} = 0.334\Delta E_{RGB} + 0.746 \quad (0.14)$$

Table 0.23: ANOVA for correlation of CIE colour difference with RGB colour distance in MRG-20 nuts

	df	SS	MS	F	Significance F
Regression	1	1277.516	1277.516	996.392	6.0E-06
Residual	4	5.129	1.282		
Total	5	1282.645			

4.5.3 Non-enzymatic Browning

Table 4.24 shows the BI for both KRG-15 and MRG-20 varieties of macadamia nuts that were dried using the six drying methods. It was observed that as the temperature increased from 50^{o}C to 60^{o}C, the browning index increased from 35.75 to 40.63 and 28.00 to 31.10 for KRG-15 and MRG-20, respectively. Similar observation was reported by (Olatidoye, et al., 2017) when roasting cashew nuts. Using the classification index, oven drying at 50^{o}C produced 1st grade MRG-20 nuts and 2nd grade KRG-15 nuts, while air dried at 60^{o}C produces 2nd grade MRG-20 nuts and 3rd grade KRG-15 nuts. This means that when oven drying, avoid mixing KRG-15 and MRG-20 nuts.

Regarding the other drying methods, it was observed that solar tent-MW affect the colour of the nuts with BI of 49.03 and 88.21 for KRG-15 and MRG-20 respectively. Using the classification index in Table 4.1, drying nuts using solar tent dryer and Solar tent-60 would result to 1st grade nuts for both KRG-15 and MRG-20 nuts, while drying nuts using Oven 50-60 is likely to produce 1st grade MRG-20 nuts and 2nd grade KRG-15 nuts.

Table 0.24: Browning index for macadamia nuts

	Browning Index	
Drying Method	KRG-15	MRG-20
Solar Tent	25.52	28.94
Oven 50	35.73	28.00
Solar Tent -60	30.82	29.78
Oven 50-60	37.06	29.88
Oven 60	40.63	31.10
Solar Tent-MW	49.03	88.21

4.6 Texture Analysis

4.6.1 Statistical Texture Parameters Extraction from GLCM

4.6.1.1 KRG-15

Figures 4.19-4.23 shows the means of the five GLCM texture parameters (angular second moment, homogeneity, contrast, variance, and correlation) of KRG-15 nuts dried using different drying methods in all directions (0˚, 45˚, 90˚ and 135˚). From Figure 4.19, the contrast value for KRG-15 nuts dried using oven dryer at 50°C, 50-60°C and solar tent-MW were higher compared to the contrast for KRG-15 nuts that were dried using other drying methods in all the directions. Figure 4.20 further shows that these dryers produced KRG-15 nuts with the highest contrast value at 0° direction and were significantly different ($P \leq 0.05$) from those dried using Solar tent, solar tent-60°C and the nuts before drying. However, this difference was inconclusive when comparing to those dried at 60°C. This means that drying KRG-15 nuts using oven dryer at 50°C, 50-60°C and solar tent-MW triggered high local variation in KRG-15. This resulted in loss of the bright creamy white colour of the KRG-15 nuts due to the brown spots observed on their surface while those dried using solar tent and solar tent-60°C produced nuts with lower local variation. The nuts dried at an oven temperature of 60°C had a mixture of high and low local variation. Figure 4.21 shows that the nuts dried using oven dryer at 50°C and 50-60°C were less homogeneous as compared to those dried using the other drier due to inconsistency of the colour texture of the nuts after drying.

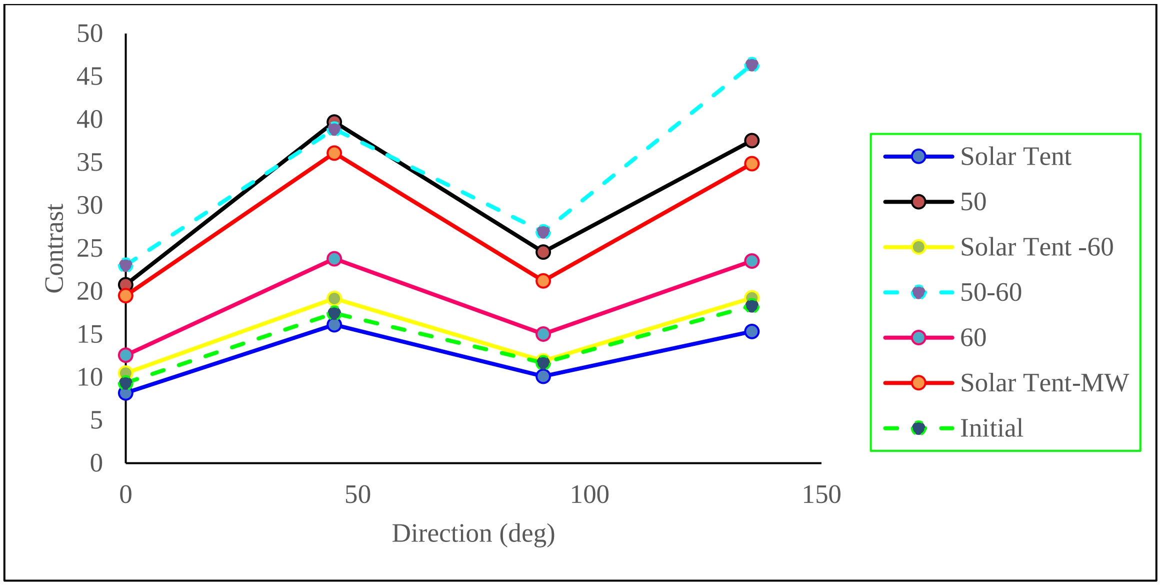

Figure 0.19: Contrast value graph for KRG-15 in all directions.

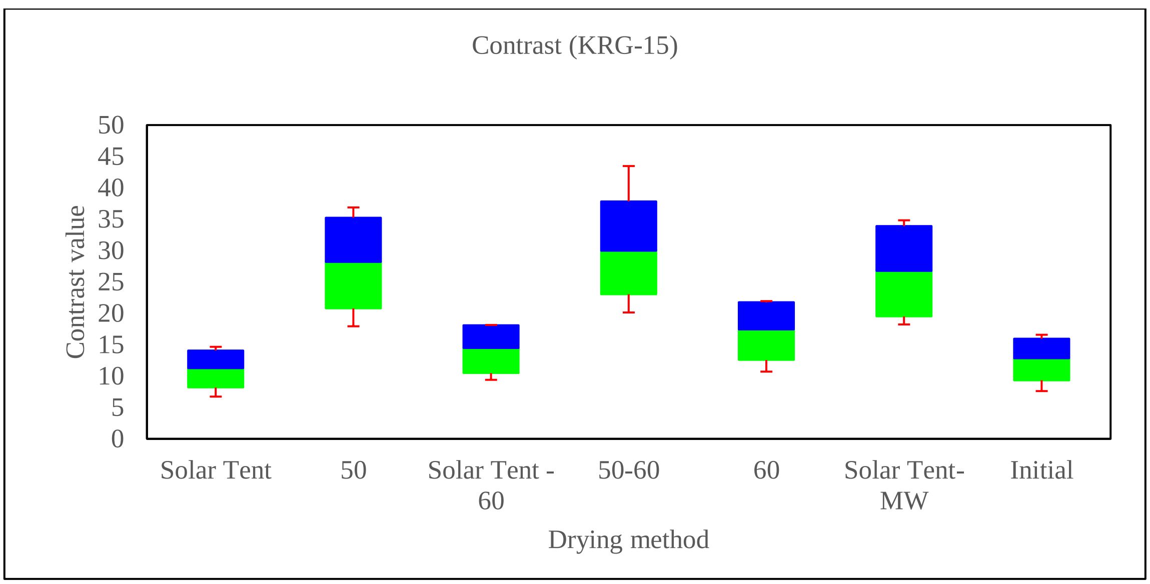

Figure 0.20: Contrast value graph for KRG-15.

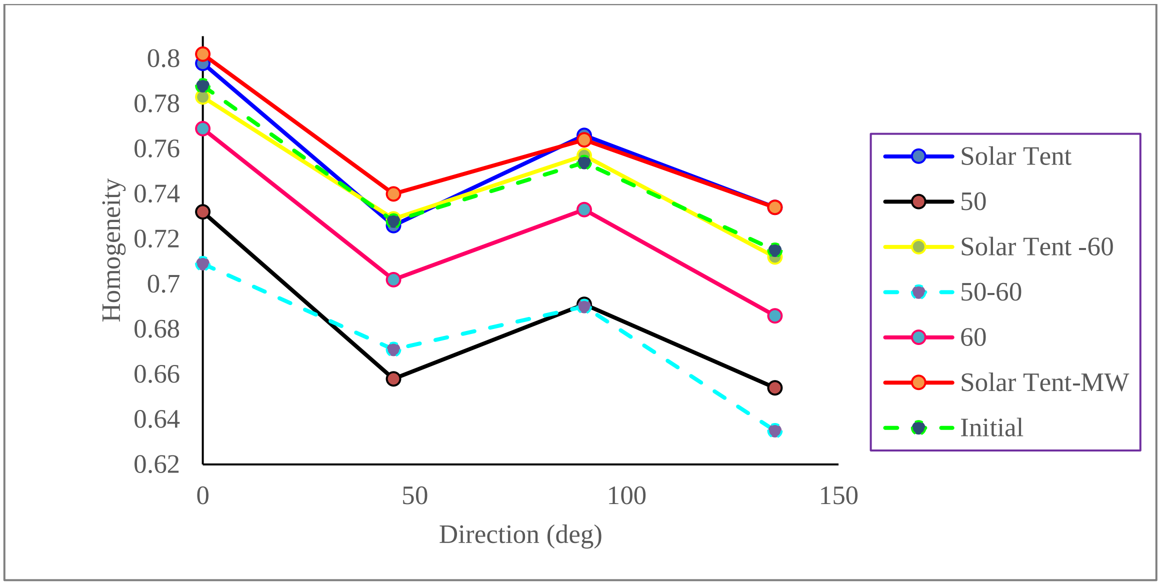

Figure 0.21: Homogeneity graph for KRG-15 in all directions.

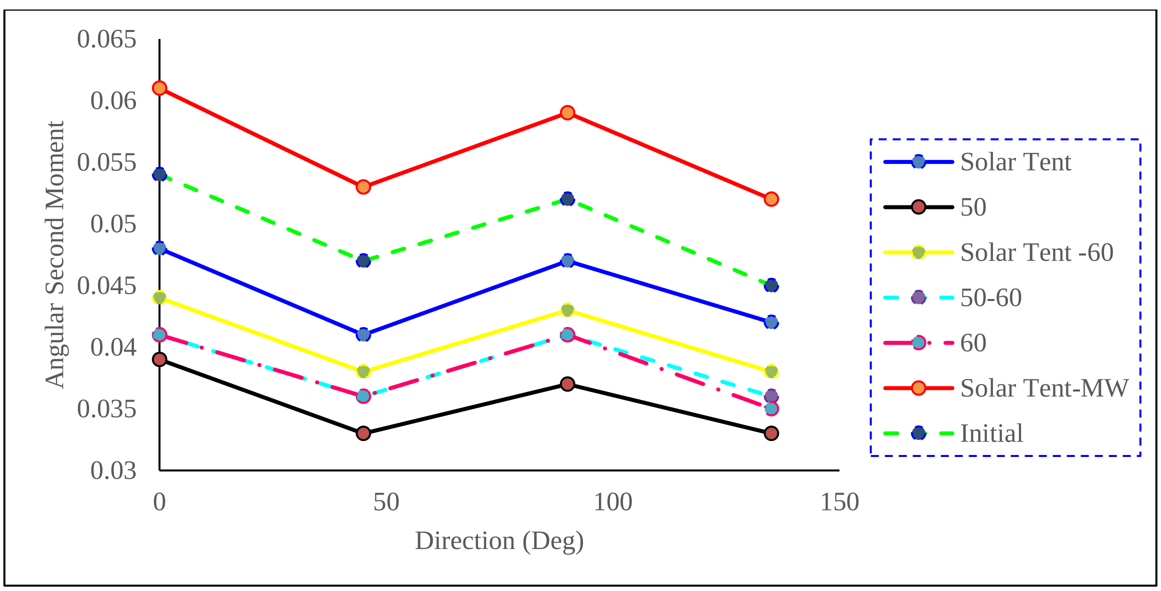

Figure 0.22: Angular second moment curve for KRG-15 in all directions.

From Figure 4.22, ASM for solar tent –MW was the highest followed by solar tent dryer, solar tent-60, oven drying at 50-60 and 60 but was least in oven drying at 50 for all directions. This indicates that KRG-15 nuts dried using solar tent and microwave have uniform local texture distribution as compared to the other drying methods. From Figure 4.23, the low correlation values of KRG-15 nuts dried using solar tent-MW indicate that these nuts had rough texture compared with initial KRG-15 nuts before drying and those dried using solar tent dryer (highest correlation values) which are smooth in their texture.

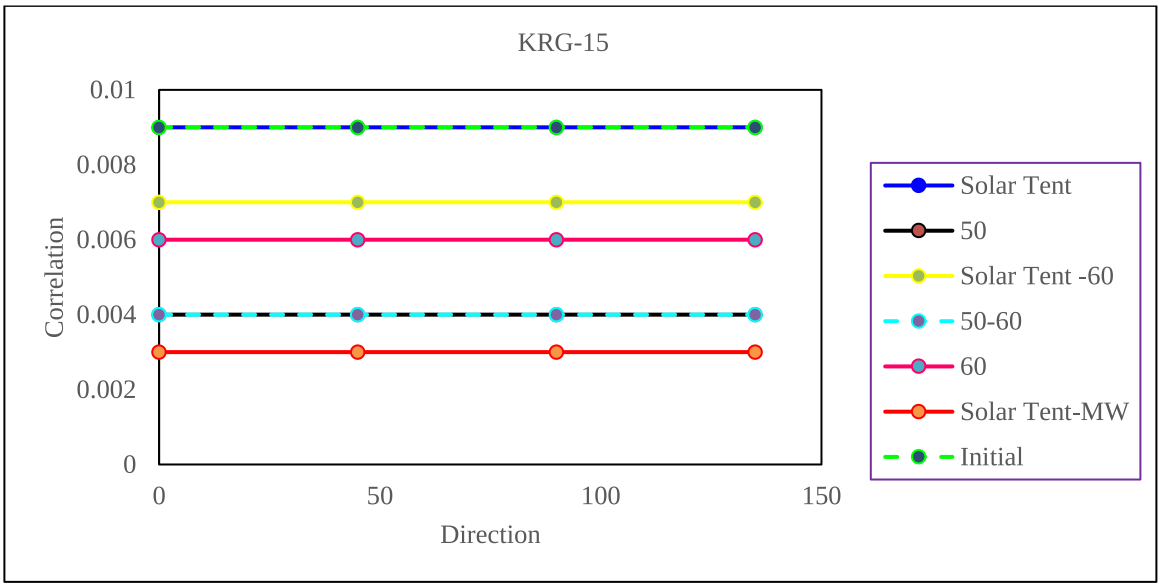

Figure 0.23: Correlation graph for KRG-15 in all direction.

4.6.1.2 MRG-20

Figures 4.24-4.28 shows the means of the five-texture parameters (angular second moment, homogeneity, contrast, variance, and correlation) of MRG-20 dried using different drying methods in all direction (0˚, 45˚, 90˚ and 135˚). From Figure 4.25, contrast value for MRG-20 nuts dried using solar tent-MW was significantly different ($P \leq 0.05$) from the nuts dried using other drying methods in all the directions. The contrast value for those dried using solar tent-MW was conclusively the highest in comparison to those dried using the oven dry 50C, 60C, 50-60C, solar tent and solar tent-60C. This is because solar tent-MW triggered high local variation in MRG-20 nuts while the other dryers produced nuts with lower local variation. However, the difference in contrast value for MRG-20 nuts dried using the other dryers were inconclusive.

In Figure 4.26, the nuts dried using solar tent-MW and oven dryer at 50˚C were less homogeneous compared to those dried using solar tent, solar tent-60°C, 50-60°C and 60°C. In Figure 4.27, ASM value for MRG-20 nuts dried using solar tent –MW was the highest followed by those dried using solar tent dryer, oven drying at 50-60, solar tent-60 and 60 but was least in oven drying at 50 for the direction. This indicate that MRG-20 nuts dried using solar tent and microwave have uniform local texture distribution as compared to the other drying methods. Solar tent-60˚C and oven drying at 60˚C produced nuts with good texture.

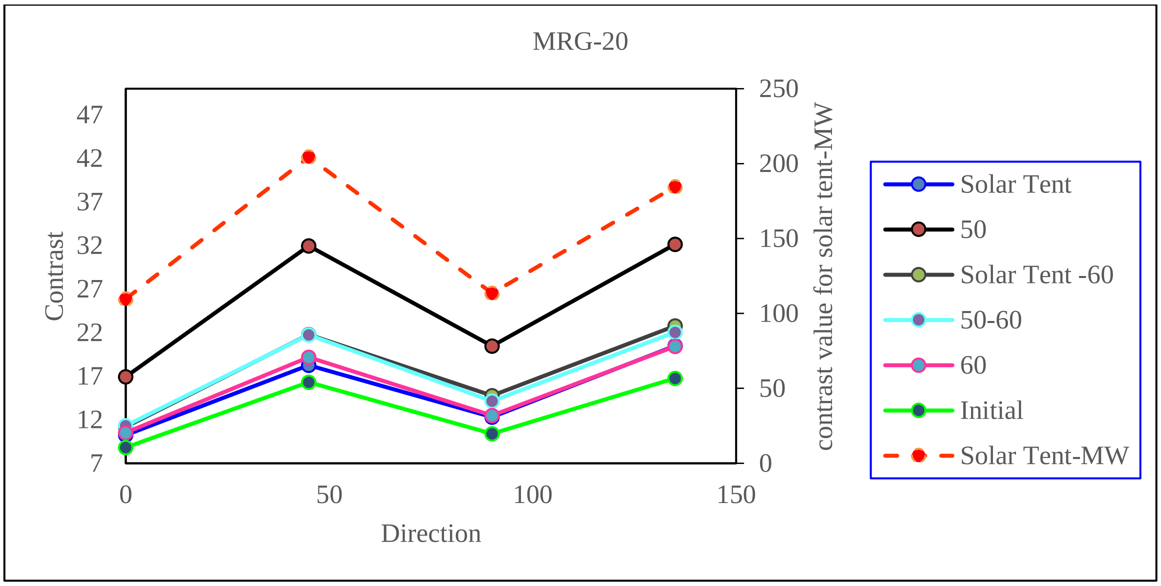

Figure 0.24: Contrast value graph for MRG-20 in all directions.

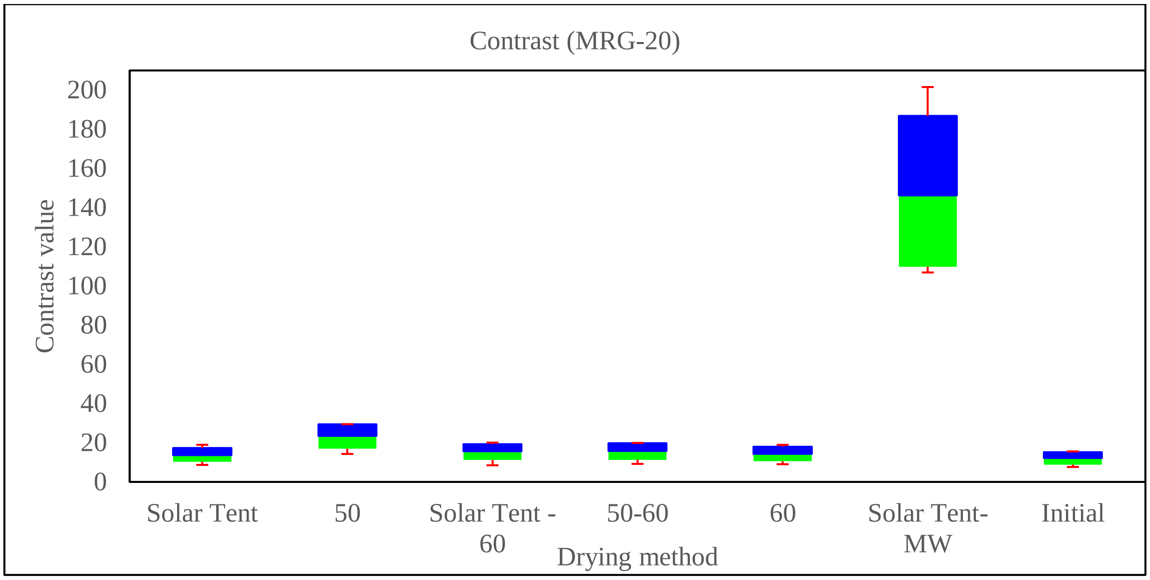

Figure 0.25: Contrast graph for MRG-20.

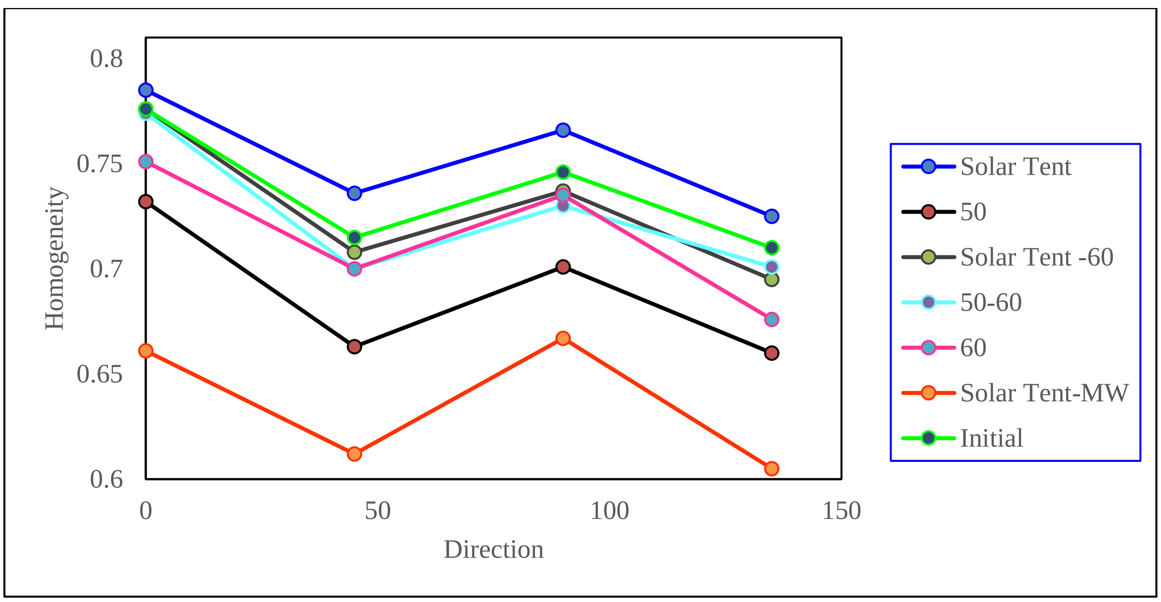

Figure 0.26: Homogeneity graph for MRG-20 in all directions.

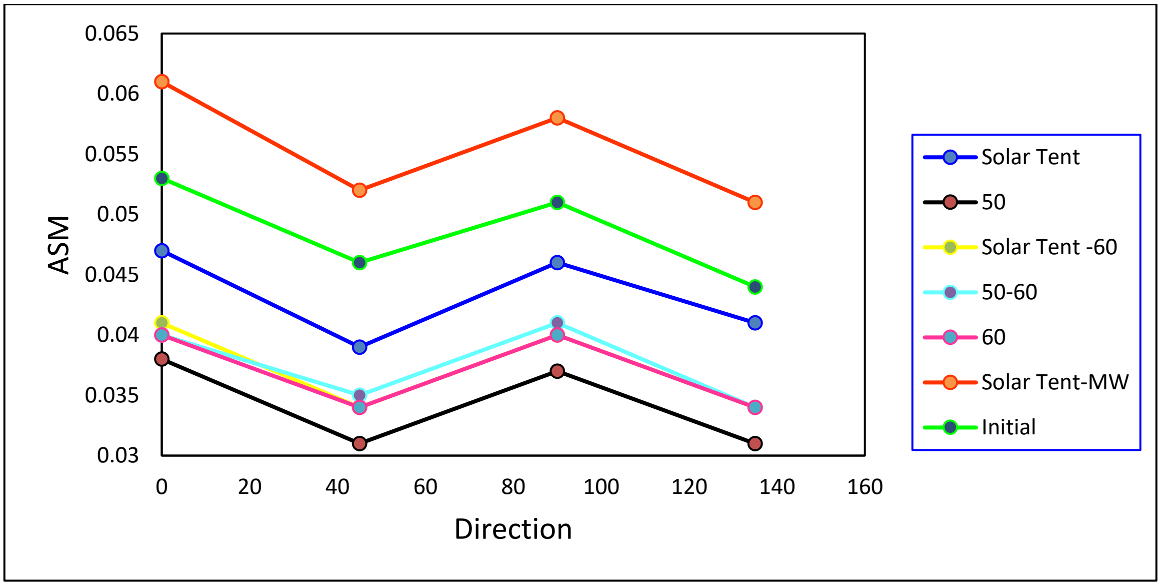

Figure 0.27: Angular second moment graph for MRG-20 in all directions.

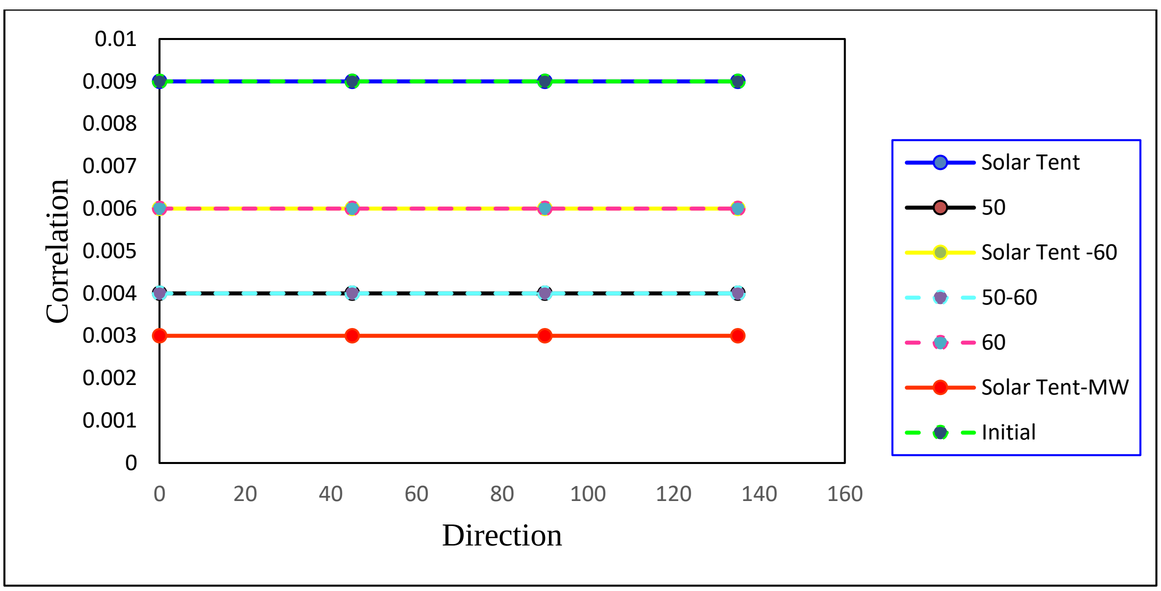

Figure 0.28: correlation graph for MRG-20 in all directions.

4.6.2 Classification of Drying Method Based on Texture Parameters

The discrimination efficiency of the different varieties of macadamia nuts in all directions (0˚ 45˚, 90˚ and 135˚) is shown in Table 4.25. It is evident that the horizontal direction at angle 0˚ had the highest average discriminative efficiency of 77% as compared to the other directions. As a result, nuts were classified at horizontal direction of angle 0˚. This means that at angle 0°, gave the base result of classifying nuts randomly when compared the other direction using RGB dataset to compute texture parameters.

Table 0.25: Classification of Macadamia nuts variety in different pixel direction

Direction	0˚	45˚	90˚	135˚	Mean
KRG-15	71%	79%	71%	71%	73%
MRG-20	82%	68%	71%	71%	73%
Mean	77%	74%	71%	71%	73%

4.6.3 Classification of Drying Method Based on Texture Parameters at Angle 0˚

From Figure 4.29, the accuracy for classification was highest on nuts dried using solar tent-MW for variety at 0˚ direction. Drying nuts using solar tent-MW for both varieties became brownish in comparison to the nuts dried using the other dryers. This means that both KRG-15 and MRG-20 nuts dried using solar tent-MW were easily classified with an accuracy of 90% using the GLCM-based features compared to the other drying methods. The GLCM-based feature extracted from RGB dataset is considered to be accurate for classifying nuts as observed by Bhole et. al., (2020).

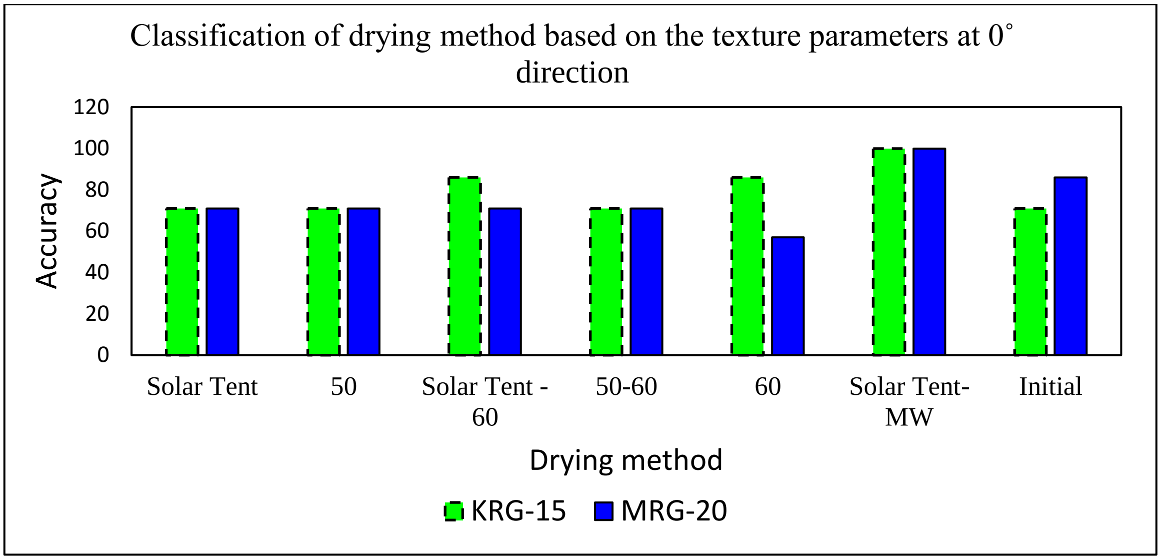

Figure 0.29: Classification of drying method based on the texture parameters at 0˚ direction

4.7 Effect of Drying Methods on Chemical Attributes of KRG-15 and MRG-20

4.7.1 Rancidity

4.7.1.1 Peroxide value

Figure 4.30 shows the peroxide value (PV) of nuts before and after drying using different drying methods. The PV level was between 2.33 to 5.23 meq/kg. According to Moigradean, Poiana, & Gogoasa (2012), PV between 1 and 5 meq/kg is classified at low oxidation state; that between 5 and 10 meq/kg at moderate oxidation and above 10 meq/kg is classified at high oxidation state.

From Table 4.26, the drying method had a significant (P≤0.05) effect on the PV values of dried macadamia nuts of the KRG-15 varieties. This was clearly shown in Figure 4.30, where the error bars indicated that the majority of the data collected about the PV for KRG-15 nuts dried using solar tent, 50°C, solar tent- 60°C and solar tent-MW dryer were significantly different from those dried using oven drying at 50-60°C. It is conclusive that oven drying at 50-60°C produce nuts with lowest oxidation compared to the other drying methods. The KRG-15 nuts varieties dried using solar tent dryer and drying methods involving solar tent dryer had the highest oxidation due to the variation of temperature inside the solar tent dryer, due to longer drying time (Mokhtarian & olipour, 2019).

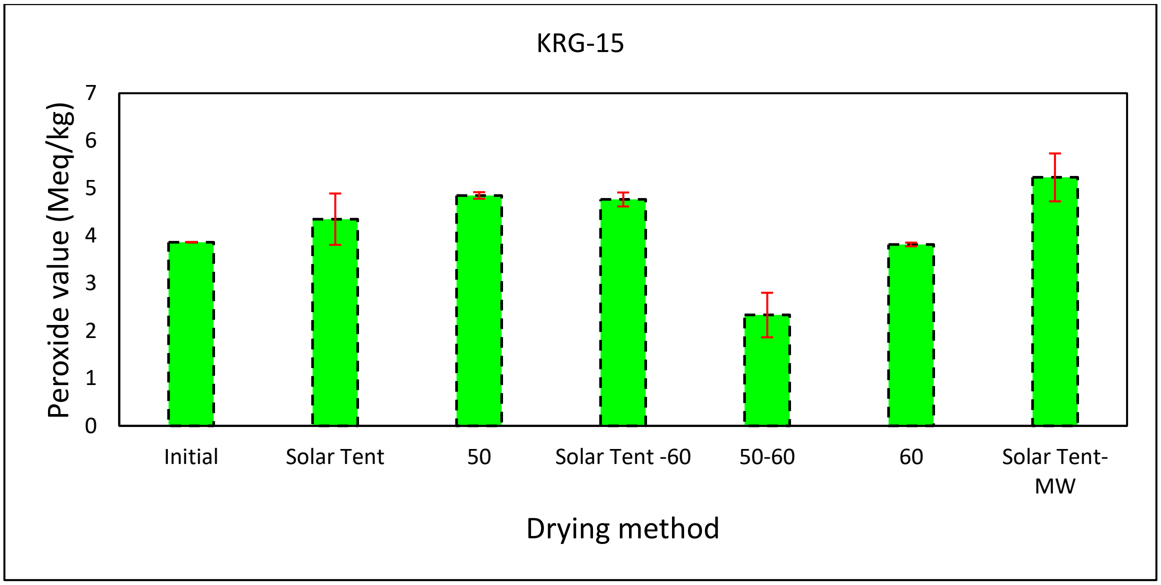

Figure 0.30: Peroxide value for KRG-15.

Table 0.26: ANOVA for KRG-15 PV from different dryers

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16.69	6	2.78	24.52	1.14821E-06	2.85
Within Groups	1.59	14	0.11			
Total	18.27	20				

Regarding the MRG-20 varieties, it was observed as shown in Figure 4.31 that the oxidation level for was within the recommended levels, ranging between 2.30 to 4.77meq/kg. However, the drying method had a significant ($P \leq 0.05$) effect on the PV values of dried macadamia nuts of the MRG-20 varieties as shown in Table 4.27. For instant, the error bar in Figure 4.31 indicated that the majority of the data collected about the PV for MRG-20 nuts dried using solar tent, 50-60°C, oven drying at 50°C and 60°C and solar tent-MW dryer were significantly higher than those dried using solar tent- 60°C.

Table 0.27: ANOVA for MRG-20 PV from different dryers

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11.957	6	1.993	6.689	0.002	2.848
Within Groups	4.171	14	0.298			
Total	16.128	20				

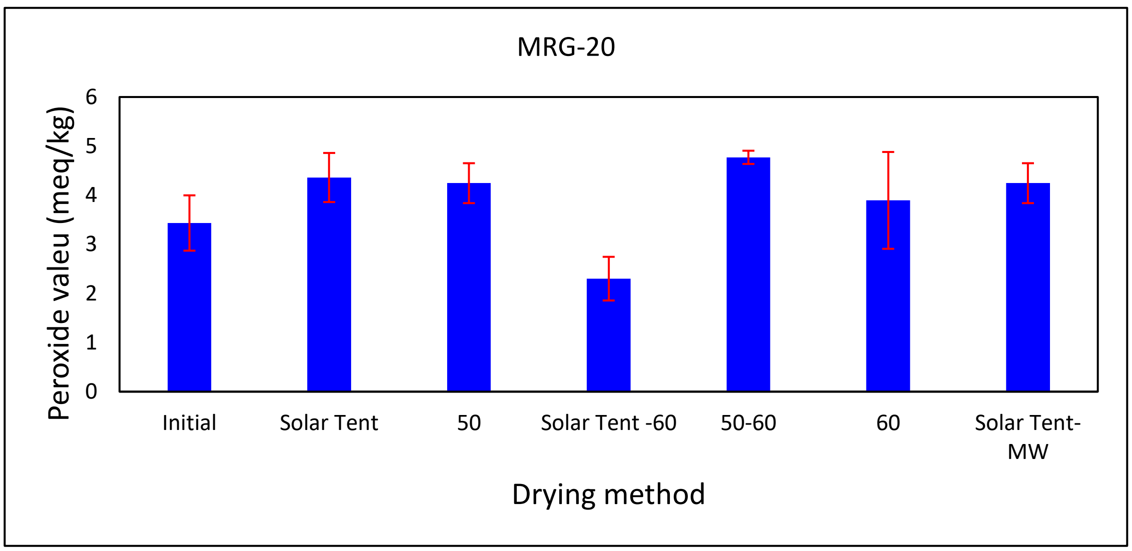

Figure 0.31: Peroxide value for MRG-20.

4.7.1.2 TBARS Test

The TBAR test was carried out for both KRG-15 and MRG-20 nuts before drying and after drying using solar tent dryer and solar tent-MW. This was done to evaluate the effect of microwave heating on the level of oxidation for the two varieties of macadamia nuts. From Table 4.28, the dried macadamia nuts of the KRG-15 and MRG-20 had no significant ($p>0.05$) difference in TBAR value. However, the drying method had a significant ($p\leq0.05$) effect on the TBAR value of dried nuts. Further statistical analysis using KRG-15 data showed that there is a significant ($p \leq 0.05$) in TBAR value due to the different drying methods as shown in Table 4.29. Hence post-hoc test was carried out to determine which drying method brought about the difference. It was observed that KRG-15 nuts dried using solar tent-MW differed significantly ($p \leq 0.05$) from the nuts before drying and those dried using solar tent dryer as shown in Table 4.30. The TBAR value for KRG-15 nuts dried using solar tent dryer were significantly ($p \leq 0.05$) higher with a mean TBAR value of 0.005918μg TMPE/g while KRG-15 nuts dried using solar tent-MW had a mean value of 0.002665μg TMPE/g. This is because of the duration of drying which was shorter when drying both varieties of macadamia nuts using solar tent-MW. The level of TBAR value was high for KRG-15 nuts before drying due to long refrigeration storage of the nuts' samples. This was due to long queue at the laboratory.

Table 0.28: Two-way ANOVA of macadamia nut's TBAR values

Source of Variation	SS	df	MS	F	P-value	F crit
Drying method	3.8E-05	2	1.9E-05	38.0510	2.1E-05	4.1028
Variety	1.1E-06	5	2.2E-07	0.4415	0.8101	3.3258
Error	4.9E-06	10	4.9E-07			
Total	4.4E-05	17				

Table 0.29: ANOVA showing the effect of drying methods on TBAR value for KRG-15 nuts

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replica stratum	2	3.36E-07	1.68E-07	1.24	
Drying method	2	1.85E-05	9.25E-06	68.49	<.001
Residual	4	5.40E-07	1.35E-07		
Total	8	1.94E-05			

Table 0.30: Post-hoc test for KRG-15

Drying method	Mean	Significant difference (p≤0.05)
Solar Tent-MW	0.002665	a
solar Tent	0.005438	b
Initial	0.005918	b

Similarly, the ANOVA test showed that the drying methods had significant effect (p≤0.05) on the TBAR values of the MRG-20 nut as shown in Table 4.31. Further post-hoc test showed that there was no significant difference on the TBAR value dried using solar tent and solar tent-MW. Table 4.32. However, MRG-20 nuts before drying had a TBAR value of 0.006967 μg TMPE/g which was significantly higher (p≤0.05) than those dried using solar tent and solar tent-MW dryers, which had a mean TBAR value of 0.004427 μg TMPE/g and 0.003172 μg TMPE/g respectively. This means that the use microwave energy in further drying of both KRG-15 and MRG-20 results in low lipid oxidation that is acceptable for consumption. This agrees with the finding of Zhang, *et al.* (2018) when he was drying fruits and vegetables using microwave related drying methods.

Table 0.31: ANOVA for MGR-20 TBAR test from different dryers

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replica stratum	2	6.04E-07	3.02E-07	1.25	
Drying method	2	2.24E-05	1.12E-05	46.44	0.002
Residual	4	9.66E-07	2.42E-07		
Total	8	2.40E-05			

Table 0.32: Post-hoc test for MRG-20

Post-hoc's 95% confidence intervals		
Drying method	Mean	Significant difference (p≤0.05)
Solar Tent-MW	0.003172	a
solar Tent	0.004427	a
Initial	0.006967	b

4.7.2 Free Fatty Acid

Table 4.33 indicates that the varieties had no significant effect (p>0.05) on the value of Free Fatty Acid (FFA). However, the drying method had a significant (p≤0.05) effect on the FFA value for these varieties as shown in Table 4.34. The error bar in Figure 4.32 and post-hoc test in Table 4.35 further showered that the majority of the data collected about the FFA value for KRG-15 nuts dried using solar tent, oven drying at 50°C and 60°C, and solar tent-MW dryer significantly lower (P≤0.05) from those dried using oven drying at 50-60°C. However, the FFA for nuts dried using oven drying at 50-60°C were not significantly different from those dried using Solar Tent -60°C. It is therefore concluded that oven drying at 50-60°C had the highest FFA level compared to the other drying methods. In addition, Figure 4.32 as shows that the level of FFA decreases with increase in drying temperature and the rate of drying. This agrees with the finding of (Bai, et al., 2017).

Table 0.33: ANOVA showing the effect of drying methods on free fatty acid for the KRG-15 and MRG-20 nuts

Source of Variation	SS	df	MS	F	P-value	F crit
Drying method	1.801	6.000	0.300	3.120	0.017	2.421
Variety	0.740	5.000	0.148	1.538	0.208	2.534
Error	2.885	30.000	0.096			
Total	5.426	41.000				

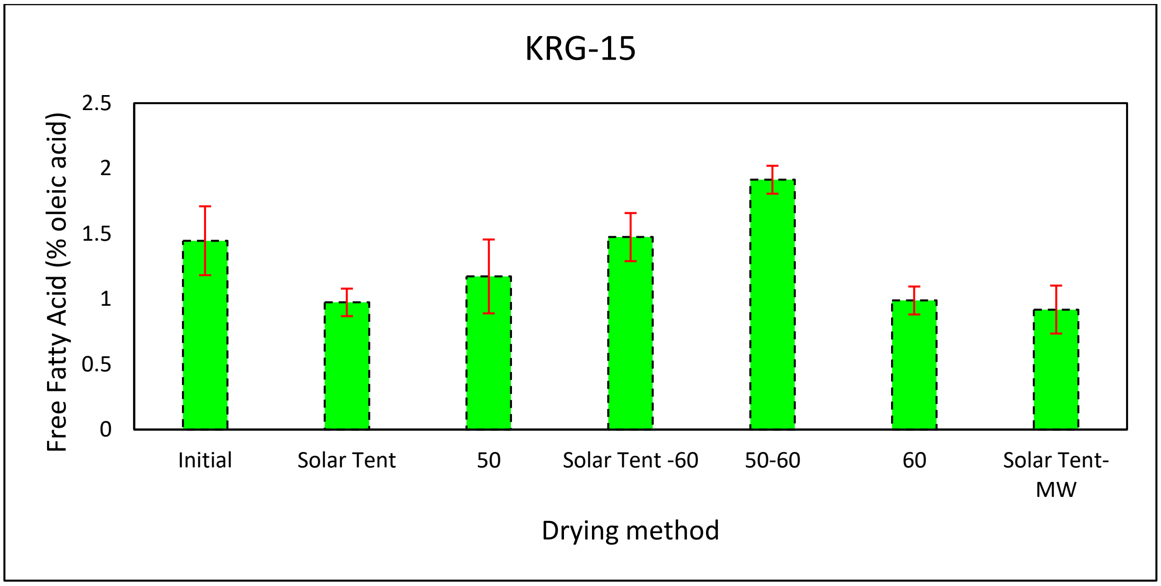

Figure 0.32: Free Fatty Acid value for KRG-15.

Table 0.34: ANOVA showing effect of drying methods on FFA value for KRG-15 nuts

Source of variation	df	ss	ms	vr	Fpr
Replica stratum	2	0.07526	0.03763	1.06	
Drying method	6	2.35903	0.39317	11.04	<0.001
Residual	12	0.42732	0.03561		
Total	20	2.86161			

Table 0.35: Post-hoc Test for FFA value for KRG-15 from different dryers

Drying method	Mean Significant difference (p≤0.05)
Solar Tent-MW	0.919a
solar Tent	0.974ab
oven 60	0.989ab
Oven 50	1.173ab
Initial	1.446 abc[12]
Solar Tent -60	1.474bc
Oven 50 then 60	1.914c

[12] a, b, c – groups that differed statistically significantly ($p < 0.05$) from one another according to drying method

Similarly, the drying method had a significant (p≤0.05) effect on the FFA value for the MRG nut variety as shown in Table 4.36. The error bar in Figure 4.33 and post-hoc test analysis in Table 4.37 further indicated that the majority of the data collected about the FFA value for MRG-20 nuts dried using solar tent dryer were significantly different (P≤0.05) from those dried using oven drying at 60°C and 50-60°C and solar tent- MW. It is conclusive that oven drying at 50-60°C and solar tent –MW, had the highest FFA level. In addition, the MRG-20 nuts dried using solar tent-MW were significantly different (P≤0.05) from those dried using solar tent dryer, solar tent-60°C, and oven drying at 50°C.

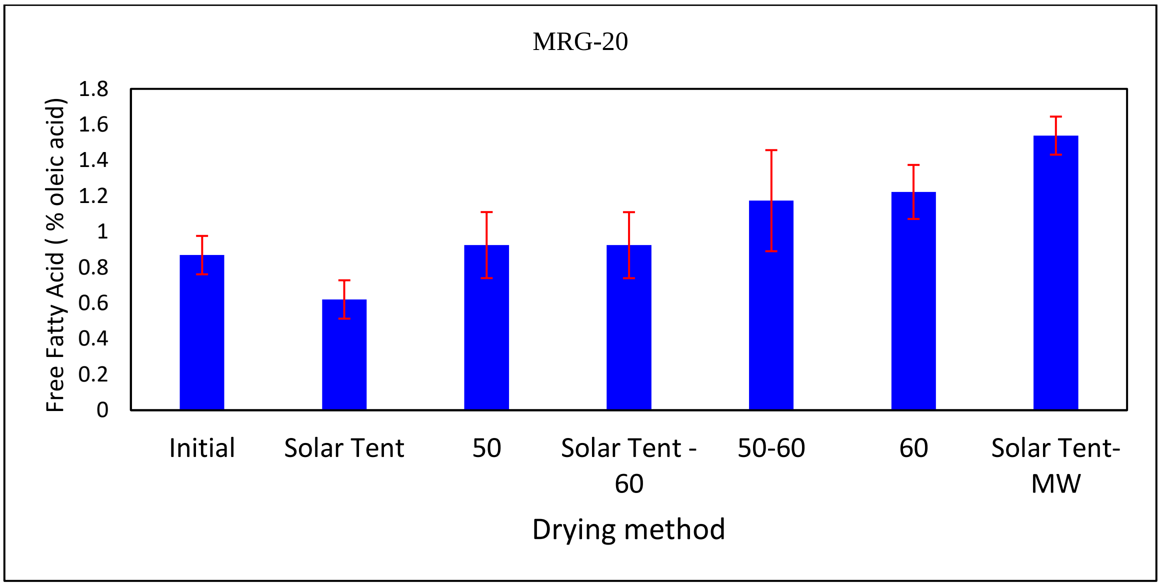

Figure 0.33: Free Fatty Acid value for MRG-20

However, solar tent-MW differed significantly (P≤0.05) from the nuts before drying. This difference was in terms of the level of FFA.

Table 0.36: ANOVA for FFA in MRG-20

Source of variation	df	ss	ms	vr	Fpr
Replica stratum	2	0.10576	0.05288	2.07	
Drying method	6	1.59373	0.26562	10.41	<0.001
Residual	12	0.30609	0.02551		
Total	20	2.00558			

Table 0.37: Post-hoc's Test for FFA in MRG-20 from different dryers

Drying method	Mean Significant difference ($p \leq 0.05$)
solar Tent	0.620a
Initial	0.869ab
Solar Tent -60	0.925ab
Oven 50	0.925ab
Oven 50-60	1.174bc
Oven 60	1.223bc
Solar Tent-MW	1.538c

a, b, c – groups that differed statistically significantly ($p \leq 0.05$) from one another according to drying method.

4.7.3 Fatty Acid Composition

From Table 4.38, it is evident that the varieties had no significant effect ($p>0.05$) in fatty acid composition when drying using the different drying methods. Similar result was observed by Fu *et al.*, (2016). However, the drying method had a significant ($p \leq 0.05$) effect on the FFA value for these varieties.

Table 0.38: ANOVA for effect of drying methods on fatty acid composition in different dryers

Source of Variation	SS	df	MS	F	P-value	F crit
Drying method	2.865	6	0.478	0.153	0.988	2.179
Varieties	33223.146	19	1748.587	559.258	4E-103	1.679
Error	356.434	114	3.127			
Total	33582.446	139				

Tables 4.39 and 4.40 presents the fatty acid composition for KRG-15 and MRG-20, respectively. The major fatty acids were oleic acid, palmitoleic acid and palmitic acid; which ranged between 78.4 to 80.1% of the total fatty acids while the polyunsaturated fatty acid (18:2+18:3) content was the lowest, ranging from 3.3 to 4.2% of the total fatty acids. Similar results were observed when drying MRG-20 whereby, the major fatty acids were oleic acid, palmitoleic acid and palmitic acid; accounted between 72.09 to 80.63% of the total fatty acids while the polyunsaturated fatty acid (18:2+18:3) content was the lowest, ranging from 3.9 to 4.33% of the total fatty acids. Macadamia nuts oil composition was dominated by unsaturated fatty acid amounting to more than 75% of the total free fatty acids present. This makes them highly susceptible to lipid oxidation that leads to spoilage, Turan, (2018).

Table 0.39: Free acid composition for KRG-15 from different dryers

		Initial	Solar Tent	oven 50	Solar Tent - 60	oven 50-60	oven 60	Solar Tent-MW
Fatty acid composition	C12:0	0.1	0.2	0.3	0.4	0.1	0.1	0.2
	C14:0	6.0	1.2	1.1	1.9	1.1	1.0	1.0
	C16:0	8.9	10.4	9.9	10.1	10.6	10.1	10.0
	C16:1	22.7	27.2	27.3	31.4	25.4	26.3	24.9
	C18:0	1.5	2.1	1.5	2.4	1.7	1.3	1.9
	C18:1	52.6	51.6	51.1	47.9	52.4	53.8	54.0
	C18:2	2.7	2.4	2.3	1.9	2.5	2.5	2.1
	C18:3	1.4	1.7	1.5	1.4	1.7	1.3	1.6
	C20:0	2.7	1.4	0.7	1.1	2.2	3.0	2.7
	Others	0.7	0.9	2.1	0.7	1.2	0.3	0.8

C12:0=lauric acid, C14:0=myristic acid, C16:0=palmitic acid, C16:1=palmitoleic acid, C18:0=stearic acid, C18:1=oleic acid, C18:2=linoleic acid, C18:3=linolenic acid, C20:0=arachidic acid, C20:1=eicosenic acid, and C22:0=behenic acid

Table 0.40: Free Acid composition for MRG-20 from different dryers

		Initial	Solar Tent	oven 50	Solar Tent - 60	oven 50-60	Oven 60	Solar Tent-MW
Fatty acid composition	C12:0	0.12	0.16	0.27	0.16	0.62	0.19	0.18
	C14:0	0.86	0.93	1.29	0.92	1.49	0.95	1.01
	C16:0	9.51	9.25	9.76	8.35	12.27	9.83	9.15
	C16:1	29.27	28.47	29.09	23.23	26.70	30.41	25.47
	C18:0	1.99	2.58	2.73	2.09	4.55	2.58	2.29
	C18:1	51.36	51.76	48.56	42.52	45.46	48.96	46.62
	C18:2	2.32	1.97	1.75	3.31	1.65	2.08	3.63
	C18:3	1.57	1.98	2.36	0.64	2.02	1.82	0.70
	C20:0	1.90	1.68	1.29	1.20	0.82	1.60	1.31
	Others	0.56	0.62	1.44	8.79	0.71	0.79	0.58

C12:0=lauric acid, C14:0=myristic acid, C16:0=palmitic acid, C16:1=palmitoleic acid, C18:0=stearic acid, C18:1=oleic acid, C18:2=linoleic acid, C18:3=linolenic acid, C20:0=arachidic acid, C20:1=eicosenic acid, and C22:0=behenic acid

4.8 Summary of the Effect of Drying Method

Colour, texture and chemical composition are factors that should be observed when drying macadamia nuts. This is because they influence the purchase power of the consumers of these nuts. From the above results, it is evident that.

1) A high linear correlation ($P \leq 0.05$, $R^2=0.9993$) was found between the normalized colours and ΔE_{RGB} for KRG-15. Similarly, there was a linear correlation ($P \leq 0.05$, R2=0.9) normalized colour and ΔE_{RGB} for MRG-20. It was also observed that a normalized colour blue and red had linear correlation ($P \leq 0.05$, R2=0.9118) with lightness L^* value. A good correlation also existed between normalized colour blue and the browning index (BI) with a coefficient of 0.9238. For texture analysis, there was a linear correlation ($P \leq 0.05$, R2=0.8667) between normalized colour blue and the GLCM contrast. It was showed that colour can be used to classify the nuts.

2) Increase in temperature as indicated in able A1 and A2 resulted in decrease in lightness L^* value. For 50°C, L^* was 82.34±0.67 and 83.35±2.83 for KRG-15 and MRG-20 respectively while drying at 60°C, was 78.20±2.53 and 82.10±3.19 for KRG-15 and MRG-20 respectively. However, increase in temperature resulted in increase in browning level of the nuts. At 50°C, $\Delta E_L{}^*{}_{ab}$ was 6.1 and 2.9 for KRG-15 and MRG-20 respectively while drying at 60°C, was 6.6 and 4.2 for KRG-15 and MRG-20 respectively. This means that drying macadamia nuts at 50˚C produces good quality nuts as compared to oven drying at 60˚C.
3) Drying nuts using solar tent dryer produces colour change of below 5 using the CIE colour model. In addition, the dryer produced nuts having a browning index of 25.52 and 28.94 with contrast values of 10 and 14 for KRG-15 and MRG-20, respectively. This means that the nuts both KRG-15 and MRG-20 are highly acceptable by sight. Hence classified as grade one nuts. The dryer altered slightly the peroxide value and free fatty acid but within the acceptable levels; with a PV of below 5meq/kg. However, this method of drying takes time compared to the other methods of drying and was unable to achieve a drying moisture content of 3% d.b. This means it requires further drying using other methods.
4) Drying nuts using solar tent-60 dryer produces colour change of about 5 using the CIE colour model. In addition, the dryer produced nuts having a browning index of 29.78 and 30.82 for MRG-20 and KRG-15, respectively with contrast values of 15 and 17 KRG-15 and MRG-20. This means that both KRG-15 and MRG-20 are highly acceptable by sight. Hence classified as grade one nuts. Again, this type of dryer altered slightly peroxide value and free fatty acid but within the acceptable level However, this method of drying evolved combination of both solar tent drying and oven drying at 60°C, hence reduced the time interval of drying.
5) Drying nuts using solar tent-MW dryer produces colour change of about 15 and 40 for KRG-15 and MRG-20 respectively using the CIE colour model. In addition, the dryer produced nuts having a browning index of 49.03 and 88.21 for KRG-15 and MRG-20,

respectively with a contract values of 24 and 138 for KRG-15 and MRG-20, respectively. This means that both KRG-15 and MRG-20 are likely to be rejected by sight alone. Hence classified as rejects. Again, this type of dryer altered moderately peroxide value and free fatty acid but within the acceptable levels. However, this type of dryer is faster than the other method of drying.

6) Drying nuts using oven dryer at a temperature of 50^{o}C produces colour change of about 6 using the CIE colour model. In addition, the dryer produced nuts having a browning index of 28.00 and 35.73 for MRG-20 and KRG-15, respectively with a contract values of 27 for both KRG-15 and MRG-20. This means that both KRG-15 and MRG-20 are likely to produce acceptable nuts by sight. Hence classified as grade two nuts. Again, this type of dryer altered slightly peroxide value and free fatty acid but within the acceptable level
7) Drying nuts using oven dryer at a temperature of 60^{o}C produces colour change of about 15 using the CIE colour model. In addition, the dryer produced nuts having a browning index of 31.10 and 40.63 for MRG-20 and KRG-15, respectively with a contract values of 10 and 17 for MRG-20 and KRG-15, respectively. This means that both KRG-15 and MRG-20 are likely to produce slightly acceptable nuts by sight. Hence classified as grade three nuts. Again, this type of dryer altered slightly peroxide value and free fatty acid but within the acceptable level.
8) Drying nuts using oven dryer at a temperature of 50^{o}C to a moisture content of 5 d.b and the quickening the drying process by increasing the temperature to 60^{o}C. This method produced colour change of about 7 using the CIE colour model. In addition, the dryer produced nuts having a browning index of 29.88 and 37.06 for MRG-20 and KRG-15, respectively with a contract values of 12 and 30 for MRG-20 and KRG-15, respectively. This means that both KRG-15 and MRG-20 are likely to produce acceptable nuts by sight. Hence classified as grade two nuts. Again, this type of dryer altered slightly peroxide value and free fatty acid but within the acceptable level.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The broad objective of this study was to evaluate the effect of drying methods on the quality of dried macadamia nuts using colour image analysis. From the results, the following specific conclusions were drawn: -

(i) A strong correlation ($P \leq 0.05$, $R^2=0.9993$) was found between the normalized colours C'b and C'r and ΔE_{RGB} for KRG-15. Similarly, there was a linear correlation ($P \leq 0.05$, R2=0.9) between normalized colour C'b and C'r and ΔE_{RGB} for MRG-20. It was also observed that a normalized colour blue and red had linear correlation ($P \leq 0.05$, R2=0.9118) with lightness L^* value. A strong correlation also existed between normalized colour blue and the browning index (BI) with a coefficient of 0.9238. For texture analysis, there was a linear correlation ($P \leq 0.05$, R2=0.8667) between normalized colour blue and the GLCM contrast. These results show that colour can be used to grade the nuts.

(ii) The drying rate for oven drying of macadamia nuts at 60˚C was 1.08 faster than oven drying at 50˚C while the drying rate for KRG-15 was 1.19 faster than MRG-20. Increase in temperature resulted in decrease in lightness L^* value. For 50°C, L^* was 82.34±0.67 and 83.35±2.83 for KRG-15 and MRG-20 respectively while drying at 60°C, was 78.20±2.53 and 82.10±3.19 for KRG-15 and MRG-20 respectively. However, increase in temperature resulted in increase in browning level of the nuts. At 50°C, ΔE_{L*ab} was 6.1 and 2.9 for KRG-15 and MRG-20, respectively while drying at 60°C, was 6.6 and 4.2 for KRG-15 and MRG-20 respectively. On the other hand, the browning index for KRG-15 was at 35.717 and 40.5854 for oven drying at 50˚C and 60˚C respectively while for MRG-20 was at

28.017 and 31.122 for oven drying at 50˚C and 60˚C respectively. This means that drying macadamia nuts at 50˚C produces good quality nuts as compared to oven drying at 60˚C.

(iii) The varieties of macadamia nuts had no significant effect ($p>0.05$) on the lightness L^* value but solar tent–MW drying method significantly ($p\leq 0.05$) affected negatively both KRG-15 and MRG-20. Solar Tent-MW and SolarTent-60˚C significantly ($p\leq 0.05$) affected MRG-20 nuts but KRG-15 was not affected. The browning index for KRG-15 ranged between 22.52 and 49.03, while MRG-20 ranged between 28.94 and 88.21. solar tent MW produced the least quality nuts with a BI of 49.03 and 88.21 for KRG-15 and MRG-20 respectively, while solar tent and solar tent-60℃ produced the best quality nuts with a BI between (25.52-30.82) for KRG-15 and 28.95-29.78 for MRG-20. Oven 50-60℃ drying produced the best quality MRG-20 nuts with the BI of 28.00 and 29.88 respectively but low quality KRG-15 nuts with BI of 35.73 and 37.06 respectively. Drying methods had significant influence on the FFA in both KRG-15 and MRG-20. FFA in KRG-15 decreased after drying using solar tent dryer alone; from 1.4% to 0.9% but increased to 1.6% when the nuts were dried using solar Tent- 60˚C. However, FFA remained unchanged when dried using solar tent-MW. Similarly, FFA in MRG-20 decreased after drying using solar tent dryer only; from 0.9% to 0.6% but increased to 1.0% when they were dried using solar tent-60 dryer. Finally, the major fatty acids for KRG-15 were oleic acid, palmitoleic acid and palmitic acid; accounted for 78.4 to 80.1% of the total fatty acids with a polyunsaturated fatty acid (18:2+18:3) content ranging from 3.3 to 4.2% while for MRG-20, oleic acid, palmitoleic acid and palmitic acid; accounted for 72.09 to 80.63% of the total fatty acids with a polyunsaturated fatty acid (18:2+18:3) ranging from 3.9 to 4.33%. Seven of the eight thin layer drying models showed the goodness of fit with R^2 ranging from 0.9978-0.9585, RMSE; 0.0089-0.0755 and χ^2; 0.0001 – 0.0060 for KRG-15 and R^2 ranging from 0.8830 to 0.9973, RMSE; 0.0082-0.1595 and χ^2; 8.19E-05 – 0.026782 for MRG-20. Comparison of the eight thin layer drying models indicated that

Approximation of Diffusion and Modified Handerson and Pabis the best of fit model to describe the drying of macadamia nuts for KRG-15 and MRG-20 when using Solar Tent dryer, Solar Tent-60˚C, Oven 50˚C and Oven 50-60˚C.

5.2 Recommendations

(i) Further work should be done in the development of colour index for all the varieties of macadamia nuts grown in Kenya and a standard developed for industrial application for classification of these nuts.

(ii) For 1st grade commercial nuts, dry MRG-20 only in an oven at 50˚C and there should be no mixing of the varieties.

(iii) In the event of mixing KRG-15 and MRG-20, only use Solar Tent Dryer and Solar Tent-60 drying method for 1st grade commercial nuts. However, Techno-Economic analysis and Optimization analysis is further required to evaluate the benefit of these solar tent dryer before being adopting for on-farm application.

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APPENDICES

Appendix I: List of Tables

Table A1: Colour values for both Lab and RGB for KRG-15

	L	A	b	ΔE_{Lab}	H^*_{Lab}	Chroma	ΔE_{RGB}	H^*_{RGB}
Drying Method				KRG-15				
Oven 50	82.34±0.67	-2.1	26.7	6.1	265.5	22.7±2.3	12.3	53.9
Oven 60	78.20±2.53	0.8	26.5	6.6	88.3	28.1±2.8	24.6	48.6

Table A2: Colour values for both Lab and RGB for MRG-20

	L	a	b	ΔE_{Lab}	H^*_{Lab}	Chroma	ΔE_{RGB}	H^*_{RGB}
Drying Method				MRG-20				
Oven 50	83.35±2.53	-2.5	22.5	2.9	263.6	22.7	5.6	54.8
Oven 60	82.10±3.19	-1.8	23.7	4.2	265.7	23.7	8.3	53.3

Table A3: Colour values for both Lab and RGB for KRG-15

	L	A	b	ΔE_{Lab}	H^*_{Lab}	Chroma	ΔE_{RGB}	H^*_{RGB}
Drying Method								
Solar Tent	83.32±0.02	-2.6	21.0	1.4	262.9	21.1±2.9	2.3	52.5
Solar Tent -60	83.03±1.72	-1.3	23.5	3.8	266.8	23.5±2.7	13.3	53.0
Oven 50-60	83.36±1.40	-1.6	27.6	6.7	266.6	23.6±3.0	20.6	50.9
Solar Tent-MW	71.67±6.05	1.9	27.8	12.6	86.2	27.8±1.0	35.0	44.2

Table A4: Colour values for both Lab and RGB for MRG-20

	L	a	b	ΔE_{Lab}	H^*_{Lab}	Chroma	ΔE_{RGB}	H^*_{RGB}
Drying Method								
Solar Tent	82.73±2.52	-2.7	23.0	3.0	263.4	23.2	3.0	54.0
Solar Tent -60	82.92±1.90	-1.7	23.0	3.3	265.8	23.1	10.4	52.6
Oven 50-60	84.21±1.10	-2.1	23.7	3.6	265.0	23.8	12.9	52.1
Solar Tent-MW	44.75±0.80	9.7	23.8	42.6	67.8	25.7	125.0	31.1

Table A5: Normalized imaging colour values for KRG-15 for different drying method

Drying Method	KRG-15 B/RGB	G/RGB	R/RGB
Initial	31.52	34.12	34.36
Solar Tent	31.31	34.12	34.58
50	31.03	34.27	34.70
Solar Tent -60	30.50	34.45	35.05
50-60	30.43	34.38	35.18
60	30.14	34.37	35.49
Solar Tent-MW	29.58	34.29	36.13

Table A6: Normalized imaging colour values for KRG-15 for different drying method

Drying Method	MRG-20 B/RGB	G/RGB	R/RGB
Initial	31.22	34.24	34.54
Solar Tent	31.05	34.27	34.68
50	31.12	34.27	34.62
Solar Tent -60	30.32	34.50	35.18
50-60	30.17	34.53	35.29
60	30.50	34.46	35.04
Solar Tent-MW	26.61	33.48	39.91

Table A7: Colour saturation for both KRG-15 and MRG-20

Drying Method	KRG-15	MRG-20
Initial	0.68	0.69
Solar Tent	0.69	0.69
50	0.69	0.69
Solar Tent -60	0.69	0.70
50-60	0.70	0.70
60	0.70	0.70
Solar Tent-MW	0.70	0.73

Table A8: Average temperature, relative humidity and solar radiation readings (24th Feb 2016)

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
7:59	0.76	79.4	18.842	89.7

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
8:09	1.01	111.9	18.699	88.7
8:19	1.26	131.9	19.08	87.6
8:29	1.26	169.4	19.151	86.6
8:39	1.51	110.6	19.08	85.5
8:49	1.26	125.6	19.436	85.3
8:59	0.76	179.4	19.865	84.5
9:09	1.26	146.9	19.627	83.4
9:19	0.5	193.1	20.627	83
9:29	0.76	220.6	20.531	81.7
9:39	0.76	356.9	21.294	79.2
9:49	0.76	928.1	21.676	77.4
9:59	1.01	273.1	22.369	75.4
10:09	0.5	413.1	22.657	74.2
10:19	1.51	1044.4	22.489	73
10:29	1.26	931.9	24.05	70.2
10:39	1.76	926.9	23.689	67.7
10:49	2.01	1044.4	23.713	67.2
10:59	1.51	788.1	25.404	66.3
11:09	1.01	1038.1	25.574	64.3
11:19	1.76	1048.1	24.847	63.6
11:29	1.76	1151.9	24.46	64.2
11:39	1.51	380.6	24.968	62.7
11:49	1.76	321.9	24.919	61.7
11:59	1.26	1226.9	25.817	61.6
12:09	1.76	315.6	24.847	60
12:19	0.76	1199.4	26.329	60.5
12:29	2.01	1250.6	25.866	59.1
12:39	1.76	1168.1	25.963	57.8
12:49	2.27	213.1	25.501	56.3
12:59	1.01	156.9	24.629	58.7
13:09	1.01	294.4	26.842	58.9
13:19	1.26	1031.9	26.867	53.9
13:29	1.26	880.6	27.579	51.8
13:39	1.26	1031.9	27.481	52.6
13:49	1.26	1029.4	28.023	50.2
13:59	2.01	1038.1	27.998	48.3
14:09	3.02	164.4	26.744	47.5
14:19	1.76	1014.4	27.112	48.7
14:29	2.01	215.6	26.598	48.5
14:39	1.26	285.6	28.692	48.3

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
14:49	1.51	179.4	27.407	48.3
14:59	2.01	374.4	27.407	48.4
15:09	2.01	903.1	27.481	47.2
15:19	1.26	845.6	28.468	47.1
15:29	1.01	334.4	27.481	46.2
15:39	0.76	653.1	27.21	48.4
15:49	1.51	99.4	26.085	48.8
15:59	1.01	670.6	27.998	50.2
16:09	2.27	186.9	27.333	47.6
16:19	0.76	569.4	26.524	49.7
16:29	1.26	555.6	27.604	49.1
16:39	1.01	581.9	27.751	47.3
16:49	1.51	101.9	26.867	48.4
16:59	0.76	476.9	26.671	50.5
	1.36	566.65	24.77	62.24
	0.51	394.14	3.04	14.15

Table A9: Temperature, relative humidity and solar radiation readings (25th Feb 2016)

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
7:59	0	261.9	20.126	80.8
8:09	0	299.4	21.199	78
8:19	0	338.1	22.561	75.1
8:29	0	379.4	22.561	71.2
8:39	0	421.9	24.195	67.2
8:49	0	461.9	23.376	63.5
8:59	0.25	496.9	23.256	63.5
9:09	0	534.4	24.605	62.4
9:19	0.25	563.1	24.992	59.7
9:29	0	598.1	25.72	58.2
9:39	0.25	625.6	24.919	57.7
9:49	0.5	659.4	25.939	56.9
9:59	0.25	690.6	26.109	55.1
10:09	0.5	719.4	25.671	53.2
10:19	0.5	759.4	26.573	52.5
10:29	0.76	791.9	26.72	51.1

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
10:39	1.01	824.4	26.549	51.2
10:49	0.25	848.1	28.097	48.8
10:59	0.76	906.9	27.579	46.3
11:09	0.25	930.6	28.593	45.7
11:19	0.76	945.6	29.04	44.5
11:29	1.01	978.1	28.941	42.8
11:39	1.76	1016.9	28.593	43.4
11:49	1.51	444.4	28.196	42.1
11:59	0.76	995.6	29.815	40.1
12:09	1.01	1086.9	29.941	39
12:19	0.5	908.1	30.243	39.1
12:29	1.51	1058.1	29.24	41.1
12:39	0.76	1046.9	30.621	39.1
12:49	0.76	1016.9	30.343	38.7
12:59	1.26	1066.9	29.19	37.5
13:09	1.01	1018.1	30.142	37.9
13:19	1.51	1019.4	29.765	36.6
13:29	1.76	1024.4	29.941	35.6
13:39	1.26	1016.9	31.052	35
13:49	1.26	996.9	31.001	35.1
13:59	1.76	985.6	30.369	33.7
14:09	1.01	936.9	30.925	33.8
14:19	1.26	916.9	29.966	33
14:29	1.51	886.9	30.646	32.2
14:39	1.51	856.9	31.077	29.8
14:49	1.26	815.6	30.016	30.1
14:59	1.26	778.1	30.824	33.1
15:09	0.76	749.4	31.153	32.1
15:19	1.26	723.1	30.849	32.5
15:29	1.76	690.6	30.469	32.4
15:39	1.51	661.9	30.874	31.7
15:49	1.26	635.6	30.52	32
15:59	2.01	591.9	30.167	33.3
16:09	1.26	548.1	30.596	34.7
16:19	1.76	531.9	30.167	34.9
16:29	1.76	489.4	29.665	34
16:39	2.01	454.4	29.74	35.5
16:49	1.76	410.6	29.59	36.1
16:59	1.01	380.6	29.79	36.7
Mean	0.94	741.74	28.23	44.68

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
Stdev	0.62	238.26	2.89	13.47

Table A10: Temperature, relative humidity and solar radiation readings (26th Feb 2016)

Time, GMT+03:00	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
7:59	0	234.4	21.127	78.6
8:09	0	280.6	21.652	76.9
8:19	0	306.9	22.226	75.2
8:29	0	330.6	22.345	74
8:39	0	349.4	23.016	73.1
8:49	0.25	444.4	23.304	72
8:59	0.25	489.4	23.497	71.3
9:09	0	553.1	24.074	69.9
9:19	0.5	238.1	23.136	68.7
9:29	0.25	688.1	23.617	70.1
9:39	0.5	804.4	25.089	67.8
9:49	0.76	674.4	25.331	66.1
9:59	0.5	685.6	25.404	64.5
10:09	0.5	720.6	25.866	63.5
10:19	0.76	748.1	25.283	62.8
10:29	1.26	783.1	25.137	63
10:39	0.76	813.1	26.256	61.4
10:49	0.76	853.1	27.235	60.2
10:59	0.76	884.4	27.235	57.6
11:09	0.5	929.4	27.358	57
11:19	0.25	950.6	28.766	55.2
11:29	0.5	978.1	28.941	53.4
11:39	0.76	986.9	29.315	51
11:49	1.01	1043.1	28.27	50.7
11:59	0.76	308.1	28.717	51.5
12:09	0.76	1205.6	28.245	52.7
12:19	0.5	339.4	27.85	51.6
12:29	0.76	288.1	29.215	52.9
12:39	1.26	1143.1	28.493	51.9
12:49	1.76	1046.9	27.186	53.6
12:59	2.01	1209.4	27.554	53.5

Time, GMT+03:00	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
13:09	2.01	1139.4	27.825	54.5
13:19	2.01	1164.4	27.431	54.1
13:29	1.76	1130.6	28.965	52.6
13:39	2.27	1013.1	27.727	51.4
13:49	1.51	1023.1	29.165	51.7
13:59	1.76	809.4	29.24	49.9
14:09	1.51	978.1	28.742	48.9
14:19	1.76	224.4	28.593	49.3
14:29	2.01	196.9	27.899	50.9
14:39	1.76	1008.1	29.165	51.4
14:49	1.76	928.1	29.389	47.9
14:59	1.26	786.9	30.419	47
15:09	2.01	809.4	28.717	47.3
15:19	1.76	846.9	29.565	47.6
15:29	1.01	361.9	30.343	47.5
15:39	1.01	886.9	29.265	48.5
15:49	1.26	295.6	28.841	49.7
15:59	1.01	210.6	26.72	52.1
16:09	1.01	159.4	26.109	55.6
16:19	0.76	140.6	25.866	58
16:29	0.5	145.6	25.671	59.1
16:39	1.01	123.1	25.186	59.6
16:49	0.25	126.9	25.404	60.4
16:59	0.25	160.6	25.258	60.4
Mean	0.94	654.19	26.77	57.95
Stdev	0.66	354.23	2.40	8.83

Table A11: Temperature, relative humidity and solar radiation readings (29th Feb 2016)

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
7:59	0.76	79.4	18.842	89.7
8:09	1.01	111.9	18.699	88.7
8:19	1.26	131.9	19.08	87.6
8:29	1.26	169.4	19.151	86.6
8:39	1.51	110.6	19.08	85.5
8:49	1.26	125.6	19.436	85.3

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
8:59	0.76	179.4	19.865	84.5
9:09	1.26	146.9	19.627	83.4
9:19	0.5	193.1	20.627	83
9:29	0.76	220.6	20.531	81.7
9:39	0.76	356.9	21.294	79.2
9:49	0.76	928.1	21.676	77.4
9:59	1.01	273.1	22.369	75.4
10:09	0.5	413.1	22.657	74.2
10:19	1.51	1044.4	22.489	73
10:29	1.26	931.9	24.05	70.2
10:39	1.76	926.9	23.689	67.7
10:49	2.01	1044.4	23.713	67.2
10:59	1.51	788.1	25.404	66.3
11:09	1.01	1038.1	25.574	64.3
11:19	1.76	1048.1	24.847	63.6
11:29	1.76	1151.9	24.46	64.2
11:39	1.51	380.6	24.968	62.7
11:49	1.76	321.9	24.919	61.7
11:59	1.26	1226.9	25.817	61.6
12:09	1.76	315.6	24.847	60
12:19	0.76	1199.4	26.329	60.5
12:29	2.01	1250.6	25.866	59.1
12:39	1.76	1168.1	25.963	57.8
12:49	2.27	213.1	25.501	56.3
12:59	1.01	156.9	24.629	58.7
13:09	1.01	294.4	26.842	58.9
13:19	1.26	1031.9	26.867	53.9
13:29	1.26	880.6	27.579	51.8
13:39	1.26	1031.9	27.481	52.6
13:49	1.26	1029.4	28.023	50.2
13:59	2.01	1038.1	27.998	48.3
14:09	3.02	164.4	26.744	47.5
14:19	1.76	1014.4	27.112	48.7
14:29	2.01	215.6	26.598	48.5
14:39	1.26	285.6	28.692	48.3
14:49	1.51	179.4	27.407	48.3
14:59	2.01	374.4	27.407	48.4
15:09	2.01	903.1	27.481	47.2
15:19	1.26	845.6	28.468	47.1
15:29	1.01	334.4	27.481	46.2

Time	Wind Speed, m/s	Solar Radiation, W/m²	Ambient Temp, °C	Ambient RH, %
15:39	0.76	653.1	27.21	48.4
15:49	1.51	99.4	26.085	48.8
15:59	1.01	670.6	27.998	50.2
16:09	2.27	186.9	27.333	47.6
16:19	0.76	569.4	26.524	49.7
16:29	1.26	555.6	27.604	49.1
16:39	1.01	581.9	27.751	47.3
16:49	1.51	101.9	26.867	48.4
16:59	0.76	476.9	26.671	50.5
Mean	1.36	566.65	24.77	62.24
Stdev	0.51	394.14	3.04	14.15

Table A12: Average ambient temperature, relative humidity and Solar radiation readings

Time	wind speed	Solar rad	Tempt	RH
7:59	0.34	199.80	19.50	83.93
8:09	0.42	235.63	20.14	82.10
8:19	0.50	267.70	20.87	79.60
8:29	0.42	308.57	21.16	76.93
8:39	0.50	316.03	21.96	74.37
8:49	0.67	347.30	21.61	72.40
8:59	0.50	389.80	22.06	72.03
9:09	0.42	404.40	22.88	70.23
9:19	0.33	441.43	23.28	68.20
9:29	0.34	415.60	23.42	66.87
9:39	0.50	540.20	23.84	65.53
9:49	0.50	752.30	24.26	63.63
9:59	0.76	555.20	24.80	62.37
10:09	0.75	622.30	24.60	61.07
10:19	0.92	851.90	24.80	59.73
10:29	0.84	841.07	26.00	58.23
10:39	1.01	856.47	25.79	56.20
10:49	0.92	916.87	26.18	55.47
10:59	0.84	872.70	27.23	53.07
11:09	0.50	964.77	27.50	51.70
11:19	1.18	985.60	27.45	51.20
11:29	1.26	1035.63	27.20	49.80
11:39	1.34	785.20	27.39	49.70
11:49	1.51	586.47	26.76	47.90
11:59	0.93	1077.30	28.12	47.43
12:09	1.34	807.30	28.01	46.47
12:19	0.84	1043.53	28.33	46.17
12:29	1.43	1112.70	28.15	46.63
12:39	1.18	1085.20	28.82	45.30
12:49	1.43	757.30	28.46	44.37
12:59	1.26	760.63	27.86	44.60
13:09	1.34	788.97	28.87	44.73
13:19	1.26	1032.30	29.07	42.37
13:29	1.51	993.97	28.90	40.80
13:39	1.26	1032.73	29.39	41.43
13:49	1.60	1016.90	29.35	40.97
13:59	1.59	1017.27	29.61	40.00
14:09	1.68	698.57	29.36	39.20
14:19	1.51	971.07	28.78	39.03

Time	wind speed	Solar rad	Tempt	RH
14:29	1.43	678.53	28.79	39.50
14:39	1.09	686.87	30.17	38.20
14:49	1.51	621.03	28.90	38.83
14:59	1.26	666.87	29.90	39.73
15:09	1.34	755.20	29.18	39.50
15:19	1.51	776.87	29.44	40.03
15:29	1.51	583.53	29.11	39.13
15:39	1.18	673.13	29.50	39.60
15:49	1.18	449.37	28.92	39.60
15:59	1.34	631.87	29.22	40.57
16:09	1.76	348.97	28.81	40.50
16:19	1.26	499.80	28.49	41.73
16:29	1.51	516.87	28.35	41.43
16:39	1.43	513.57	28.80	41.17
16:49	1.76	223.97	28.43	41.53
16:59	0.84	314.37	28.21	42.60
Mean	1.08	684.17	26.84	51.37
Stdev	0.43	264.31	2.89	13.32

Table A13: Average temperature of the dryer in the dryer at different try levels

Time	Temperature					
	Ambient	SN_12	SN_13	SN_15	SN_16	Average Drying chamber
8:00	19.5	19.4	20.1	19.5	19.7	19.6
8:10	20.1	19.9	20.5	20.0	20.2	20.0
8:20	20.9	20.5	21.0	20.5	20.9	20.6
8:30	21.2	21.1	21.5	21.1	21.4	21.2
8:40	22.0	21.7	22.0	21.7	22.1	21.8
8:50	21.6	22.3	22.5	22.3	22.7	22.4
9:00	22.1	22.9	23.0	22.8	23.3	23.0
9:10	22.9	23.5	23.6	23.4	24.0	23.6
9:20	23.3	24.4	24.4	24.2	25.0	24.5
9:30	23.4	25.3	25.1	25.1	26.0	25.5
9:40	23.8	26.6	26.0	26.1	27.3	26.7
9:50	24.3	27.9	26.8	27.1	28.6	27.9
10:00	24.8	29.7	28.0	28.5	30.1	29.4
10:10	24.6	31.5	29.1	29.9	31.4	30.9
10:20	24.8	33.6	30.4	31.4	33.1	32.7
10:30	26.0	36.1	31.9	33.2	34.7	34.7
10:40	25.8	38.6	33.3	35.0	36.5	36.7

Time	Temperature					
	Ambient	SN_12	SN_13	SN_15	SN_16	Average Drying chamber
10:50	26.2	40.8	34.6	36.7	37.8	38.5
11:00	27.2	42.9	35.9	38.4	39.0	40.1
11:10	27.5	44.7	37.4	39.9	40.4	41.7
11:20	27.5	46.2	39.4	41.6	41.8	43.2
11:30	27.2	47.5	40.8	42.9	42.9	44.5
11:40	27.4	48.5	42.0	44.0	43.8	45.4
11:50	26.8	49.3	42.9	44.8	44.7	46.3
12:00	28.1	49.5	43.1	45.0	44.9	46.5
12:10	28.0	49.3	43.2	45.0	44.9	46.4
12:20	28.3	49.1	43.2	45.0	44.9	46.3
12:30	28.1	49.4	43.6	45.1	45.2	46.6
12:40	28.8	50.0	44.0	45.6	45.7	47.1
12:50	28.5	50.3	44.3	45.7	45.9	47.3
13:00	27.9	50.1	44.1	45.6	45.7	47.1
13:10	28.9	50.4	44.5	46.0	46.0	47.5
13:20	29.1	50.9	45.2	46.5	46.5	48.0
13:30	28.9	51.7	46.4	47.5	47.6	48.9
13:40	29.4	51.9	47.1	48.1	48.2	49.4
13:50	29.3	52.2	47.9	48.6	49.1	50.0
14:00	29.6	52.8	48.6	49.3	49.8	50.6
14:10	29.4	53.2	49.2	49.7	50.3	51.1
14:20	28.8	53.3	49.5	50.0	50.6	51.3
14:30	28.8	52.0	48.8	49.1	49.6	50.2
14:40	30.2	51.7	49.1	49.1	49.8	50.2
14:50	28.9	52.2	49.8	49.7	50.7	50.9
15:00	29.9	52.5	50.1	50.2	51.1	51.3
15:10	29.2	52.3	50.2	50.1	51.2	51.2
15:20	29.4	52.1	50.4	50.2	51.4	51.2
15:30	29.1	51.8	50.2	50.0	51.3	51.0
15:40	29.5	50.9	49.8	49.3	50.7	50.3
15:50	28.9	50.0	49.1	48.6	49.9	49.5
16:00	29.2	48.6	48.5	47.6	48.8	48.3
16:10	28.8	47.4	47.4	46.6	47.7	47.2
16:20	28.5	45.3	45.9	44.9	45.7	45.3
16:30	28.3	44.0	45.9	43.8	44.5	44.1
16:40	28.8	43.9	48.0	43.9	44.9	44.2
16:50	28.4	43.4	46.9	43.4	44.3	43.7
17:00	28.2	42.0	45.2	42.2	42.8	42.3
Mean	26.8	45.9	39.3	39.7	40.3	42.0

Time	Temperature					
	Ambient	SN_12	SN_13	SN_15	SN_16	Average Drying chamber
Stdev	2.9	11.5	10.3	10.4	10.3	10.7

Table A14: Fatty acid composition (mg/100g db) in KRG-15 oil from extracted samples subjected to different drying method

	KRG-15		
Drying Method	sample 1	sample 2	sample3
Initial	0.006079767	0.006322957	0.005350195
	0.005514706	0.005744485	0.005055147
Solar Tent	0.002422481	0.002664729	0.002906977
Solar Tent-MW			

Table A35: Fatty acid composition (mg/100g db) in KRG-15 oil from extracted samples subjected to different drying method

	MRG-20		
Drying Method	sample 1	sample 2	sample 3
Initial	0.00627032	0.007199257	0.007431491
	0.004648074	0.004205401	0.004426737
Solar Tent	0.003092293	0.002616556	0.003805899
Solar Tent-MW			

Table A46: Fatty acid composition (mg/100g db) in KRG-15 oil from extracted samples subjected to different drying method

		Initial	Solar Tent	50	Solar Tent - 60	50-60	60	Solar Tent-MW
Fatty acid composition	C12:0	0.1	0.2	0.3	0.4	0.1	0.1	0.2
	C14:0	6.0	1.2	1.1	1.9	1.1	1.0	1.0
	C16:0	8.9	10.4	9.9	10.1	10.6	10.1	10.0
	C16:1	22.7	27.2	27.3	31.4	25.4	26.3	24.9
	C18:0	1.5	2.1	1.5	2.4	1.7	1.3	1.9
	C18:1	52.6	51.6	51.1	47.9	52.4	53.8	54.0
	C18:2	2.7	2.4	2.3	1.9	2.5	2.5	2.1
	C18:3	1.4	1.7	1.5	1.4	1.7	1.3	1.6
	C20:0	2.7	1.4	0.7	1.1	2.2	3.0	2.7
	Others	0.7	0.9	2.1	0.7	1.2	0.3	0.8

Table A57: Fatty acid composition (mg/100g db) in MRG-20 oil from extracted samples subjected to different drying method

		Initial	Solar Tent	50	Solar Tent - 60	50-60	60	Solar Tent-MW
Fatty acid composition	C12:0	0.12	0.16	0.27	0.16	0.62	0.19	0.18
	C14:0	0.86	0.93	1.29	0.92	1.49	0.95	10.06
	C16:0	9.51	9.25	9.76	8.35	12.27	9.83	9.15
	C16:1	29.27	28.47	29.09	23.23	26.70	30.41	25.47

	C18:0	1.99	2.58	2.73	2.09	4.55	2.58	2.29
	C18:1	51.36	51.76	48.56	42.52	45.46	48.96	46.62
	C18:2	2.32	1.97	1.75	3.31	1.65	2.08	3.63
	C18:3	1.57	1.98	2.36	0.64	5.02	1.82	0.70
	C20:0	1.90	1.68	1.29	1.20	0.82	1.60	1.31
	Others	0.56	0.62	1.44	8.79	0.71	0.79	0.58

Appendix II: List of Plates

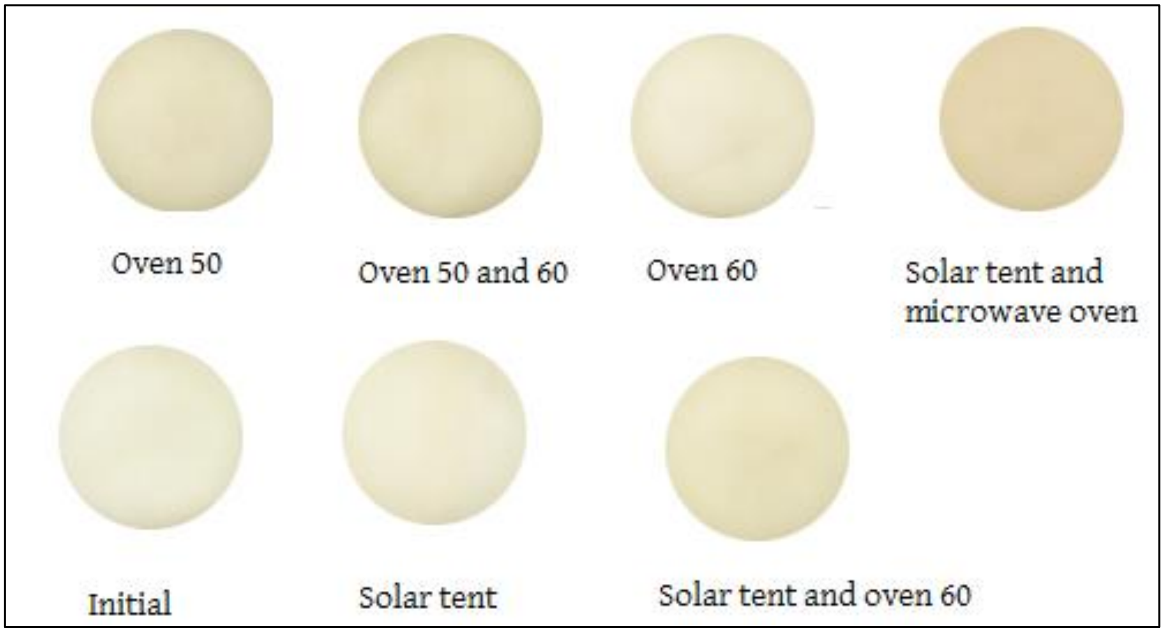

Plate B1: A sample of colour image of KRG-15 nuts dried using different methods.

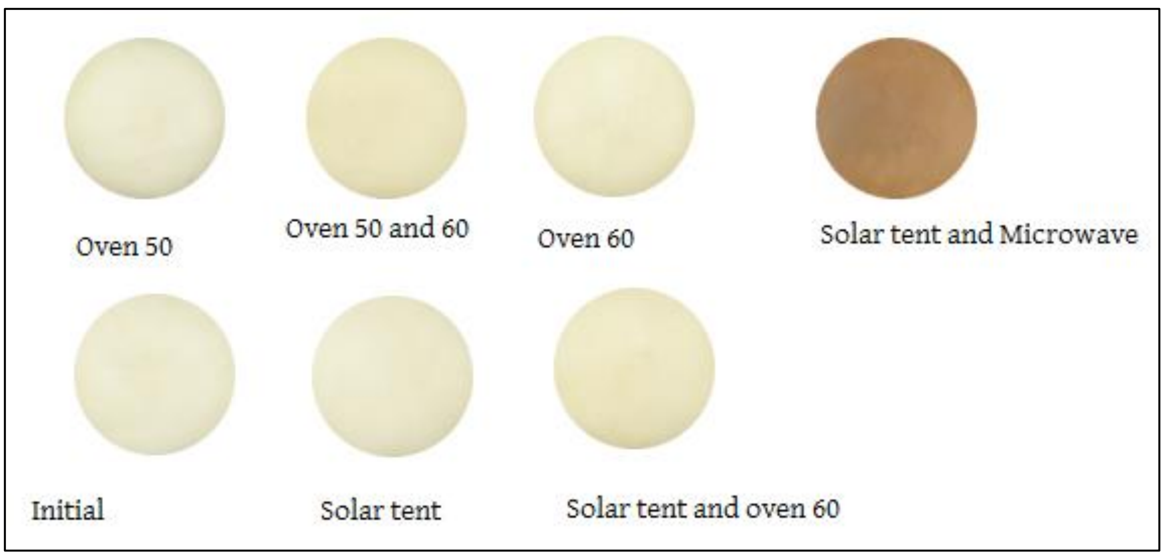

Plate B2: A sample of colour image of MRG-20 nuts dried using different methods.

Appendix III: Publications and Conference Presentations

a) Journal Articles

Njuguna, S. N., Ondimu, S., & Kenji, G. M. (2016). Mathematical Modelling of Thin Layer Drying Characteristic of Macadamia Nuts Varieties in Different Drying Environment. International Journal of Engineering Research & Technology (IJERT), 5(07), 531–535.

b) Conference Proceedings

Njuguna, S. N., Ondimu, S., & Kenji, G. M. (2016). Classification of Drying Methods for macadamia Nuts based on the GLCM Texture parameters. Proceedings of 2018 Sustainable Research & Innovation (SRI) Conference (pp. 4-5). Retrieved from http://jkuat-sri.jkuat.ac.ke.