UNIVERSITY OF CAPE COAST

DRYING KINETICS AND QUALITY OF DRIED MORINGA LEAVES USING DIFFERENT DRYING METHODS

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Name: Catherine Mbabazi

Signature: ……. Date: …….…….

Supervisors' Declaration

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: …….. Date: …..…..……

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ABSTRACT

The drying kinetics and effect quality of dried moringa leaves using different drying methods. The methods were microwave (MW) alone, solar, sun, shade, hot air alone and blanch-assisted and MW-assisted hot air drying methods. The drying experiments were performed in the temperature range of 50 to 70 °C, MW-power of 270 to 720 W, blanching time of 1 to 3 min and sample thickness 3 to 20 mm. MW-pretreatment time, blanching time, sample thickness, microwave power and hot air temperature had significant effects on the drying time but they generally affected negatively the quality attributes (AA, TP, AOA, BI and FL) of the dried samples. Four thin layer drying models were fitted to the experimental data and the Midilli et al model most appropriately described the drying behavior of moringa leaves. Rehydration studies were carried out at the temperature of 60 ^{o}C and the hot air drying method best fitted Weibull equation, first order kinetic and exponential association equations. The optimal drying conditions of moringa leaves were found to be 50 ^{o}C at the thickness of 4.79 mm for hot air, and that for MW-alone was 501.1 W at 3 mm thickness. For blanch-assisted hot air drying, optimal conditions were 70 ^{o}C and blanching time of 2.58 min while for MW-assisted hot air drying, they were 70 °C at MW-power of 270 W and MW-time of 3 min. The results demonstrated that all the drying methods differentially affected the drying rates and the desirable and deleterious quality characteristics. The implications for the choice of drying method are discussed.

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DEDICATION

To my sponsors METEGA.

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LIST OF ABBREVIATIONS

RR	Rehydration ratio
W_r	Weight rehydrated sample (g)
W_d	Weight of dried sample (g)
RC	Rehydration capacity
W_w	Weight of the water absorbed during rehydration
W_d	Weight of dried sample (g)
WAC	Water absorption capacity
M_w	Mass of water absorbed during rehydration
M_{wr}	Mass of water removed during drying.
MP	Microwave power (watts)
MW	Microwave
Mt	Microwave pretreatment time (min)
A_0	Absorbance of the control
A_1	Absorbance in the presence of the sample
MR	Moisture ratio
M	Moisture content at any time
M_0	Initial moisture content
M_e	Equilibrium moisture content
DR	Drying rate
M_{t+dt}	Moisture content (kg water per kg dry matter)
t	Time
dt	Drying time (min)
M_t	Moisture content
$MR_{expt,i}$	Experimental moisture ratio
$MR_{expt,i}$	Predicted dimensionless moisture ratio
N	Number of observations

Z	Number of model constants
K	Drying rate constants
a, b & n	Coefficients of the model equations
R^2	Correlation coefficient
RMSE	Root mean square error
χ^2	Reduced chi-square
D_{eff}	Effective moisture diffusivity (m^2/s)
L	Half the thickness of the sample of moringa leaves (mm)
D_0	Constant in the Arrhenius equation (m^2/s)
E_a	Activation energy (KJ/mol)
T	Temperature of hot air (^oC)
R	Universal gas constant
W	Watts
MP	Microwave power (W)
q	Sample thickness
E_c	Energy consumption (kWh)
c	Energy unit charge
n^*	Independent variables
di	Desirability index for each response variable (Y_i)
Y_i	A multicriteria optimization approach
DI	Overall desirability index
X_w	Moisture content at any time (kg/kg db.)
X_0	Moisture content at time zero (kg/kg d.b.)
t^*	Rehydration time (s)
A	A kinetic constant of the model (s. [kg d.b.]/kg)
X_e	Equilibrium moisture content (kg/kg d.b.)
B	Characteristic constant of the model (kg d.b./kg)

H	Kinetic constant
T	Temperature (^{o}C)
RH	Relative humidity (%)
RSM	Response surface methodology
BBD	Box–Behnken design
DT	Drying time (min)
AA	Ascorbic acid (mg/g)
TP	Total phenolic (mg/g)
FL	Flavonoids (mg/g)
BI	Browning index
AOA	Antioxidant activity (% of inhibition)
DW	Dry weight
db	Dry basis

CHAPTER ONE

INTRODUCTION

Background of the Study

Moringa oleifera (Lam) belongs to the monogeneric family of shrubs and trees called Moringaceae (Offor, Ehiri, & Njoku, 2014). Moringa is a highly valued plant that is mostly cultivated in the tropics and subtropics (Moyo, Masika, Hugo, & Muchenje, 2013). It is considered as one of the World's most useful trees; almost every part of the moringa tree can be used as food for human consumption as well as animal feed and other industrial uses because of its nutritional and medicinal value and water purifying characteristics (Mukunzi et al., 2011). Moringa is used as an alternative to imported food supplements to treat and combat malnutrition, especially among infants and nursing mothers because it is rich in antioxidant compounds (Iqbal & Bhanger, 2006; Santos, Argolo, Coelho, & Paiva, 2005)

The leaves of moringa are cooked and eaten like spinach or used to make soups, sauce and salads (Fuglie, 2001). It has been reported that the micro-nutrient content is more concentrated in the dried leaves: ten (10) times the vitamin A of carrots, seventeen (17) times the calcium of milk, fifteen (15) times the potassium of bananas, twenty five (25) times the iron of spinach and nine (9) times the protein of yogurt but the vitamin C drops to a half of that of oranges (Mukunzi et al., 2011).

Moringa leaves contain phytochemicals, with powerful anticancer and antihypertensive activity and are considered full of medicinal properties used for treating fevers, sore throat, bronchitis, eye and ear infections, scurvy and catarrh; leaf juice is believed to control glucose levels and is applied to reduce

glandular swelling (Makonnen, Hunde, & Damecha, 1997; Morton, 1991). In the Philippines studies done by Estrella, Jacinto Bias III, David and Taup (2000) discovered that moringa leaves are ‘mothers’ best friend’ because of its use in increasing nursing mothers’ milk production and is sometimes prescribed for anemic patients.

It has been reported that moringa leaves act as a good source of natural antioxidants such as ascorbic acid, flavonoids, phenolics and carotenoids (Dillard & German, 2000). Moringa leaves are commonly dried and ground into powder and can be stored without refrigeration for months without appreciable loss of nutritional value (Fuglie, 2001).

The leaves of moringa are fragile and have high moisture, which account for their perishability after harvest. The phytochemicals in the leaves are also susceptible to losses if not dried appropriately. According to Krokida, Maroulis, & Saravacos (2001), it is important to dry moringa leaves because quality changes occur when stored in its fresh form. Such changes include, changes in optical properties (colour, appearance), sensory properties (odour, taste, flavour), structural properties (density, porosity, specific volume), textural properties, rehydration properties (rehydration rate, rehydration capacity) and nutritional characteristics (vitamins loss, proteins denaturation).

Recently, in Ghana, moringa leaf products particularly leaf powder, are becoming increasingly widespread because of its outstanding nutritional value. When the leaves are dried they can be consumed in different ways; for example as part of the main meal or in beverages. In Ghana, moringa powder is mostly used in tom brown, weanmix and cakes. Therefore, it is of importance to develop suitable drying methods that will reduce the drying

time and the incidence of nutritional losses. Consequently, this study was undertaken to investigate the drying of moringa leaves using microwave alone, solar, sun, shade, hot air alone, blanch-assisted and microwave-assisted hot air drying methods.

Problem Statement

According to Premi, Sharma, Sarkar and Singh (2010), the method adopted for drying moringa leaves is mainly traditional in nature and time consuming; and thus needs systematic methodology for obtaining a good quality product. Studies done by Lakshmi and Vimala (2000) and Premi et al. (2010) on green leafy vegetable powders, traditional vegetable processing and drumsticks leaves respectively, show that drying in direct sun and under shade affect considerably the nutritional value by reducing the concentration and availability of proteins, vitamins and other essential compounds in these vegetables.

Nevertheless, drying in direct sun and under shade are the common practices used in most parts of Africa to preserve vegetables for consumption. Researches indicate losses in nutrients from vegetables during sun drying (Kendall, Safford, Flannery-Schroeder, & Webb 2004; Yadav & Sehgal, 1995). Investigators such as Khachik et al. (1992) reported cooking of vegetables as another cause of loss of nutrients in vegetables. Studies done by Kiremire, Musinguzi, Kikafunda, and Lukwago (2010) using sun drying method to dry green leafy vegetable *Amaranthus dubius* showed that it resulted in the greatest loss of β-carotene, 58 % and vitamin C contents (84 %).

Studies have also been done on other methods of drying such as hot air, microwave, infrared, microwave-assisted drying and freeze drying. Several researchers such as Feng, Tang, Cavalieri, and Plumb (2001) dried diced apples using microwave. Nijhuis et al. (1998) dried various fruits and vegetables using microwave to determine the quality. Torringa, Esveld, Scheewe, van den Berg and Bartels (2001) dried mushrooms using microwave-assisted drying. These researchers reported that the use of microwave can significantly reduce the drying time because of its advantages such as automatic adjustment of the energy absorption level by the wet products. The possible selective heating of the interior portions and microwave focusing effect is another advantage that the microwave methods possess. The rapid energy dissipation throughout the material and relatively minor migration of water-soluble constituents, lower product temperatures in combination with vacuum and any other drying method like hot air and more efficient drying in the falling rate period .

Numerous studies on drying kinetics have been done on different agricultural products such as pear fruit (Lahsasni, Kouhila, Mahrouz, & Jaouhari, 2004), drumstick leave (Premi et al., 2010), fever leaves (Sobukola & Dairo, 2007), red pepper (Doymaz & Pala, 2002), garlic cloves (Sharma, Prasad, & Datta, 2003) and tomato slices (Abano, Ma, & Qu, 2011). Therefore it is important to compare methods of drying such as solar, sun, shade, microwave alone, hot air, blanch-assisted and microwave-assisted drying on the drying kinetics of moringa leaves in order to determine which drying method is appropriate for preservation of phytochemicals and more cost effective for adoption by famers.

Justification

An approach intended to increase consumption of moringa leaves is to convert the leaves into dried powder to be used as a functional ingredient in food formulation. Processing perishable moringa leaves into intermediate product such as powder, which is more stable and less bulky, widens the potential opportunities and diversity for its utilization (Tetteh, 2008). Different drying methods have been employed to convert moringa leaves into powder and the common method of drying is solar drying. However, this drying method is time consuming and reduces productivity due to the reduction in the essential nutrients.

Studies done by Prabhanjan, Ramaswamy, and Raghavan (1995), show that microwave drying has advantages such as high thermal efficiency, shorter drying time and improved product quality when compared with the conventional hot air drying. This method of drying eliminates the case hardening problem in conventional drying (Prabhanjan et al., 1995). Combined microwave and hot air, in comparison with hot air alone was found to greatly reduce the drying time of biological materials without damaging the quality attributes of the final products (Ren & Chen, 1998).

When adopting a new technology, it is important to establish the various conditions necessary for its effective use. This will allow processors of moringa leaves to have the optimum quality of the dried leaves and reduce the drying time in comparison to traditional methods of drying.

Main Objective

To determine the effect of solar, sun, shade, and hot air, microwave alone, blanch-assisted and microwave-assisted hot air drying on the drying kinetics and quality of dried moringa leaves.

Specific Objectives

1. To investigate the effect of solar, sun, shade, hot air alone, microwave alone, microwave and blanch-assisted hot air drying on the drying rate, moisture diffusivity, activation energy for moisture removal, rehydration and quality attributes such as ascorbic acid, total phenolic, antioxidant activity, non-enzymatic browning and flavonoids of dried moringa leaves.
2. To establish a thin layer drying model for the different drying methods.
3. To determine the optimal drying conditions for moringa leaves for all the various drying methods used in this study.

Hypotheses

Null Hypothesis

1. There is no significant difference between solar, sun, shade, hot air alone, microwave alone, microwave and blanch-assisted hot air drying on the drying rate, moisture diffusivity, activation energy for moisture removal, rehydration and quality attributes
2. There is no significant effect while establishing a thin layer drying model for the different drying methods.
3. There is no significant effect on the determination of the optimal drying conditions for moringa leaves for all the various drying methods used in this study.

Alternative Hypothesis

1. There is a significant difference between solar, sun, shade, hot air alone, microwave alone, microwave and blanch-assisted hot air drying on the drying rate, moisture diffusivity, activation energy for moisture removal, rehydration and quality attributes
2. There is a significant effect while establishing a thin layer drying model for the different drying methods.
3. There is a significant effect on the determination of the optimal drying conditions for moringa leaves for all the various drying methods used in this study.

Significance of the Study

The results from this study could be used by farmers and industries to dry moringa leaves and the optimal drying conditions would be used for obtaining the best quality of dried moringa leaves.

Delimitation

The drying of the leaves in this study was done at the laboratory of the University of Cape Coast Research Farm and for the determination of the quality parameters were all determined at the chemistry laboratory of the University of Cape Coast. Cape Coast lies on the latitude of 05-06 ºN and longitude of 01-15 ºS at an altitude of 1.1 m above sea level. The annual temperature is 30–34^{o}C during the day and 22–24^{o}C during the night and a relative humidity of 75–79 %.

Limitations

In this study the main methodological weakness was having a lot of samples for the determination of quality parameters. The samples were being

exposed to light for a long period of time while preparing them for extractions thus, may have contributed to the losses of these quality parameters (ascorbic acid, total phenolics, antioxidant activity and flavonoids). Therefore, the losses of quality parameters in the dried samples was not only caused by the various drying methods (sun, solar, shade, hot air, microwave a lone, blanch and microwave assisted hot air drying methods).

Definition of Terms

1. Drying is a process of moisture removal due to simultaneous heat and mass transfer
2. Rehydration studies measures the structural changes or damages that may have occurred during drying process.
3. Relative humidity is the amount of water vapor in the air expressed in percentage (%).
4. Blanching is the process of heating vegetables to high temperature for a short period in order to destroy enzymes present in the tissue.

Organisation of the Study

The background of the research, problem statement, justification and the objectives of the study were defined in Chapter One. The literature review related to the study investigated was presented in Chapter Two. The materials and methods used to carry out the research are described in Chapter Three. The mathematical background and determination of quality attributes were also presented in Chapter Three. The results obtained in the study are presented in Chapter Four. Finally, Chapter Five contains of summary, conclusions and recommendations derived from the complete study.

CHAPTER TWO

LITERATURE REVIEW

Moringa Oleifera

Moringa oleifera (horseradish or drumstick tree), a non-toxic (at low concentrations) tropical plant that is found throughout India, Asia, Latin America sub-Saharan Africa and is now grown around the world (Jahn, 1988). There are major production sites in Ghana, Uganda, Senegal, and Malawi, minor production in New Zealand and Fiji recently, production has begun in Nicaragua and Bolivia. Moringa species are often important famine foods because of their high tolerance to arid conditions due to the formation of very large tuberous roots (Sena et al., 1998).

The uses of moringa tree parts are many including the use of roots, stems, leaves, flowers, green pods, petioles and seeds for human foods and for animal feed. Moringa roots, leaves, flowers, gum and the aqueous infusion of seeds have been found to possess diuretic activity (Cáceres et al., 1992; Morton, 1991) and such diuretic components are likely to play a complementary role in the overall blood pressure lowering effect of this plant. Figure 1 shows a typical moringa oleifera tree.

Figure 1: Moringa oleifera tree.

The Health Benefits of Moringa Leaves

Moringa leaves are purgative, applied as poultice to sores, rubbed on foreheads of people with headaches, used for piles, fevers, sore throat, bronchitis, eye and ear infections, scurvy and catarrh; leaf juice is believed to control glucose levels, applied to reduce glandular swelling (Dahot, 1988; Fuglie & Fuglie, 2001; Makonnen et al., 1997; Morton, 1991; Sastri, 1962). Studies done by Anwar, Ashraf and Bhanger (2005) prove that moringa leaves are decent source of natural antioxidant due to the presence of various types of antioxidant compounds such as ascorbic acid, flavonoids, phenolics and carotenoids. On the other hand, the high concentrations of ascorbic acid, oestrogenic substances and β-sitosterol, iron, calcium, phosphorus, copper, vitamins A, B and C, α-tocopherol, riboflavin, nicotinic acid, folic acid, pyridoxine, β-carotene, protein, and in particular essential amino acids such as methionine, cystine, tryptophan and lysine present in moringa leaves and pods make it a virtually ideal dietary supplement. Studies done by Sastri (1962) and Dahot (1988) show that moringa leaf juice has got a stabilizing effect on blood pressure.

The crude extract of moringa leaves has a significant cholesterol lowering action in the serum of high fat diet fed rats which might be attributed to the presence of a bioactive phytoconstituent, β-sitosterol (Ghasi, Nwobodo, & Ofili, 2000). Moringa leaves have been widely studied pharmacologically by different investigators (Dahot, 1988; Dangi, Jolly, & Narayanan, 2002), it has been found that the ethanol extracts and its constituents exhibit antispasmodic effects possibly through calcium channel blockade. According to Gilani, Janbaz, Lateef and Zaman, 1994) the antispasmodic activity of the

ethanol extract of moringa leaves has been attributed to the presence of 4-[α-(L-rhamnosyloxy) benzyl]-o-methyl thiocarbamate (trans), which forms the basis for its traditional use against diarrhoea.

Furthermore, spasmolytic activity exhibited by different constituents provides pharmacological basis for the traditional uses of this plant in gastrointestinal motility disorder (Gilani et al., 1994). The methanol fraction of moringa leaf extract showed antiulcerogenic and hepatoprotective effects in rats (Pal, Mukherjee, & Saha, 1995). Aqueous leaf extracts also showed anti-ulcer effect (Pal et at., 1995) indicating that the antiulcer component is widely distributed in this plant. The fresh leaf juice was found to inhibit the growth of microorganisms (*Pseudomonas aeruginosa* and *Staphylococcus aureus*), pathogenic to man (Cáceres et al., 1992).

Makonnen et al. (1997) found moringa leaves to be a potential source for anti-tumor activity. O-Ethyl- 4-(α-L-rhamnosyloxy)benzyl carbamate together with 4(α-L-rhamnosyloxy)-benzyl isothiocyanate, niazimicin and 3-O-(6′-O-oleoyl-β-D-glucopyranosyl)- β-sitosterol have been tested for their potential antitumor promoting activity using an in vitro assay which showed significant inhibitory effects on Epstein–Barr virus-early antigen. Niazimicin has been proposed to be a potent chemopreventive agent in chemical carcinogenesis (Guevara et al., 1999).

It has been found that niaziminin, a thiocarbamate from moringa leaves, exhibits inhibition of tumor-promoter-induced Epstein–Barr virus activation. On the other hand, among the isothiocyanates, naturally occurring 4-[(4′-O-acetyl-α-i-rhamnosyloxy) benzyl], significantly inhibited tumor-promoterinduced Epstein–Barr virus activation, suggesting that the

isothiocyano group is a critical structural factor for activity (Makonnen et al., 1997). Numerous investigators (Pal et al., 1995; Tahiliani & Kar, 2000) reported that moringa oleifera also exhibit other diverse activities. Aqueous leaf extracts regulate thyroid hormone and can be used to treat hyperthyroidism and exhibit an antioxidant effect. A methanol extract of *Moringa oleifera* leaves conferred significant radiation protection to the bone marrow chromosomes in mice (Rao et al., 2001). Tahiliani and Kar (2000) show that moringa leaves are effective for the regulation of thyroid hormone status. According to Lipipun et al. (2003), moringa leaves may be applicable as a prophylactic or therapeutic anti-HSV (Herpes simplex virus type 1) medicine and may be effective against the acyclovir-resistant variant. Studies done by Makonnen et al. (1997) show that an infusion of moringa leaves juice reduces glucose levels in rabbits.

Other parts of moringa tree such as the root, stem bark, gum, flowers and seed are also known for their health benefits. Studies by Dahot (1988) and Sastri (1962) reported the health benefits of the roots, stem, bark, gum, flowers and seeds of moringa as antilithic, rubefacient, vesicant, carminative, antifertility, anti-inflammatory, stimulant in paralytic afflictions; act as a cardiac/circulatory tonic, used as a laxative, abortifacient, treating rheumatism, pain killers, lower back or kidney pain and constipation. Table 1 presents mineral contents of moringa leaves from different agro climatic regions in Nicaragua, India and Niger whereas Table 2 shows the nutritional analysis of fresh moringa leaves and dried leaf powder per 100 gramnes.

Table 1: Mineral Contents of Moringa Leave from Different Agro-Climatic Origins

Mineral	Nicaragua	India	Niger
Micro elements (g/kg-1DM)			
Calcium	17.5	24.4	13.9
Phosphorus	1.16	1.362	1.2
Magnesium	0.11	0.11	0.11
Sodium	1.16	2.73	2.61
Potassium	19.1	21.7	18.4
Micro elements (mg kg-DM)			
Iron	582	175	347
Magense	47.1	51.8	113.9
Zinc	13.5	13.7	24.2
Copper	11.2	7.1	10.6

Source: (Foidl, Makkar, & Becker, 2001)

Table 2: Nutritional Analysis of Fresh Moringa Leaves and Dried Leaf Powder (per 100 grams)

	Fresh leaves	Leaf powder
Moisture (%)	75.0	7.5
Energy (Kcal)	92.0	205.0
Protein (g)	6.7	27.1
Fat (g)	1.7	2.3
Carbohydrate (g)	13.4	38.2
FiberFibre (g)	0.9	19.2
Minerals (g)	2.3	0.0
Ca (mg)	440.0	2,003.0
Cu (mg)	1.1	0.6
Fe (mg)	7.0	28.2
Oxalic acid (mg)	101.0	0.0

Source: (Fuglie & Fuglie 2001)

Blanching

Blanching can be described as the process of heating vegetables to a temperature high enough to destroy enzymes present in the tissue. Blanching

is done by exposing fresh produce to boiling water or steam for a brief period of time. Akindahunsi and Oboh (1999) reported that blanching vegetables stops the enzyme action, stablize the colour, and shortens the drying or dehydration time. Akindahunsi and Oboh further explained that blanching is usually carried out in hot water or in steam; this technique is used by indigenous people to reduce or eliminate the bitterness of the vegetables and acid components that are common in leaves. The research done by Oboh (2005) shows that in Nigeria, most green leafy vegetables are usually blanched before consumption; this is usually carried out in order to make it more palatable.

The studies done by Oboh (2005) on different tropical green leafy vegetables (*Amarantus cruentus, Ocimum gratissimum, Telfairia occidentalis, Vernonia amygdalina, Baselia alba, Corchorus olitorus, Structium sparejanophora* and *Solanum macrocarpon)* reported that blanching caused a significant increase in the total phenol content [fresh (0.1–0.3 g/100 g), blanched (0.2–0.6 g/100 g)] of the vegetables. Dewanto, Wu, Adom and Liu (2002) reported that cooking or wet heating could increase phenol content in tomatoes. The basis of the increase could not be categorically stated. However, it could be attributed to the possible breakdown of the tannins (Akindahunsi & Oboh, 1999) that is present in the vegetables during blanching converts to simple phenol.

According to the studies done by Doymaz (2012), blanched samples of persimmon slice were found to have a shorter drying time compared to the control samples. The drying time required to reach final water content of 20 ± 0.5 % (w.b.) for blanched samples was 315, 285 and 180 min at 50, 60 and 70

^{o}C, respectively. The corresponding values for control samples were 450, 345 and 240 min at the same respective temperatures. The drying time was reduced by about 21–42.8 % for persimmon slices, as drying temperature was increased from 50 to 80 ^{0}C. Similar findings were reported in drying of carrots (Chen, Peng Chen, 1995) and spinach plus broccoli (Desouza & Eitenmiller, (1986).

Blanching also relaxes tissues of the produce thus leads to reduction in the drying time (Greve et al., 1994; Waldron, Parker, & Smith, 2003) thus the cells in the produce lose their wall integrity when blanched and thus bound water is lost faster during drying than when un-blanched. Another effect of blanching is that it makes some vegetables such as broccoli or spinach more compact, and reduces the time needed to refresh vegetables before cooking (Kendal et al., 2004).

Koca, Burdurlu, and Karadeniz (2007) studied the effect of drying of carrot with and without blanching. It was found that blanching prior to drying enhanced the retention of β-carotene in dehydrated carrots compared to unblanched dehydrated samples. The high loss of β-carotene in unblanched carrots was attributed to oxidation during drying process with active enzyme system.

Blanching as a preservative method for vegetables often leads to loss of nutrients, mostly vitamins and minerals because of the leaching of these important nutrients (Makanjuola, 2013). However, Fellows (2009) reported that though blanching is an important pre-processing heat-treatment of vegetables, it inevitably causes separation and losses of water soluble nutrients such as minerals, water-soluble vitamins and sugars. Steam blanching takes

more time, but fewer water-soluble nutrients are lost. To minimize the loss of nutrients, blanching is done only for the required length of time. However, it is necessary that food produce are not under-blanched; the enzymes will not be inactivated, and the quality of the dried foods will be inferior (Kendall et al., 2004). The vegetable must then be rapidly cooled in ice water or by use of evaporative cooling to prevent it from cooking. The quality of water used to blanch vegetables can have an effect on the texture of certain vegetables. Very hard water can cause the toughening of vegetables such as green beans (Korus, 2011).

Types of Blanching

There are many ways of blanching vegetables: blanching in boiling water, steam blanching and microwave blanching. Blanching in boiling water requires a large pot with a tight-fitting lid. For leafy greens, 3.571 litres can be used for 0.454 kilogram. Water is boiled and the blanching basket containing the vegetable is fully immersed. The pot is covered and boiled at 100 ^{o}C for the required length of time. The same blanching water may be used two or three times, keeping water at the required level. The water could be changed if it becomes cloudy. It is important to chill vegetables immediately after blanching. This can be done by plunging the basket of vegetables into pots of ice water for the same time used for blanching water. The water must be kept cold by changing frequently or by adding ice. Vegetables are then drained thoroughly, ensuring the removal of extra water, which will form too many ice crystals. Vegetables are spread in a single layer in front of a fan. As the water evaporates, the vegetables are cooled. This chilling method does not add water to the vegetables. The result is often a less mushy product. With either

method, the center of a piece of food must be checked to be sure it is cool. Vegetables must never be packaged warm in order to avoid introducing more moisture to them (Korus, 2011; Tetteh, 2008).

Blanching by steam is done by boiling water in a pot and placing the blanching basket over the pot such that only the steam generated from the boiling water is in contact with the vegetables, and the pot tightly covered with a lid. The blanching basket must cover the pot fully to prevent the steam from being lost escaping into the atmosphere. If they are leafy vegetables ensure even and thin spreading of leaves in the blanching basket. The basket is then removed from the steam after the time scheduled for blanching. Evaporative cooling is the best method of cooling for this form of blanching; this cooling process will not add water to the vegetables (Korus, 2011). Vegetables are then ready to be canned, frozen or dried. However, Kendall, Safford, Flannery-Schroeder and Webb (2004) reported that water blanching is recommended over steam blanching or blanching in a microwave, superheated steam and infrared blanching because water blanching achieves a more even heat penetration than the other methods.

Drying of Agricultural Products

Drying of agricultural products is probably the oldest method of food preservation practised by humankind and has enabled civilizations to exist and evolve to date (Mwithiga & Olwal, 2005). Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer (Gulia, Sharma, Sarkar, Upadhyay, & Shitandi, 2010). Ranganna (1986) described drying as the reduction of moisture content as much as possible from foods in order to deactivate enzyme and microbial activities hence avoiding deterioration.

Mujumdar and Devahastin (2000) defined drying as a process that converts solid, liquid or a semi- solid feedstock into a solid material through the evaporation of liquid into vapourr by application of heat.

In other application such as freeze drying, heat is supplied and it directly causes drying through sublimation. According to Baysal, Icier, Ersus, and Yıldız (2003) during drying, many changes take place including structural and physico-chemical modifications which affect the final product quality. Green and Schwarz (2001) explained the importance of drying of food as the process that minimises food spoilage.

Benefits of Drying Agriculture Products

The major benefits for the popularity of dried food have been summarised by (Mujumdar & Devahastin, 2000; Mwithiga & Olwal, 2005; Prabhanjan et al., 1995) as avoiding microbial spoilage in food material which can occur after harvest. Thus, drying is done for preservation. Drying lowers weights and volumes of the product hence, it is beneficial because it reduces the size of the product by the removal of the excess water from the products by enhancing the quality of dried product (Fudholi, Sopian, Ruslan, Alghoul, & Sulaiman, 2010). Thus convenient in handling, lowering transportation costs and storage requirements as well as reducing prices fluctuations in the market by ensuring continuous supply when the crop is out of season (Mwithiga & Olwal, 2005). Without food drying processing, operations could be difficult or even impossible to do.

Mwithiga and Olwal (2005) indicated that drying improves the storage ability for a very long period of time without affecting the nutritive element. They explained that moisture content in the dried food varies between 2-30 %

depending on the type of a food. In tropical countries, solar dryers can be used to dry fresh produce when average relative humidity is below 50 % (Kendall et al., 2004; Mujumdar & Devahastin, 2000).

Some of the Methods for Drying Agricultural Produce

Sun, Shade and Solar Drying

Drying in ancient days was done primarily in the sun. Nowadays, many types of sophisticated equipment and methods are used to dry foods. During the past few decades, considerable efforts have been made to understand some of the chemical and biochemical changes that occur during drying and to develop methods for preventing undesirable quality losses. In direct sun drying the product is heated directly by the sun's rays and moisture is removed by natural circulation of air due to density differences (Green & Schwarz, 2001; Tetteh, 2008). In solar and shade drying samples are not exposed to directly to the sun.

Hot Air or Conventional Drying

Hot air drying can be applied by placing fruit or vegetables in a heated chamber with a ventilating fan, or by applying forced hot air where the temperature, relative humidity and speed of air circulation are precisely controlled (Lurie, 1998). The hot air chamber has been utilized to study physiological changes in fruits and vegetables in response to heat (Klein & Lurie, 1991).

Hot air drying is the easiest method of preserving perishable agricultural products (Min, Chunli, & Xiaolin, (2005). When a high moist product is dried by hot airflow, it generally experiences a warming-up period, a constant drying rate period, and one or several falling rate periods. Drying

with only hot airflow takes a long time and has low energy efficiency, especially during the falling rate periods. This is mainly caused by rapid reduction of surface moisture and consequent shrinkage, which often results in reduced moisture transfer and, sometimes, reduced heat transfer. Prolonged exposure to elevated drying temperature may result in substantial degradation of quality attributes such as: colour, nutrients and flavour (Min et al., 2005). Severe shrinkage also reduces bulk density and rehydration capacity.

Forced hot air, however, been used to develop quarantined procedures (Gaffney & Armstrong, 1990). One reason is that the high humidity in vapor heat can sometimes damage the fruit and vegetables being treated, while the slower heating time and lower humidity of forced hot air can cause less damage. A high temperature forced air quarantine treatment to kill Mediterranean fruit fly, melon fly and oriental fruit fly on papayas has been developed (Armstrong, Hu, & Brown, 1995). This procedure may require rapid cooling after the heat treatment to prevent fruit injury, as may the forced hot air treatment for citrus (Sharp & McGuire, 1996).

Microwave Drying Process

Microwave drying process consists of three drying periods. The first period is a heating-up period in which microwave energy is converted into thermal energy within the moist material, whereby the temperature of the product increases with time. This occurs if the moisture vapour pressure in food is above that of the environment; the material starts to lose moisture, however at relatively smaller rates (Zhang, Tang, Mujumdar, & Wang, 2006).

The second is the rapid drying period, during which a stable temperature profile is established, and thermal energy converted from

microwave energy is used for the vaporization of moisture. When it comes to porous food structures, rates of moisture vaporization at different locations in foods depend, to a large extent, upon the local rates of thermal energy conversion from microwave. In this second period of microwave drying is where abundant of the moisture loss takes place, and moisture distribution in spherical foods is determined at this period through experimental measurements of moisture profiles and computer simulation. The most important characteristic of microwave heating is volumetric heating which is a unique characteristic of microwave heating for drying heat-sensitive materials (Funebo et al., 2002; Mullin, 1995). Dielectric heating with microwave energy has found industrial applications in drying food products such as fruits and vegetables (Zhang et al., 2006).

The third microwave drying process is the reduced drying rate period, when the local moisture is reduced to a certain point; the energy needed for moisture vaporization is less than thermal energy converted from microwave hence the local temperature rises above the boiling temperature of water. Even though loss factors of the food materials decrease with moisture reduction and the conversion of microwave energy into heat is reduced at lower moisture content, to cause chemical changes by the direct interaction with molecules and chemical bonds (Khraisheh, Cooper, & Magee, 1997). The product temperature still continues to rise, resulting in overheating or charring. Development of temperature profiles in the microwave heating period has been studied for various geometries. During microwave drying processes the heating period is relatively short and moisture loss is little (Bouraoui, Richard, & Durance, 1994).

Advantages of Microwave Drying

Studies have proved that microwave drying has unique advantages such as high thermal efficiency, adjustment of energy absorption level by the wet products automatically, moisture-leveling effect of microwaves; opportunities to shorten the drying time and improves the final quality of the dried products; possible selective heating of the interior portions-microwave focusing effect; rapid energy dissipation throughout the material; relatively minor migration of water-soluble constituents; lower product temperatures in combination with vacuum; and more efficient drying in the falling rate period (Feng et al., 2001; Nijhuis et al., 1998; Prabhanjan et al., 1995; Zhang et al., 2006).

A study by Haile (2013) reported the effect of four microwave powers and three vacuum pressures on drying time of tomato slices. In the study, the drying time reduced from 84 to 14 min as the microwave power increased from 200 to 700 W. To remove the incidence of case hardening problem of the products in conventional drying, Prabhanjan et (1995) advised to the use of microwave drying.

According to studies by Ren and Chen (1998), combined microwave hot air in comparison with hot air highly reduced the drying time of biological materials without damaging the quality attributes of the final products. A smaller floor space is needed for microwave drying compared to conventional drying since the upsurge in processing rate makes it possible to design more compact equipment and therefore the plant capacity can be increased without supplementary building space. Mullin (1995) and Thuéry (1992) reported that in bread baking application of microwave energy can decrease the processing

time by 50 %. The operational cost in microwave drying is also lower because energy is not consumed in heating the walls of the apparatus or the environment.

Disadvantages of Microwave-related Drying

The non-uniformity of the electromagnetic field within a microwave cavity is the main problem when drying using a microwave (Cohen & Yang, 1995). It is important to ensure the microbial safety and high quality of microwave-dried foods by controlling heating uniformity (Błaszczak, Gralik, Klockiewicz-Kamińska, Fornal, & Warchalewski, 2002). The success of microwave heating of vegetables and fruits with high initial moisture contents often depends on uniformity of heating. Although this problem can be partially offset by using wave-guides and a rotating tray, there are limits to the energy level that can be applied. Cohen and Yang (1995) reported that arcing occurred when the power was increased to above 500 W in their small-scale drying cavity.

According to Cohen and Yang (1995) and Nijhuis et al. (1998), excessive temperatures along the edges and corners of products may lead to overheating and irreversible drying-out resulting in possible scorching and development of off-flavour. If the application of microwave drying is not done properly it results in poor-quality product (Yongsawatdigul & Gunasekaran, 1996).

In microwave drying, the materials to be dried should be in constant motion in the cavity to avoid any hot spots. Since only a limited amount of water is available during the final stages of drying processes, the material temperature can easily rise to a level that causes excessive heating, which may

result in physical damages to the product such as scorching, off-colour and non-uniform temperature distribution in the final product (Yongsawatdigul & Gunasekaran, 1996). The final product temperature in microwave drying is difficult to control, compared to that in hot air drying in which product temperature never rises beyond air temperature. Another disadvantage of microwave drying is the rapid mass transport by microwave power which may cause quality damage or undesirable changes in the food texture by 'puffing' (Nijhuis et al., 1998). Microwave drying sometimes results in browning of the dried product and the colour parameters can adversely be affected compared to the freeze dried products.

Due to the high cost associated with microwave drying, it was used only in cases where drying of final products has to meet high-quality specifications or as a supplementary drying method for further product-quality improvement (Drouzas & Schubert, 1996). It is reported that in the USA, the cost of hot air process was 20 % of the microwave process cost (Funebo et al., 2002). Although microwave power at 915 MHz penetrates to a greater depth than it does at 2450 MHz, in large-scale drying applications, the penetration depth is still much smaller compared to that attained in radio frequency (RF) heating at 10-300 MHz (Wang, Chen, & Gao, 2005). However, with the microwave heating, there is no common method to monitor or control the electromagnetic field distribution and its effect after the microwave is switched on (Kelen, Ress, Nagy, Pallai, & Pintye-Hodi, 2006).

Rehydration Studies

Rehydration studies of dried food measures the structural changes that have occurred in the food matrix after a single or multiple processing steps.

According to the study by Lewicki (1998), it reported rehydration as a measure of the magnitude of injuries inflicted on food products during a drying process and other handling operations prior to rehydration.

There are different ways to carry out rehydration tests according to equation 1 to 3 (Lewicki & Maskan, 2001): The rehydration ratio was calculated as follows:

$$RR = \frac{W_r}{W_d} \quad (1)$$

where, RR is the rehydration ratio, W_r is the weight of rehydrated sample (g) and W_d is the weight of dried sample (g).

$$RC = \frac{W_w}{W_d} \quad (2)$$

where, RC is the rehydration capacity, W_w is weight of the water absorbed during rehydration, and W_d is the weight of dried sample (g).

$$WAC = \frac{M_w}{M_{wr}} \quad (3)$$

where, WAC is the water absorption capacity, M_w is the mass of water absorbed during rehydration and M_{wr} mass of water removed during drying.

The rehydration capacity also described as the percentage of water gained and calculated using equation 4.

$$W_g = \left(\frac{W_t - W_d}{W_d}\right) 100\ \% \quad (4)$$

where, W_g represents the weight gain (%), W_t is the rehydrated weight after time t and W_d the initial weight before rehydration.

CHAPTER THREE

MATERIALS AND METHODS

Sample Preparation

Fresh moringa leaves for the drying experiments were obtained from the Technology Village of the University of Cape Coast, in the Central Region of Ghana. The samples were manually sorted and cleaned to ensure that they were free from insects, branches, dirt and any other foreign matter. The samples were then stored in a refrigerator at 5^{o}C in order to minimise the physiological and chemical changes that may occur (Karaaslan & Tuncer, 2008; Maskan, 2001). The initial moisture content was determined by drying 10 g of the sample in triplicate in an oven at the temperature of 105^{o}C and leaving for 24 h in hot-air oven (AOAC, 1990).

This similar procedure of determining moisture content has been used by Abano & Amoah (2015) and Doymaz (2005) on white yam and okra respectively. The initial mean values of ascorbic acid, flavonoids, total phenolics, antioxidant activity and non-enzymatic browning were determined according to the methods described below. When the drying experiment was completed, dried samples were kept in a freezer at (-25^{o}C) for further analysis.

Experimental Designs

Microwave-assisted Hot Air Drying

The Box–Behnken design (BBD) response surface methodology (RSM) was used to design the drying experiments for microwave-assisted hot air drying. The three (3) independent variables were microwave power (X_1) in watts, microwave pretreatment time (X_2) in min and temperature (X_3) in ^{o}C at 3 levels each. The dependent variables (ascorbic acid, flavonoids, total

phenolics, antioxidant activity, non-enzymatic browning and drying time) were fitted to quadratic model. Table 3 shows the BBD RSM arrangements used for the drying experiment. The full model used to describe the dependent variables (Y) involves the linear, interaction and curvature effects as shown in Eq. (5)

$$Y_r = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_1 X_2 + \beta_5 X_1 X_3 + \beta_6 X_2 X_3 + \beta_7 X_1^2 + \beta_8 X_2^2 + \beta_9 X_3^2 \quad (5)$$

where β_0, β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8, β_9 are the regression coefficients; X_1, X_2, X_3 are the coded values of the independent variables (microwave power, microwave pretreatment time and temperature, respectively) while Y represents the dependent variables (ascorbic acid, flavonoids, total phenolic, antioxidant activity, non-enzymatic browning and drying time).

The effects of microwave power, microwave pretreatment time and temperature on ascorbic acid, flavonoids, total phenolic, antioxidants, non-enzymatic browning and drying time were analyzed.

Table 3: Factor Levels of the BBD used in the RSM Study of the Microwave-assisted Drying Conditions

Independent variables	Symbols		Levels	
	Natural	Coded	Natural	Coded
Microwave Power	MP	X_1	270 W	-1
			495 W	0
			720 W	1
Microwave drying time	Mt	X_2	1 min	-1
			2 min	0
			3 min	1
Temperature	T	X_3	50 ^oC	-1
			60 ^oC	0
			70 ^oC	1

Blanch-assisted Hot Air Drying

A 2- factor, 3-level factorial design was used to design in designing the drying experiments in this study of blanch-assisted hot air drying. Samples were blanched for 1, 2 and 3 min after which they were subjected to various drying temperatures of 50, 60 and 70^{o}C. The effect of two factors: temperature (X_1) and blanching time (X_2) was studied in this research.

Hot Air Drying

A 2-factor, 3-level factorial design was used to design the drying experiments for hot air drying without any application of pretreatment before drying. Samples were subjected to the different drying temperatures of 50, 60, and 70^{o}C. The effects of two factors temperature (X_1) and sample thickness (X_2) were studied on the responses. The various thicknesses used in the study were 3, 11.5 and 20 mm. The leaves were distributed uniformly on the trays. The initial sample weight was 30 g for each drying experiment. The dryer was run idle for 1h prior to the drying experiment to achieve steady state conditions. The samples were weighed every 10 min until the moisture content reached 8 % (d.b) using equation 6.

$$Dry\ basis\ \ Md = \frac{100 - Mw}{100 - Mw} \tag{6}$$

where, Md is the mass in dry basis and Mw is mass in wet basis

The arrangement of samples in the oven for is shown in Figure 2. The dried samples were cooled and packed in air tight polyethylene bags. A digital balance with an accuracy of ± 0.001 g was used. The experiment was conducted in triplicate as shown in (Figure 2) and the average was taken.

Figure 2: Arrangement of sample holders in the cabinet hot air dryer

Microwave Alone Drying

A 2- factor, 3-level factorial design was used to design the drying experiments for microwave alone drying. Samples were dried using different Microwave powers 270, 495 and 720 W considering thicknesses previously mentioned for hot air drying. The effect of the two factors: microwave power (X_1) and thickness (X_2) was investigated in this study.

Blanching Procedure

Steam blanching was done by boiling water in a pan and the bowl mesh was placed over the pan. The duration periods were 1, 2 and 3 min. The distance between the bowl mesh containing moringa leaves and the boiling water was 10 cm apart. This was done with the intention that the moringa leaves were not into direct contact with water. The pan was tightly covered with a lid to prevent the steam from escaping into the atmosphere it observed in Figure 3. Absorbent papers were used to remove the moisture from the surface of the blanched leaves; the samples were cooled by natural ventilation and dried in a hot-oven.

Figure 3: Blanching of moringa leaves using steam.

Drying Procedure for Microwave alone to Dry Moringa Leaves

A domestic microwave (Kenwood, model K28CB11) with a maximum power output of 900 Watts was used to dry moringa leaves (Figure 4). The same 30 g of samples in hot air drying was used in microwave drying study. Each experiment was replicated 3 times.

Figure 4**:** An open microwave containing samples of moringa leaves ready to dry.

The Drying Procedure for Shade, Solar and Sun Drying to Dry Moringa Leaves

A drying box was designed with three different sections to dry moringa leaves in direct sun and in the shade as shown in Figure 5. The dimensions

were 70 × 34 × 12 cm and contained a black plastic rubber which enabled the removal of the samples for weighing purposes until they reached the required moisture content (8 % d.b). 30 g of samples were spread in triplicate in each division for both shade and direct sun drying. For shade drying, the samples were dried under a tree shade whereas for direct sun drying, the samples were exposed to direct sun during the daytime from 9.00 am to 4.00 pm as described by Prabhu, Rajan and Santhalia (2011) until the samples reached the desired moisture content. Solar drying was done using the solar dryer (Figure 6).

The dryer was put in the sun for at least an hour prior experiment to ensure elevated temperature. The weights of the samples were monitored; as follows direct sun drying every 10 min, solar every 30 min and shade every 3 hours. Temperature and relative humidity were also recorded using a hygrometer (EXTECH, model 44550. Thermo-hygrograph every time before taking the sample weights. Figure 6 shows the solar dryer looked when closed to dry the samples and after it was opened to take the weight, temperature and relative humidity of the samples.

Figure 5: Moringa leaves drying in direct sun and shade.

Figure 6: Drying of moringa leaves using a solar dryer (closed and open).

Determination of Quality Attributes

Flavonoids (FL)

Flavonoid was determined according to the method used by Sultana et al. (2009) with modifications applying the aluminum chloride colorimetric assay. 2 g of pounded dried and fresh moringa leaves were weighed using electronic weighing scale (Sartorius AG Germany, model LE623P) with ± 0.0001 g accuracy. The sample was put into an extraction tube followed by the addition of 20 mL of 80 % ethanol solution. An aliquot of the extract or standard solution of quercetin (20, 40, 60, 80 and 100 mg/L) was added to 10 mL test tube containing 4 mL of distilled water. Immediately, 0.15 mL 5 % $NaNO_2$ solution was added to test tube. After 5 min, 0.15 mL 10 % $AlCl_3$ was added before adding 2 mL, 1.0 M NaOH and the total volume was adjusted to 10 mL with distilled water. The sample was vortexed for 10 sec. The absorbance was measured against a blank at 510 nm using spectrophotometer (Shimadzu, UV mini-1240 UV-VIS Japan), and the total flavonoid content

was expressed as quercetin Equivalent (mg/g of dry weight basis). Two measurements were taken for each sample and the results were averaged.

Ascorbic Acid Content (AA)

Ascorbic acid contents of fresh and dried samples of moringa leaves were determined spectrophotometrically by using colorimetric analysis method of Sadasivan and Balsubramanium (1987). The colorimetric analysis of ascorbic acid gives an accurate analysis of ascorbic acid content; thus, since dehydro-ascorbic acid alone reacts quantitatively and not the other reducing substances present in the sample extract. The sample weight and reagents were measured using electronic weighing scale (Sartorius AG Germany, model LE623P,) with ± 0.0001 g accuracy. One gram of the sample material was ground mechanically and 4 % of oxalic acid solution of the mixture was added, agitated and filtered. Ten milliliters of filtered sample was transferred into 25 mL flask and bromine water was added until the extract became orange red. Ten milliliter of the stock ascorbic acid standard solution was similarly converted into dehydroascorbic acid form by bromination. 70.4-563 µg of standard dehydroascorbic acid solution was pipetted into a series of tubes. Different aliquots (0.1⁻1 mL) of the brominated sample extract were similarly pipetted into test tubes. One milliliter of thiourea was added followed by 1 mL of DNPH (2, 4-dinitrophenylhydrazine) reagent. The blank was prepared similarly but distilled water was used in place of ascorbic acid solution. The contents of the tubes were mixed thoroughly and incubated at 50^{o}C in a water bath for 1 hour. After the incubation, orange-red osazone crystals formed were dissolved by adding 6 mL of 80 % of sulphuric acid. The absorbance was measured at 540 nm using spectrophotometer (Shimadzu, UV

mini-1240 UV-VIS Japan), and ascorbic acid concentration was estimated from the mathematical expression of the calibration curve of ascorbic acid concentration versus absorbance.

Non-enzymatic Browning (BI)

The protocol of Cernîşev (2010) as followed by Abano, Ma and Qu,(2014) with modifications was used to determine the browning index (BI). The sample weight was measured using electronic weighing scale (Sartorius AG Germany, model LE623P,) with ± 0.0001 g accuracy. Twenty milliliter (20 mL) of 60 % ethanol was used to extract brown pigment from 1 g test portions of the powdered moringa leaves. The browning index was measured at absorbance of 440 µm. The ground samples of the died moringa leaves were attained by using a kitchen blender for 2 min while for fresh moringa leaves a mortar and pestle were used, after 25 mL of ethanol (60 %, v/v) was added and allowed to stand for 12 h, agitated and then filtered through 0.45 µm nylon filter membrane. The filtered extract was topped up to the 25 mL mark. Evaluation of the browning index was estimated using spectrophotometer (Shimadzu, UV mini-1240 UV-VIS Japan), against 60 % ethanol as blank. All samples were extracted in duplicates.

Total Phenolics (TP)

TP of moringa leaves was determined according to the method of Sreelatha and Padma (2009). The dried moringa leaves were pounded into fine powder with a kitchen blender for 2 min, while for fresh moringa leaves a mortar and pestle were used. Two grams of each pounded samples was weighed using electronic weighing scale (Sartorius AG Germany, model LE623P) with ± 0.0001 g accuracy and put into an extraction tube followed by

addition of 20 mL of 80% aqueous methanol (v/v) solution. The samples were incubated in a warm bath at 60^{o}C for 10 min and filtered through 0.45 µm nylon filter membrane.

The amounts of phenolic compounds in the extracts of the leaves were estimated by using Folin–Ciocalteau reagent. In a series of test tubes, 0.1 mL of the extract in methanol was taken; 0.9 mL of distilled water, mixed with 2 mL of Folin–Ciocalteau reagent and 1 mL of sodium carbonate. The tubes were then allowed to stand in the dark at room temperature for 60 min before the absorbance was read at wave-length set at 765 nm against a blank. The absorbance was measured by using spectrophotometer (Kyoto, Japan) Shimadzu UV mini-1240 UV-VIS. A standard curve was prepared using gallic acid monohydrate with the following concentrations 0, 0.247, 0.611.1.479, 2.135 and 2.482 mg/mg. The total phenolic compounds content was calculated and expressed as gallic acid equivalent in (mg/g) of extracts.

Antioxidant Activity (AOA)

The free radical scavenging activity of the extract was measured in terms of radical scavenging ability using the stable free radical DPPH (2, 2-Diphenyl-1-Picrylhydrazyl) as described by Blois (1958) with modifications. Extraction method was performed using 70 % (v/v) methanol as solvent, The fresh and dried moringa leaves were ground into fine powder with a kitchen blender for 2 min, while for fresh moringa leaves a mortar and pestle were used. One gram of each pounded samples were macerated with 70 % methanol (1:20, w/v) for 72 h at room temperature (28 ± 2^{o}C) with occasional shaking. The extract was filtered through 0.45 µm nylon filter membrane and the marc was re-macerated with the same solvent until the extraction was exhausted.

Briefly, 0.5 mL solution of the extract was added to 0.004 % DPPH solution in methanol. The contents were mixed vigorously and allowed to stand in the dark at ambient temperature for 60 min. A blank solution of methanolic DPPH was also prepared but without the sample. After 60 minutes incubation in the dark, the absorbance of the samples and blank were read at 517 nm using spectrophotometer (Kyoto, Japan) Shimadzu UV mini-1240 UV-VIS. Each sample was measured in duplicate. The capability to scavenge the DPPH radical was calculated using equation 6.

$$\text{DPPH scavenging effect \%} = \left(\frac{A_0 - A_1}{A_0}\right) * 100 \quad (7)$$

where, A_0 was the absorbance of the control, and A_1 was the absorbance in the presence of the sample.

Drying Kinetics of Moringa Leaves Stated in Terms of Empirical Models

The drying kinetics of moringa leaves were studied by filling experimental data to the listed in Table 4. The experimental data obtained were converted to dimensionless moisture ratio (MR) and plotted against drying time. The MR of the moringa leaves was determined using equation (8)

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (8)$$

where M, M_0, M_e are defined as: the moisture content at any time, the initial moisture content and the equilibrium moisture content respectively.

The drying rate (DR) of moringa leaves was calculated according to Doymaz (2010) using equation (9).

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (9)$$

where, M_{t+dt} is moisture content (kg water per kg dry matter) at t + dt, M_t is the moisture content at t and t is the drying time (min).

Drying curves were fitted to four different empirical drying models broadly used in scientific literature as shown in Table 4 to describe the drying kinetics of moringa leaves. This was based on the criteria to determine the goodness of fit to the models; the correlation coefficient (R^2), the root mean square error (RMSE) and the reduced chi-square (χ^2). The highest R^2, lowest χ^2 and RMSE were used to determine the goodness of fit. This criteria to select the best models for drying has been used by several authors (Abano et at. 2011; Akpinar, 2006; Doymaz, 2011; Doymaz, 2005; Erbay & Icier, 2010; Vega, Uribe, Lemus, & Miranda, 2007) studies on tomatoes slices, okra, thyme, olive leaves, onion slices and aloe vera, respectively.

Table 4: Mathematical Models that were applied to the Drying Curves

Model name	Model Expression	References
Page	$MR = \exp(-kt^n)$	(Page, 1949)
Logarithmic	$MR = a\exp(-kt)+c$	(Doymaz, 2010)
Henderson and Pabis	$MR = a\exp(-kt)$	(Ghodake, Goswami, & Chakraverty, 2006)
Midilli et al.	$MR = a\exp(-kt^n)+bt$	(Midilli, Kucuk, & Yapar, 2002)

$$R^2 \frac{N\sum_{i=1}^{N} MR_{pred,i}\ MR_{expt,i} - \sum_{i=1}^{N} MR_{pred,i} \sum_{i=1}^{N} MR_{expt,i}}{\sqrt{\left(N\sum_{i=1}^{N} MR_{i=1}^{2} - \left(\sum_{i=1}^{N} MR_{pred,i}\right)^2\right)\left(N\sum_{i=1}^{N} MR_{expt,i}^{2} - \left(\sum_{i=1}^{N} MR_{expt,i}\right)^2\right)}} \quad (10)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{expt,i} - MR_{pred,i}\right)^2} \quad (11)$$

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{expt,i} - MR_{pred,i}\right)^2}{N - Z} \quad (12)$$

where $MR_{expt,i}$, $MR_{expt,i,}$ MR, N and Z are expressed as the experimental MR, the predicted dimensionless MR, the number of observations, and the number of model constants, respectively. The drying rate constants (k) and coefficients of the model equations (a, b, n) were determined with nonlinear regression of SPSS version 21.0 and the goodness of fit of the curves was determined with correlation analysis.

Determination of Moisture Diffusivity and Activation Energy for Hot Air

The drying process during the moisture removal was determined using Fick's second law of diffusion equation (13) as described by the following authors (Abano et al., 2011, Doymaz, 2011; Singh, Jain, Doshi, Jain, & Chahar, 2008). Fick's second law of diffusion is wildly used to describe the drying process during the falling rate period for agricultural materials.

$$\frac{\partial M}{\partial t} = D_{eff}\nabla^2 M \quad (13)$$

Using equation (13) as solved by Crank (1975) for an infinite slab, assuming uni-dimensional moisture movement volume change, constant temperature and diffusivity coefficient, and negligible external resistance. The solution is of the form equation (14)

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n-0}^{\infty}\frac{1}{(2n+1)}\exp\left(\frac{-(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad (14)$$

For long drying times only the first term of the series in the equation is applied with reasonable accuracy and equation (14) was shortened to a restrictive form of the diffusion equation as per equation (15)

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{4L^2}\right) \quad (15)$$

where, D_{eff} of moringa leaves were obtained from the slope (K) of the graph of InMR against the drying time t. InMR versus time results in a straight line with negative slope and K is related to D_{eff} using equation (16)

$$K = \frac{\pi^2 D_{eff}}{4L^2} \quad (16)$$

where MR is the moisture ratio, D_{eff} is the effective moisture diffusivity (m^2/s), and L is half the thickness of the sample of moringa leaves (mm), M is the moisture content at any time, t, M_e is the equilibrium moisture content, and M_0 is the initial moisture content.

According to Doymaz (2011) also Simal, Garau, Femenia and Rosselló (2006) D_{eff} can be associated to temperature by Arrhenius equation (17)

$$D_{0\,eff} = D_{0\,exp}\left(-\frac{E_a}{R(T + 273.15)}\right) \quad (17)$$

Where D_0 presents the constant in the Arrhenius equation (m^2/s), E_a is the activation energy (kJ/mol), T is the temperature of hot air (^oC), and R is the universal gas constant (8.31451 $kJmol^{-1}$ K^{-1}) equation (17) can be rearranged into the form:

$$In(D_{eff}) = In(D_0) - \frac{E_a}{R(T + 273.15)} \quad (18)$$

The activation energy for moisture diffusion was obtained from the slope of the graph of In (D_{eff}) against $\frac{1}{T+273.15}$.

Determination of Activation Energy for Microwave-Alone Drying

A microwave oven (Kenwood, model K28CB11) with a maximum power output of 900 W was used in the drying process of moringa leaves, according to the method of Pillai et al. (2010). The internal temperature of the

sample is not a measurable variable. The Arrhenius type equation was used in tailored form to illustrate the relationship between the diffusivity coefficient and ratio of the microwave power output to sample thickness instead of the temperature, for the calculation of the activation energy. The equation suggested by Dadali et al. (2007) was applied:

$$D_{eff} = D_o \exp\left[\frac{-E_a q}{P}\right] \quad (19)$$

where D_{eff} is the effective moisture diffusivity (m^2/s), D_0 is the constant in the Arrhenius equation (m^2s), E_a is the activation energy (W/mm), P is the microwave power (W), and q is the sample thickness and equation (19) can be rearranged into equation (20):

$$\ln(D_{eff}) = \ln(D_o) - \frac{E_a q}{P} \quad (20)$$

The activation energy for moisture diffusion of moringa leaves was obtained from the slope of the graph of $\ln(D_{eff})$ against q/P.

Calculation of Energy Consumption during Drying

The energy consumption of optimized conditions for all drying methods studied were calculated using equation (21)

$$E_c = \frac{P \times t}{1000} \quad (21)$$

where E_c is the energy consumption in kWh, P is the power rating of either the microwave equipment or the convective air dryer in W, and t is the drying time.

Optimization of the Drying Process

The optimization of the drying process was performed as described by Myers, Montgomery and Anderson-Cook (2009) by means of a multivariate

response method called overall desirability index (DI). Equation (22) was used to determine DI.

$$DI = \left[\prod_{i=1}^{n^*} di\,(Y_i)\right]^{\frac{1}{n^*}} \qquad (22)$$

where n^* represents independent variables, di symbolises the desirability index for each response variable (Y_i) and Y_i is a multicriteria optimization approach used to show how desirable the various responses are.

The DI ranges between 0 and 1 with 0 being the least desirable while 1 is the most desirable. Maximization of DI value is the goal in optimization studies. In the present study, the goal for the independent variables was at any level within the range of the design values. The optimization process combines goals and priorities for the independent and response variables. Nevertheless, the response variables goal was maximum values of the AA, TP, FL and AA whereas for BI and DT the goal of the study was minimum.

Rehydration Studies

The rehydration of dried moringa leaves was carried out according to the protocol of Doymaz (2012) at the temperature of 60^{o}C. Three grams of dried sample of moringa leaves were weighed in triplicates. The sample weight was measured using electronic weighing scale (Sartorius AG Germany, model LE623P) with ± 0.0001 g accuracy. The rehydration process was done by immersing each sample in 300 mL of distilled water in a 400 mL beaker. Rehydrated samples were drained over a mesh and blotted with tissue paper for 1 min in order to eliminate the superficial water. Subsequently, the samples were weighed every 20 min and when the water absorption by the samples

reduced the weighing time increased every 30 min until the samples attained equilibrium. The rehydration ratio (RR) was calculated using equation 1.

Rehydration Kinetics

The empirical models used for the rehydration kinetics in the present study were Peleg's model (equation 23), Weibull equation (equation 24, first-order kinetic model (equation 26) and exponential association equation (equation 27. Other researchers have used similar models in their studies (Apar, Demirhan, Özbek & Dadali, 2009; Demirhan & Özbek, 2010; García-Pascual, Sanjuán, Melis, & Mulet, 2006; Noshad, Mohebbi, Shahidi, & Mortazavi, 2012).

$$X_w = X_0 + \left[\frac{t^*}{A + Bt^*}\right] \quad (23)$$

where X_w, X_0, t, and A are presented as the moisture content at any time (kg/kg db.), the moisture content at time zero (kg/kg d.b.), the rehydration time (s), and a kinetic constant of the model (s. [kg d.b.]/kg) respectively. In case the rehydration takes long, the equilibrium moisture content (X_e) (kg/kg d.b.) is given by

$$X_e = X_0 + \frac{1}{B} \quad (24)$$

where B is a characteristic constant of the model (kg d.b. /kg).

Comparing drying process to rehydration process, many changes happen during the process of immersing samples in water. The equilibrium moisture content is considered as an additional parameter to be identified in the Weibull model (equation 24).

$$X_w = X_e + (X_0 - X_e)\exp\left[-\left(\frac{t}{B}\right)^A\right] \quad (25)$$

where B (s) and A (dimensionless) are the scale and the shape parameters, respectively.

$$X_w = X_e + (X_0 - X_e)\exp(-kt) \quad (26)$$

where k is the rehydration kinetic constant (s^{-1}).

$$X_w = X_e[1 - \exp(Ht)] \quad (27)$$

where H is the kinetic constant(s^{-1}).

Statistical Analysis

A second-order polynomial model was fitted to the mean values of the experimental results to derive the regression equations. Design Expert 9 version: 9.0.6.2 Statistical package software was used. The statistical significance of the model terms was checked at a probability of 5%. Analysis of variance was carried out to find out the statistical significance of the model terms at a probability of 5 %. The accuracy of the model to describe the response variables was diagnosed using the coefficient of determination (R^2) values. One independent variable was kept at zero level and the 3-D surface plots for 2 factors were generated for the various responses.

CHAPTER FOUR

RESULTS AND DISCUSSION

Influence of Temperature and Relative Humidity for Direct Sun, Solar and Shade Drying Methods

In the present study temperature and relative humidity were monitored for sun, shade and solar drying conditions. Influence of temperature and relative humidity for the above drying condition is presented in Figure 7. It was observed that an increase in temperature resulted in a decrease in relative humidity. This might be due to that fact that warm air can hold more water vapor than cool air. Relative humidity falls when the temperature rises if moisture is not added to the air. Temperature and relative humidity for direct sun, solar and shade drying ranged from 35.8 to 55.8^{o}C and 42 to 14 %; 33.5 to 47.9^{o}C and 47 to 17 %; 26.4 to 31.9^{o}C and 52 to 81 % respectively. These results are in good agreement with the findings of Wexler and Hasegawa (1954) on their study of relative humidity-temperature relationships of some saturated salt solutions in the temperature range of 0 to 50^{o}C.

Drying Kinetics of Moringa Leaves using Direct Sun, Solar and Shade Drying Methods

The initial average moisture content of moringa leaves was 3.167 kg water/ kg dry matter, which decreased continuously to 0.087 kg water / kg dry matter after the period of drying. The variation of moisture ratio versus drying time for the above drying methods of moringa leaves are shown in Figure 8. The direct sun drying took the shortest time of 110 min to dry followed by solar drying (330 min) however shade drying that took the longest period of 1530 min to dry. Drying in direct sun obtained the highest values of

temperatures and lowest values of relative humidity. Hence the difference in temperature and relative humidity obtained by direct sun drying compared to shade and solar drying might be the reason why direct sun drying dried faster than the other two methods of drying.

Variation of drying rate against moisture content for sun, solar and shade drying of moringa leaves are presented in Figure 9. The drying process took place in the falling rate period with a very short accelerating period in the beginning. The highest value of DR was obtained with direct sun drying compared to shade and solar drying methods. The reduction in the drying rate for solar and shade drying may be due to the reduction in temperature and increase in relative humidity. It can be seen that at higher moisture content, direct sun and solar drying have more considerable effect on the drying rates compared to shade drying, which is almost negligible towards the end.

The design of solar dryer permit large flow of high humid air out of the endosure and can improve faster DR at the beginning. Studies done by Chen, Hernandez and Huang (2005) using a closed solar dryer to dry lemon slices are in good agreement with the results attained in the current study. They compared the closed-type solar dryer with the results they got for hot air drying at 60^{o}C. The results indicated that the dried lemon slices using a closed-type solar dryer had better general levels of quality in terms of sensory parameters.

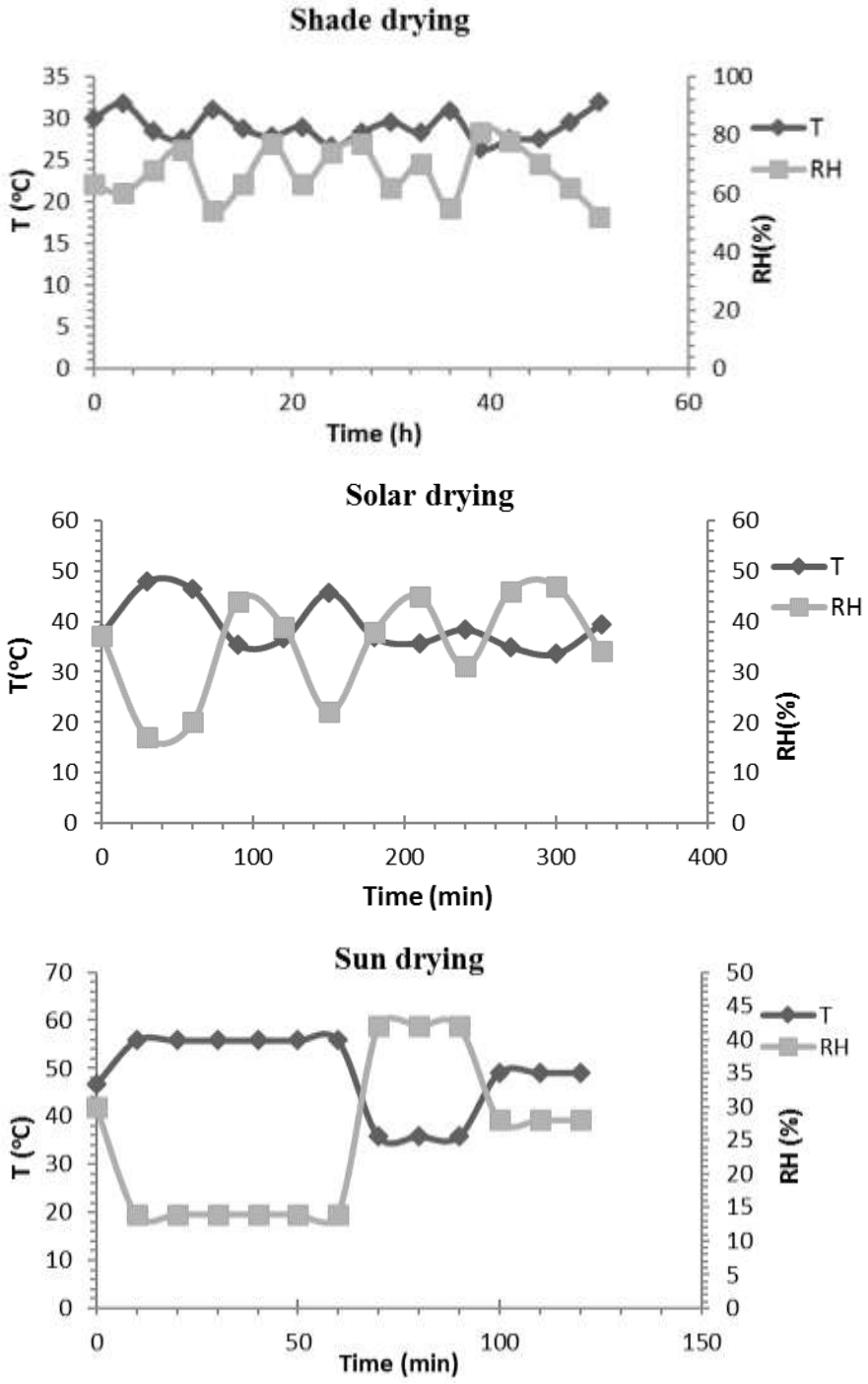

Figure 7: Effect of temperature and relative humidity on sun, shade and solar drying

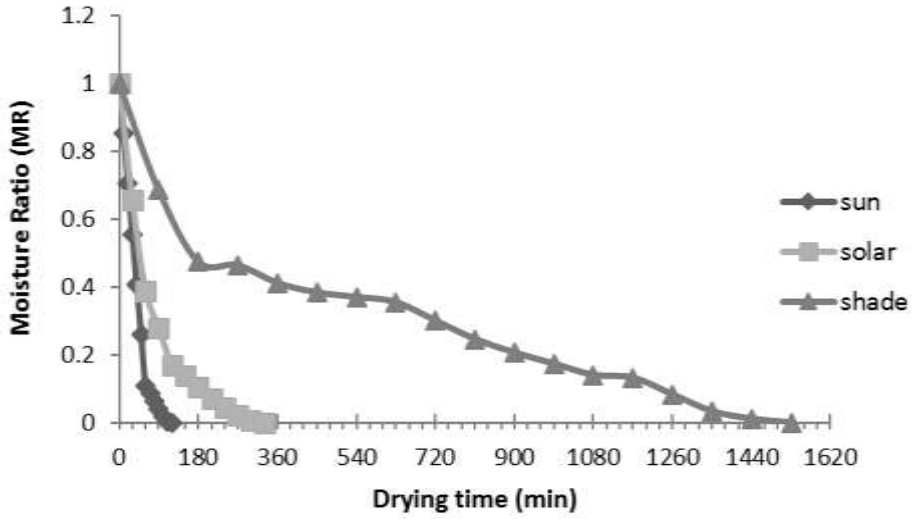

Figure 8: Variation of moisture ratio versus drying time for sun, solar and shade drying methods.

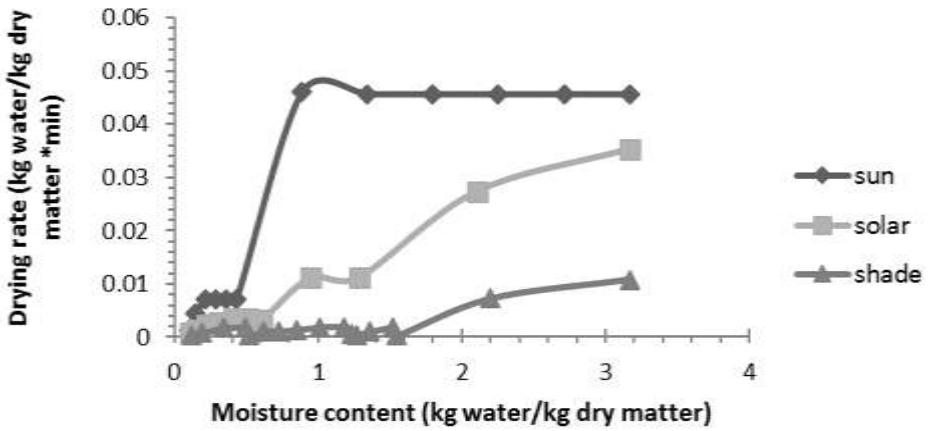

Figure 9: Variation of drying rate against moisture content for sun, solar and shade drying methods.

Effect of Hot Air Temperature and Sample Thickness on Drying Kinetics of Moringa Leaves

Figure 10 shows the drying curves of moringa leaves at different hot air temperatures of 50, 60 and 70^{o}C respectively at the sample thickness of 11.5 mm. It is clear from Figure 10 that the constant rate period was absent and the drying process of moringa leaves took place in the falling rate period. These results agree with the findings of Doymaz et al. (2006) for mint leaves and drumstick leaves by and Premi et al. (2010). The drying rate decreased

with throughout the drying period with an increase in temperature (Figure 11). Samples dried at 50^{o}C required the longest drying time of 180 min as compared to, the samples dried at 60^{o}C which took 150 min. however, the samples dried at the highest temperature of 70^{o}C required the shortest drying time of 130 min.

Table 5 shows the design used in the study of hot air drying using RSM. The results on drying time show that the increase in hot air temperatures at the sample thickness of 11.5 mm reduced the drying time. Maximum decrease of drying time was achieved when the drying temperature was increased from 50 to 70°C as compared to temperature increase 50 to 60°C. Continuous decrease in moisture ratio indicates that diffusion governs the internal mass transfer. A higher drying air temperature decreased the moisture ratio faster due to the increase in hot air supply rate to moringa leaves hence rapid moisture removal (Demir, Gunhan, Yagcioglu, & Degirmencioglu, 2004; Doymaz, 2010). Sample thickness played an important role in the drying process.

Drying time reduced from 190 to160 then 110 min, as the sample thickness decreased from 20, 11.5 and 3 mm respectively (Figure 12). The moisture ratio reduced exponentially as the samples thickness decreased from 20 to 3 mm. The variation of sample thickness at temperature of 70^{o}C used in drying of moringa leaves is shown in Figure 13. At the initial stages, drying rate was highest for 3 mm followed by 11.5 mm and then 20 mm. This shows that increase in sample thickness decreased the drying time as shown in Figure 14. It was observed in Figure 14 that when the temperature increased and sample thickness decreased it reduced the entire drying process hence

resulting in a substantial savings in drying time. Other researchers (Abano et al., 2014; Darvishi, 2012; Doymaz, 2005; Muratore, Rizzo, Licciardello, & Maccarone, 2008) reported similar results for tomato slices, potato slices, okra and cherry tomato, respectively. The results are in good agreement with the studies done by Maskan (2001) on drying of kiwi fruits and Abano et al. (2011) on drying of tomato slices. In general, hot air temperature had a significant effect on the drying time (Table 6). The main effect of temperature and sample thickness gave significant model terms on the drying time of moringa leaves. However the interaction effects between temperature and sample thickness gave insignificant model terms on the drying time (Table 6). Long time for moisture movement of moisture from the internal parts to the surface was due to the fact that drying process took place in a falling rate period in the sense that at the beginning there was high loss of moisture. Similar results have been reported on drying of thyme and drumstick by Doymaz (2011) and Premi et al. (2010), respectively.

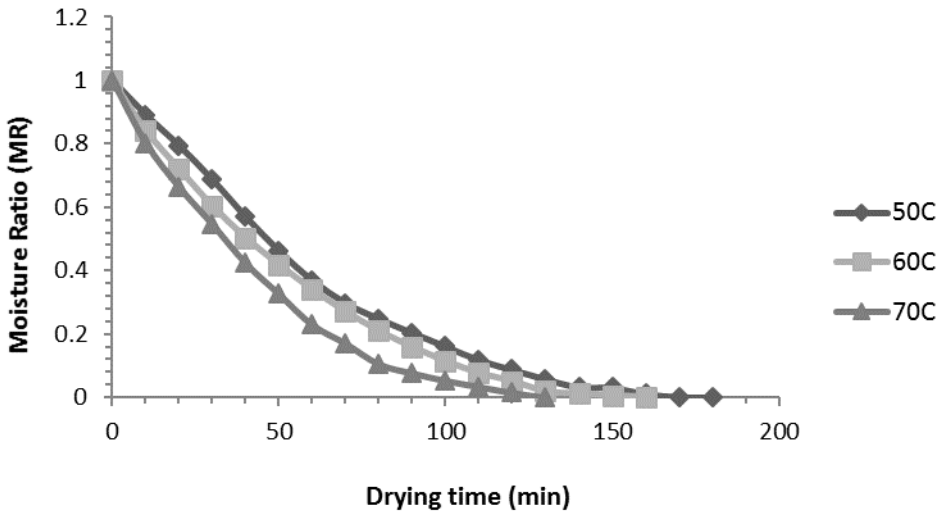

Figure 10: Drying curves of moringa leaves at sample thickness of 11.5 mm for the various temperatures

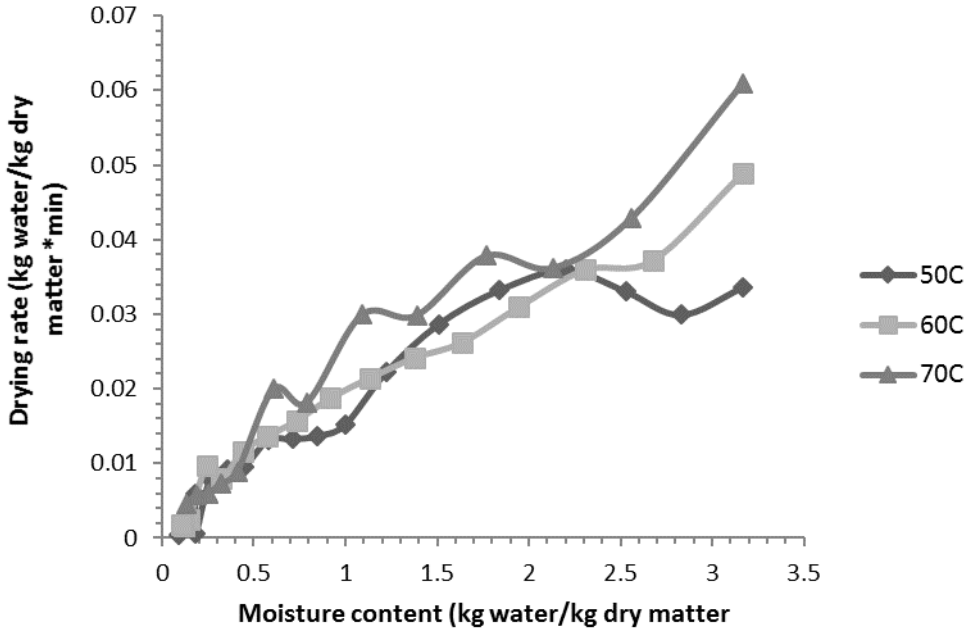

Figure 11: Drying rate against moisture content of moringa leaves at various hot air temperatures at sample thickness of 11.5 mm.

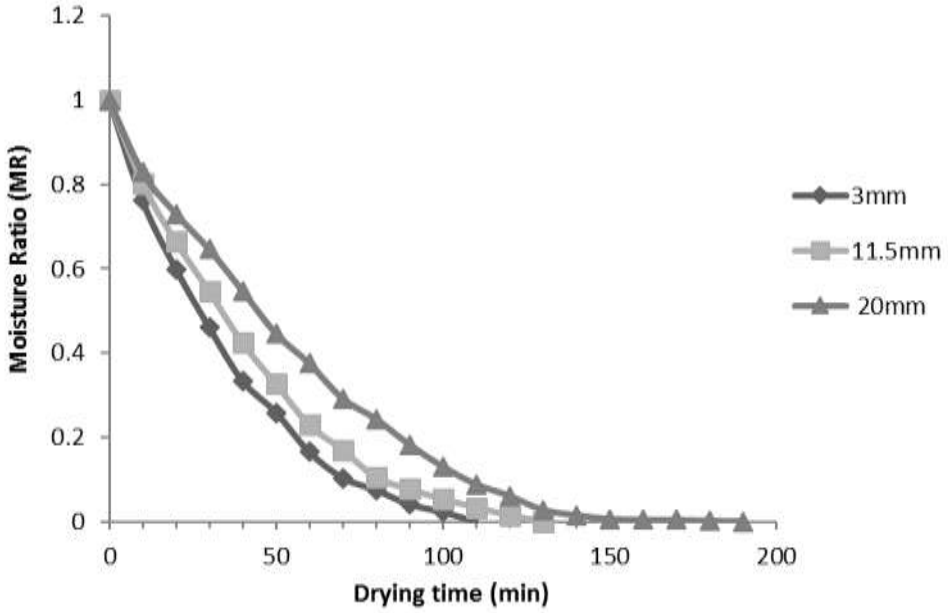

***Figure 12*:** Variation of moisture ratio against drying time of moringa leaves at 70^{o}C for various sample thicknesses.

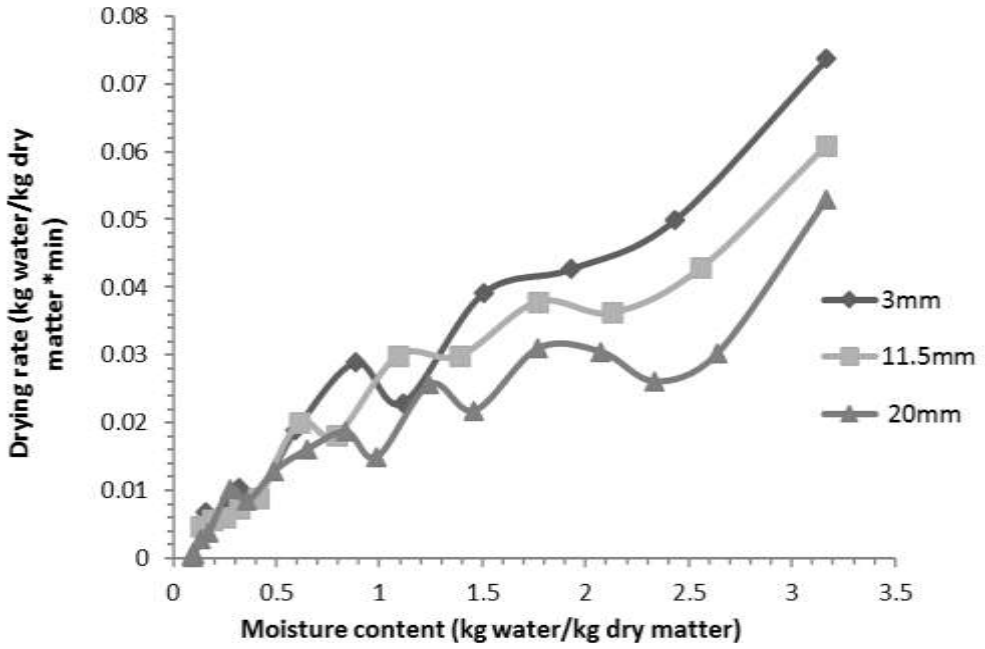

Figure 13: Drying rate versus moisture content of moringa leaves at temperature of 70^{o}C for various sample thicknesses.

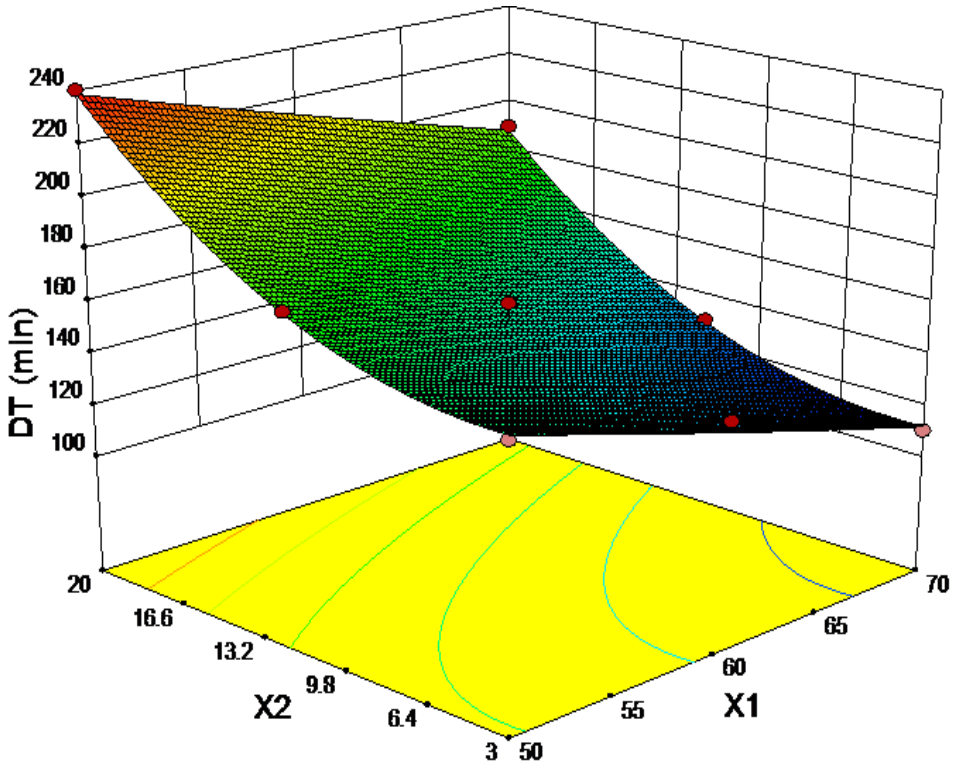

Figure 14: Effect of temperature (X1) and thickness (X2) on drying time using hot air to dry moringa leaves.

Table 5: A 2 Factor 3 Levels RSM Factorial Design of Hot air Drying and Results of DT, AA, TP, FL and AOA

	Actual values		Experimental values of responses				
Run	X_1	X_2	DT (min)	AA (mg/g)	TP (mg/g)	FL (mg/g)	AOA (% inhibition)
1	70	3	110	2.918	0.034	0.174	73.826
2	70	20	190	2.436	0.03	0.145	70.069
3	70	11.5	130	2.919	0.03	0.134	80.743
4	60	11.5	160	3.125	0.033	0.11	72.353
5	60	11.5	150	3.473	0.033	0.147	80.245
6	50	11.5	180	3.62	0.038	0.085	79.27
7	50	3	160	3.629	0.043	0.158	74.897
8	60	3	140	3.563	0.038	0.157	72.537
9	60	11.5	150	3.47	0.032	0.152	78.578
10	50	20	240	4.199	0.042	0.085	81.013
11	60	20	210	3.279	0.033	0.122	72.743

Temperature (X_1) in ^{o}C, thickness(X_2) in mm, Drying time (DT) in min, ascorbic acid (AA) in mg/g of DW, total phenolic (TP) in mg/g of DW, flavonoids (FL) in mg/g of DW, and antioxidant activity (AOA) percentage of inhibition.

Table 6: Coefficient Table of the Model Terms and their Significance for the Effects of Hot air Drying on DT, AA, TP and AOA, FL and R^2

Resp	β_0	X_1	X_2	X_1X_2	X_1^2	X_2^2	R^2
DT	153.684	-25*	38.3333*	8.04728E-015	0.789474	20.7895*	0.9927
p-value		< 0.0001*	< 0.0001*	1.0000	0.7917	0.0007*	
AA	3.36421	-0.529167*	-0.0326667	-0.263***	-0.107026	0.0444737	0.9036
p-value		0.0015*	0.7140	0.0512***	0.4464	0.7454	
TP	0.0325789	-0.00483333*	-0.00166667*	-0.00075	0.00155263***	0.00305263*	0.9756
p-value		< 0.0001*	0.0093*	0.1918	0.0555***	0.0045*	
FL	0.130474	0.0208333**	-0.0228333**	0.011	-0.0121842	0.0178158	0.8113
p-value		0.0383**	0.0280**	0.2822	0.3369	0.1812	
AOA	77.1927	-1.757	0.4275	-2.46825	2.61279	-4.75371**	0.6636
p-value		0.2466	0.7625	0.1928	0.2608	0.0693**	

*significant at p <.01, ** significant at p <.05, *** significant at p <.10

Effect of Microwave Power and Sample Thickness on Drying Kinetics of Moringa Leaves

The drying curves of moringa leaves dried at various microwave powers of 270, 495 and 720 W at the same thickness as hot air drying are shown in Figure 15. As microwave power increased from 270 to 720 W, drying time reduced from 16.3 to 4 min (Table 7) which resulted in an increase of moisture removal in moringa leaves. Researchers such as Abano (2016) on drying of mango, Darvishi (2012) on thed drying of spinach and Karaaslan and Tuncer (2008) on the drying of potato slices. In their studies, they reported a decrease in drying time with an increase in the microwave powers. In the present study, a constant drying rate period was not observed under the experimental conditions employed and the overall drying process took place in the falling rate period (Figure 16). Generally a higher drying rate was produced at 720 W and consequently moisture ratio decreased (Lahsasni et al., 2004).

Drying curves of moringa leaves at MW-power of 720 W for the various sample thicknesses of 3, 11.5 and 20 mm are shown in Figure 17. It is obvious from Figure 17 that the increase in sample thickness led to an increase in drying time. The drying time increased from 3.33 to 9 min as the sample thickness increased from 3 to 20 mm. Figure 18 shows the variation of drying rate against moisture content at various sample thicknesses of 3, 11.5 and 20 mm using MW-power of 720 W. From (Figure 18) it can be that high sample thickness slows down the moisture removal from the leaves and hence prolonged the drying time. Therefore, there was a significant time saving using microwave alone compared to hot air drying. At 70^{o}C with 3 mm

samples thickness, moringa leaves dried for 110 min whereas drying using microwave alone with the same samples thickness took just 3.33 min to dry.

The results obtained in the present study are in good agreement with the findings of Abano (2016) on mango drying. Using microwave to dry moringa leaves will save time and energy consumption because of its high thermal efficiency and adjustment of energy absorption level (Feng et al., 2001; Nijhuis et al., 1998; Prabhanjan et al., 1995; Zhang et al., 2006). The linear effect of microwave power, sample thickness and their quadratics terms were significant on the drying time of moringa leaves as shown in Table 8. However, the interaction effects between microwave power and sample thickness gave insignificant model terms. The decrease in drying time with an increase in microwave power has been reported for the drying of mango, onions and potato slices by Abano (2016), Arslan & Özcan (2010) and Darvishi (2012) respectively. The drying time reduced with increase in microwave power and decrease in sample thickness (Figure 19). On the other hand, the increase in sample thickness prolonged the drying time of the leaves. Similar results were reported by Abano et al. (2011) for tomato slices.

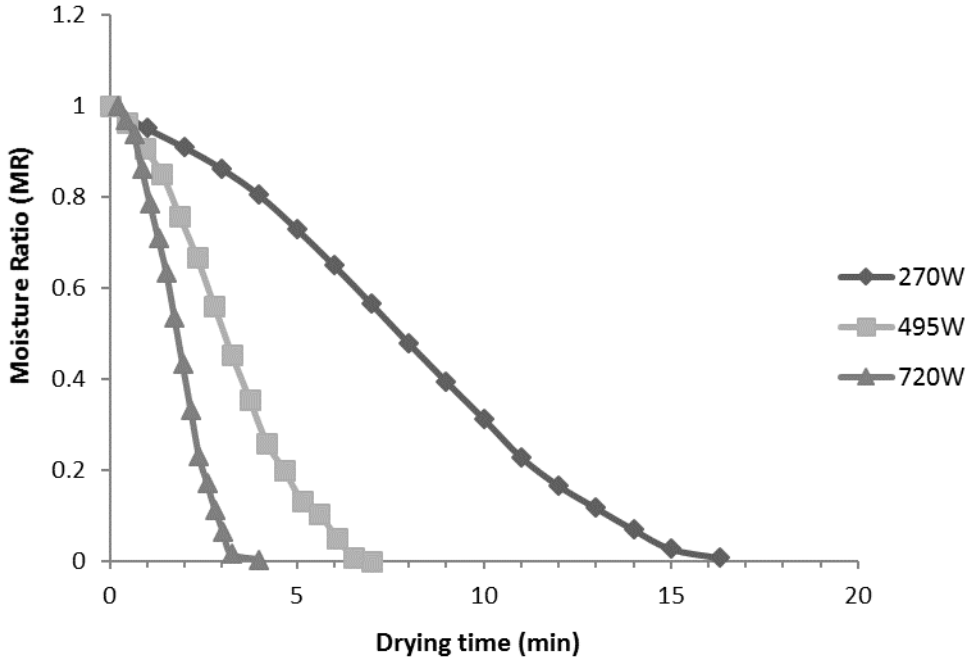

Figure 15: Variation of moisture ratio versus drying time for the various microwave powers at sample thickness of 11.5 mm.

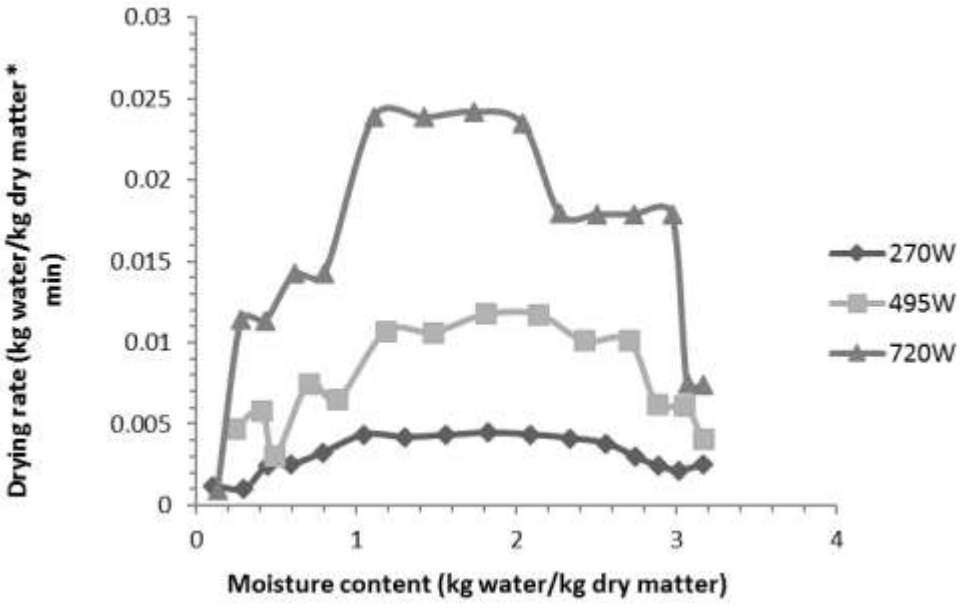

***Figure* 16**: Variation of drying rate against moisture content at various microwave powers at sample thickness of 11.5 mm.

Effects of Blanching Time and Temperature on the Drying Kinetics of Moringa Leaves

Blanching of moringa leaves was done by exposing the moringa leaves to steam from boiling water for 1, 2 and 3 min prior to hot air drying at temperatures of 50, 60 and 70^{o}C. Figure 20 presents the drying curves of moringa leaves dried at the temperature of 70^{o}C for the various periods of blanching. The increase in blanching time increased the moisture removal from the samples which ultimately resulted into reduction in drying time. Similar findings were reported on the drying of carrot by Chen et al. (1995) and also in drying of spinach and broccoli by Desouza and Eitenmiller (1986). Table 9 shows the results of the two factor 3 levels factorial experiment on blanch-assisted hot air drying. It is evident from Table 9 that the drying time decreased from 110 to 50 min as the blanching time increased from 1 to 3 min at temperature 70^{o}C. The lowest drying time was achieved when the samples were blanched for 3 min. This is in agreement with the findings of Greve et al. (1994) and Waldron et al. (2003). In their studies, they found that blanching relaxes tissues of produce thus reduces the drying time. In a similar way, cells in produce lose their wall integrity when blanched and thus bound water is lost faster during drying process than when un-blanched.

The drying process took place in the falling rate as observed in Figure 21. It clearly shows that, when the leaves were blanched for 3 min it reduced the drying rate compared to when blanched for one or two minutes. It was further observed that the drying rate was faster at the beginning than that at the end. The reduction in the drying rate at the end of drying may be due to the reduction in moisture content as drying advances (Sharma & Prasad, 2001).

The drying curves of moringa leaves blanched for 3 min and dried at different temperatures of 50, 60 and 70^{o}C are shown in Figure 22. It was observed that the increase in temperature reduced the drying time from 140 to 50 min. A higher drying air temperature produced a higher drying rate and consequently the moisture ratio decreased (Lahsasni et al., 2004) as shown in Figure 23. Similarly, in hot air drying the maximum drying time was achieved at the same hot air temperature for blanch-assisted as previously reported in the study.

The 3-D surface plot for second-order polynomial model is shown in Figure 24. This shows how drying time decreased when the blanching time and temperature were increased. The effect of blanching time and hot-air temperature on the drying time of moringa leaves is in good agreement with the studies of Akindahunsi and Oboh (1999), Doymaz (2012) and Premi et al. (2010) on tropical vegetables, persimmon slices and drumstick leaves correspondingly. On the contrary, Abano and Amoah (2015) reported an increase in drying time of white yam as the blanching time increased. In their study, they blanched white yam using steam from boiling water for 1, 3 and 5 min after which the samples were dried at temperature of 70, 80 and 90^{o}C. Samples that were blanched for one minute dried faster than those blanched for 5 min. This was due to the fact that when yam was blanched for 5 minutes the starch might have gelatinized. Higher degree of starch gelatinization affects tissue structure and increases the internal resistance to moisture movement (Mate, Gottesman, Hatton, Gribble, & Van Hollebeke, 1998).

The table of coefficient of the model terms and their significance on blanching time is shown in Table 10. The main effect of blanching time,

temperature and the quadratic effect of temperature were significant model terms. However, the interaction effect between blanching time and temperature gave insignificant model terms on drying time of moringa leaves. The effect of blanching time and drying temperature model gave (R^2) of 0.9673.

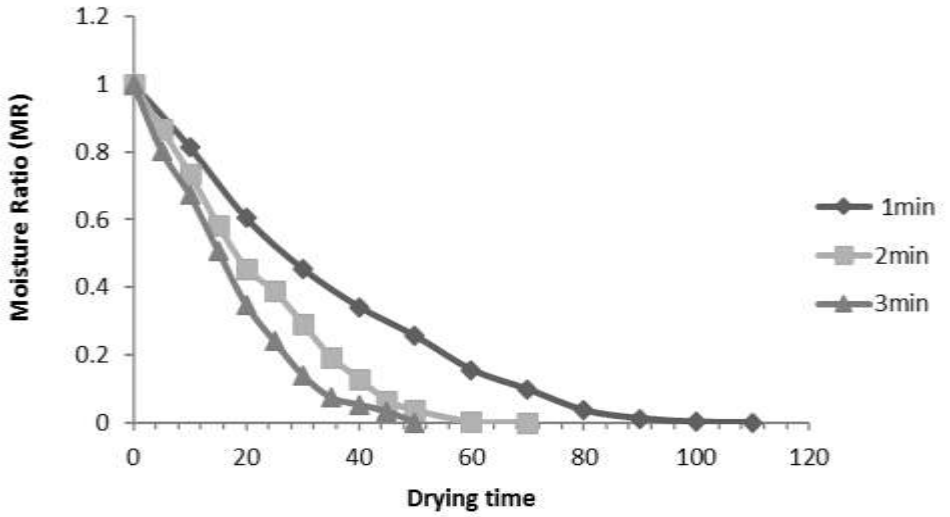

Figure 17: Drying curves of moringa leaves dried at 70^{o}C for the selected blanching minutes

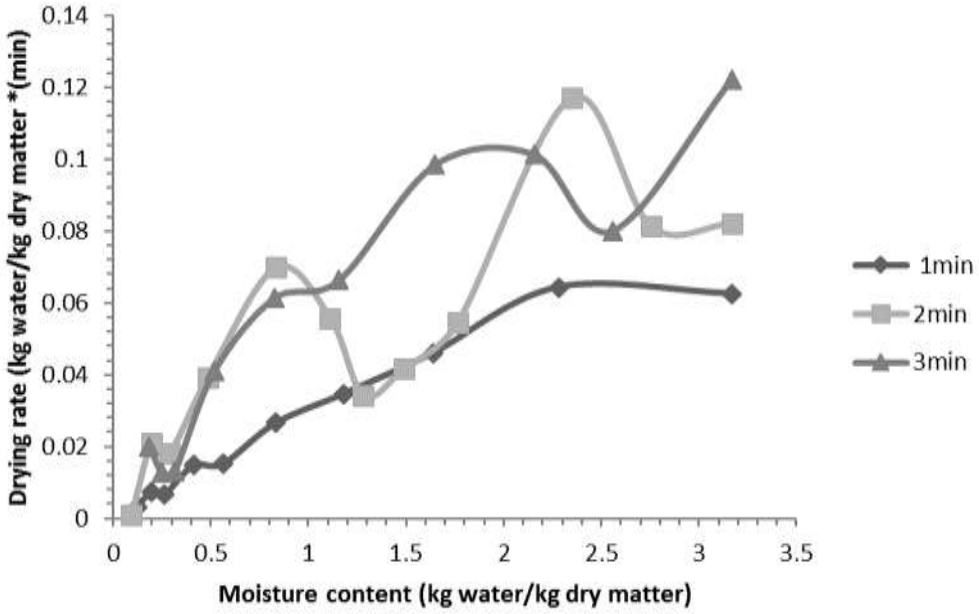

Figure 18: Variation of drying rate versus moisture content for various blanching time dried at 70^{o}C temperature.

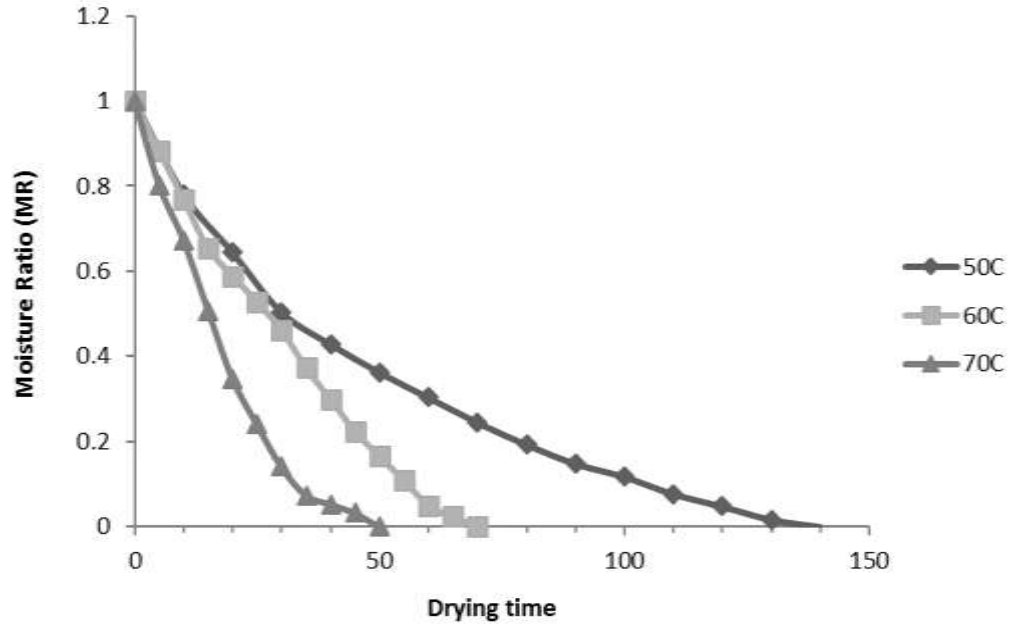

Figure 19: Drying curves of moringa leaves blanched for 3 min at the selected hot air temperatures.

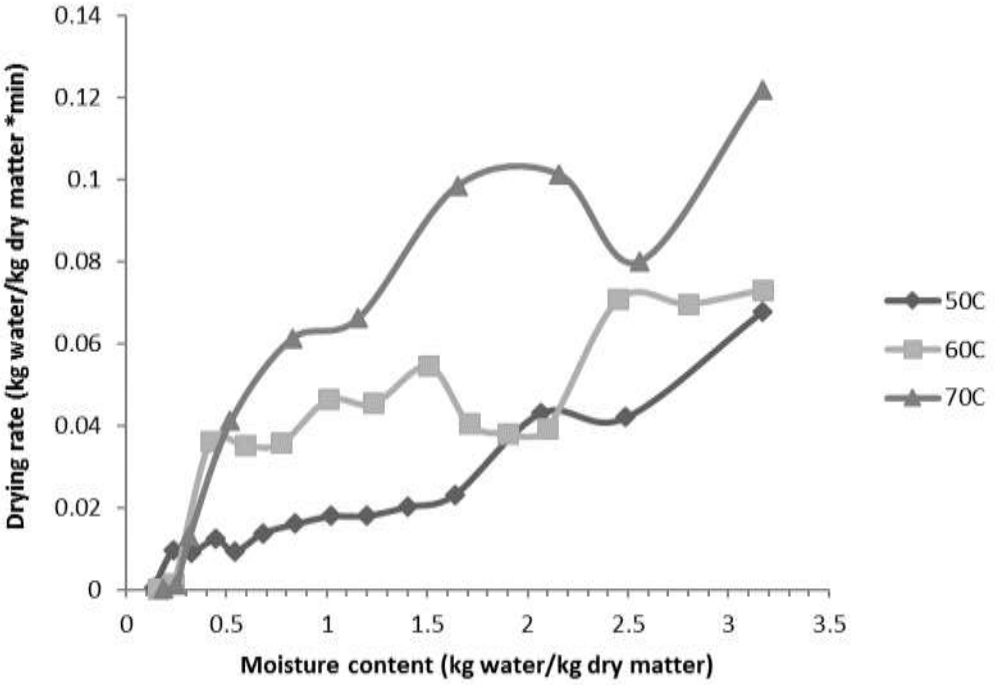

Figure 20: Variation of drying rate against moisture content of moringa leaves blanched for 3 min dried various hot air temperatures.

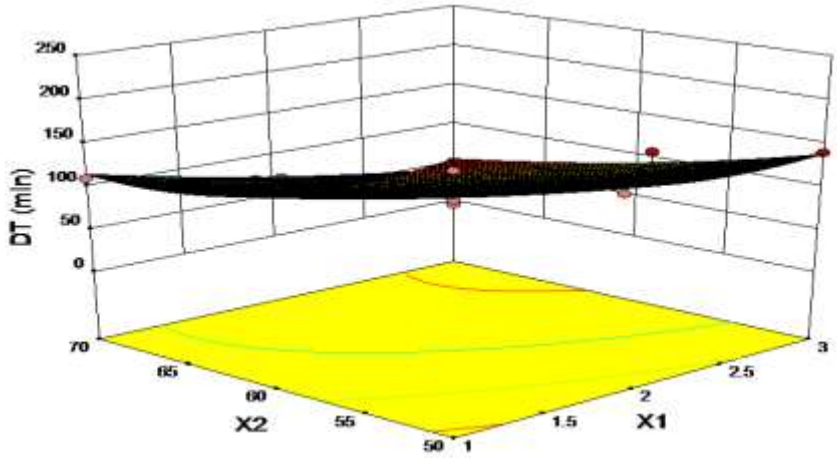

Figure 21: Effect of blanching time (X1) and temperature (X2) on drying time.

Table 7: A 2 Factor 3 Levels Factorial Design using RSM in the Study of Blanch-assisted and the Results of DT, AA, BI and AOA

	Actual values		Experimental values of responses			
Run	X_1	X_2	DT (min)	AA(mg/g)	BI (Abs unit)	AOA (% inhibition)
1	1	70	110	2.025	1.724	70.437
2	3	60	70	2.384	2.345	64.971
3	2	60	80	2.816	2.135	54.016
4	3	70	50	2.384	2.29	70.383
5	1	60	150	2.508	2.078	55.997
6	2	60	85	2.547	2.376	50.812
7	2	60	90	2.908	2.516	56.766
8	1	50	200	3.491	1.967	71.509
9	2	50	180	3.220	2.232	63.174
10	3	50	140	3.000	2.498	66.475
11	2	70	70	2.538	1.777	64.938

Blanching time (X_1) in min, temperature (X_2) in ^oC, Drying time (DT) in min, ascorbic acid (AA) in mg/g of DW, enzymatic browning (BI) in mg/g of DW, and antioxidant activity (AOA) percentage of inhibition.

Table 8: Coefficient Table of the Model Terms and their Significance for the Effects of Blanching Time on DT, AA, IB AOA and R^2

Resp	β_0	X_1	X_2	X_1X_2	X_1^2	X_2^2	R^2
DT	88.1579	-36.6667*****	-48.3333*****	-7.18211E-015	7.10526	32.1053******	0.9673
P-value		0.0010*****	0.0003*****	1.0000	0.4276	0.0114******	
AA	2.72395	-0.0426667	-0.460667*****	0.2125******	-0.228368*******	0.204632*******	0.9271
P-value		0.5455	0.0009*****	0.0462******	0.0739*******	0.0994*******	
BI	2.29053	0.227333******	-0.151*******	0.00875	-0.00131579	-0.208316	0.7834
P-value		0.0254******	0.0908*******	0.9250	0.9910	0.1198	
AOA	54.0698	0.647667	0.766667	1.245	6.10653**	9.67853*****	0.8791
P-value		0.6727	0.6184	0.5131	0.0405**	0.0073*****	

*significant at p <.01, ** significant at p <.05, *** significant at p <.10

The Effect of Microwave Pretreatment Time on Drying Kinetics of Moringa Leaves

Figure 25 shows the variation in moisture ratio versus drying time for the various microwave powers of 270, 495 and 720 W and temperatures of 50, 60 and 70^{o}C at MW-pretreatment time of 2 min. Microwave powers as well as hot air temperatures played an important role in shortening the drying time. The increase in microwave powers from 270 to 720 W and hot air temperature from 50 to 70^{o}C increased the moisture removal from the leaves and eventually managed to reduce the drying time from 90 to 16.5 min. Drying rate increased with an increase in microwave power and hot air temperature (Figure 26).

From the curves in Figure 26, it is shown that microwave powers and hot air temperature had a significant effect on the drying rate as well as the drying time hence significant savings in drying time. Similar results have been reported by Abano et al. (2011) for tomato slices in their study in which four microwave powers and three vacuum pressures were used. The drying time of tomato slices reduced from 84 to 14 min as the microwave power increased from 200 to 700 W. The reduction in drying time was highly significant using microwave-assisted compared to hot air alone drying. The present results agree with the findings of Ren and Chen (1998).

They found that combined microwave with hot air can highly reduce the drying time of biological materials without damaging the quality attributes of the final products. The results of the fifteen experiments performed according to BBD are shown in Table 11. The determination of the estimated effects for each independent variable and the interactions between the

variables are presented in Table 12. From Figure 27 A–C, it is observed that the increase in hot air temperature, microwave power and microwave pretreatment time decreased the drying time of the moringa leaves. The lowest drying time was achieved when the moringa leaves were dried in the microwave for 2 min using MW-power of 720 W at the temperature of 70^{o}C. The drying time decreased from 95 to 16.5 min (Table 11).

Temperature, microwave power and microwave pretreatment time obtained the following P-value -13.5625, -11.5625 and -17.625 respectively (Table 12). The results obtained in the present study are in agreement with the studies done by Abano (2016) on white yam, Bouraoui et al. (1994) on potato slices and Premi et al. (2010) on drumstick. The main effect of MW-power, MW-pretreatment time and temperature gave significant terms for the model. However, their interaction and quadratic effects gave insignificant model terms on drying time of moringa leaves.

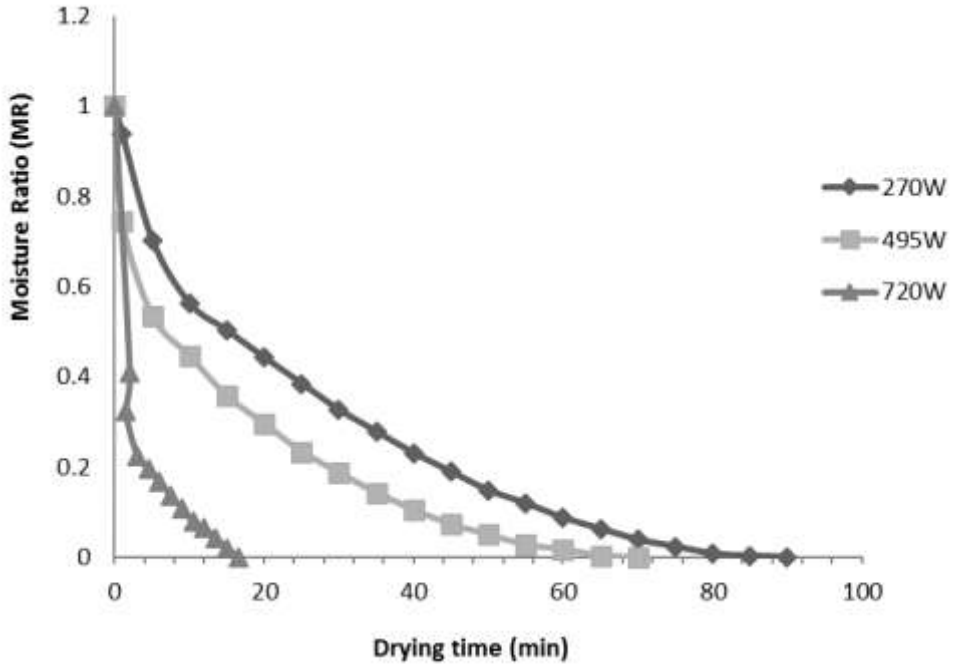

Figure 22: Variation of moisture ratio versus drying time for the various microwave powers and temperatures at MW-pretreatment time of 2 min.

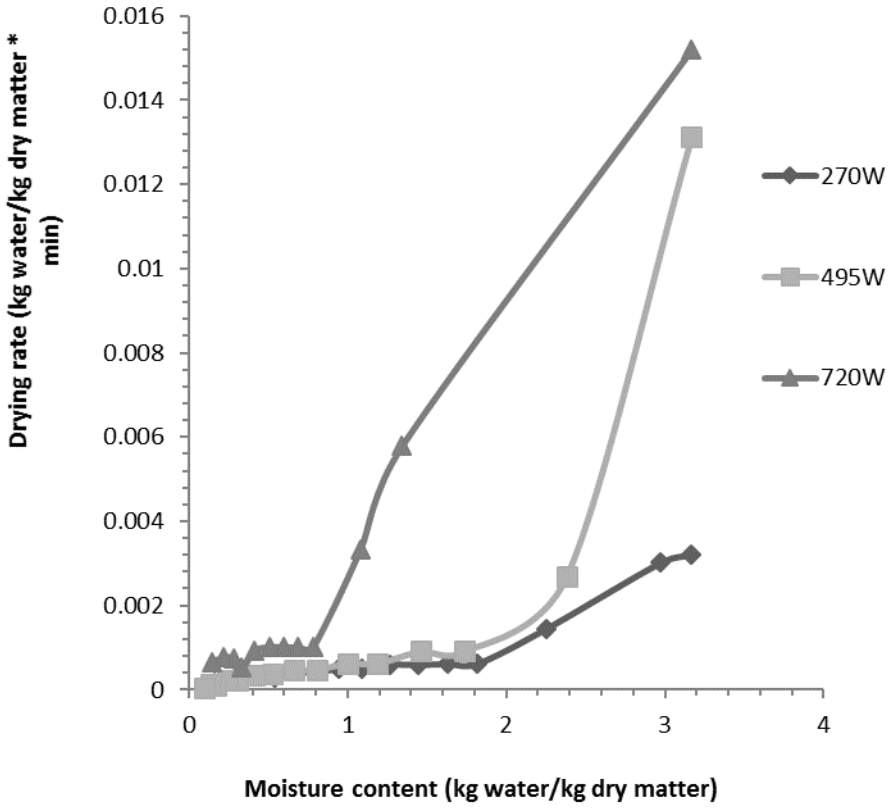

Figure 23: Drying time versus moisture ratio for the various microwave powers and temperatures at MW-pretreatment time of 2 min.

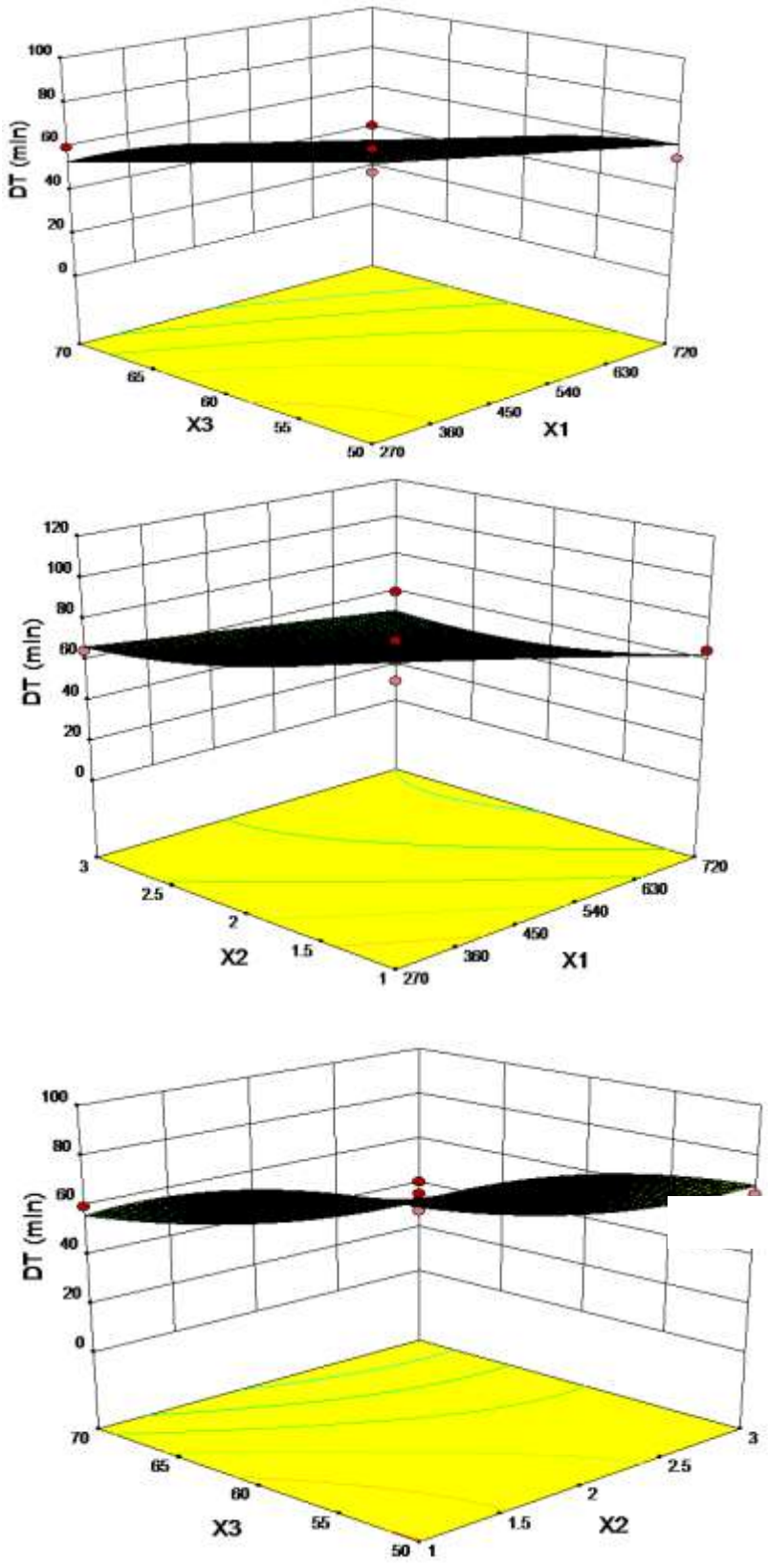

***Figure 24*:** The effects of (A) microwave power (X1) and microwave time (X2), (B) microwave power (X1) and temperature (X3), (C) microwave time (X2) and temperature (X3) on drying time.

Table 9: Box-Behnken Design for Three Factors and Results of DT, TP, FL, AOA and AA

	Actual design			Experimental values of responses				
Run	X_1 (Watts)	X_2 (min)	X_3 (C)	DT (min)	TP (mg/g)	FL (mg/g)	AOA (% inhibition)	AA (mg/g)
1	495	3	70	27.5	0.026	0.269	70.697	2.758
2	720	2	70	16.5	0.024	0.296	68.889	2.934
3	495	2	60	70	0.030	0.187	69.073	2.528
4	270	2	50	90	0.032	0.086	60.717	3.16
5	270	2	70	60	0.026	0.198	70.253	2.735
6	270	1	60	90	0.030	0.140	63.033	2.342
7	495	2	60	60	0.032	0.173	59.645	2.448
8	270	3	60	65	0.033	0.135	70.416	2.371
9	495	2	60	60	0.031	0.140	69.864	2.287
10	495	1	50	95	0.031	0.106	63.38	3.056
11	720	3	60	60	0.031	0.179	76.672	2.231
12	720	1	60	65	0.030	0.167	73.208	2.508
13	495	3	50	65	0.034	0.128	66.389	3.501
14	720	2	50	55	0.035	0.119	69.117	3.135
15	495	1	70	60	0.025	0.148	66.378	2.571

Microwave power (X_1) in watts, microwave time (X_2) in min, oven temperature (X_3) in ^{0}C, drying time (DT) in min, total phenolic (TP) in mg/g of DW, flavonoids (FL) in mg/g of DW, ascorbic acid (AA) in mg/g of DW, and antioxidant activity (AOA) percentage of inhibition

Table 10: Box-Behnken Design for Three Factors and Results of Coefficient table of the Model Terms and their Significance for the Effects of Microwave-assisted on DT, TP, FL, AOA, AA and R^2

Resp	β_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	X_1^2	X_2^2	X_3^2	R^2
DT	63.3333	-13.5625**	-11.5625**	-17.625*	5	-2.125	-0.625	0.0833333	6.58333	-8.04167	0.9185
P-value		0.0119**	0.0218**	0.0041*	0.3609	0.6870	0.9049	0.9878	0.2594	0.1810	
TP	0.031	-0.000125	0.001**	-0.003875*	-0.0005	-0.00125**	-0.0005	0.000125	-0.000125	-0.001875**	0.9724
P-value		0.7171	0.0279**	< 0.0001*	0.3276	0.0422**	0.3276	0.8048	0.8048	0.0113**	
FL	0.166667	0.02525***	0.01875	0.059*	0.00425	0.01625	0.02475	0.000291667	-0.0117083	0.00779167	0.8827
P-value		0.0804***	0.1653	0.0037*	0.8050	0.3653	0.1900	0.9870	0.5215	0.6658	
AOA	66.194	2.93338***	2.27187	2.07675	-0.97975	-2.441	0.3275	2.58562	2.05262	-1.53563	0.7417
P-value		0.0893***	0.1641	0.1965	0.6403	0.2706	0.8746	0.2632	0.3631	0.4879	
AA	2.421	0.025	0.048	-0.23175**	-0.0765	0.056	-0.0645	-0.01925	-0.03875	0.58925*	0.9126
P-value		0.7210	0.5005	0.0172**	0.4506	0.5755	0.5211	0.8510	0.7070	0.0018*	

*significant at p <.01, ** significant at p <.05, *** significant at p <.10

Effective Moisture Diffusivity and Activation Energy of Moringa Leaves

The results obtained for moisture diffusivity and activation energy show that internal mass transfer resistance was due to the presence of falling rate drying period that controls drying time. The study of the effective moisture diffusivity and activation energy was determined for hot air drying at temperatures of 50, 60 and 70^{o}C and MW-alone drying method at MW-powers of 270, 495 and 720 W for various sample thickness of 3, 11.5 and 20 mm. Also, the D_{eff} was determined for MW-assisted hot air drying method for various MW-powers and temperature mentioned above. The D_{eff} of blanch-assisted hot air drying method was calculated for the various hot air temperatures and blanching time of 1, 2 and 3 min.

The variation of In(MR) versus drying time for various temperatures of 50, 60 and 70^{o}C at a thickness of 11.5 mm is presented in Figure 28. The slopes of the straight line generated by ln(MR) against drying time were used to determine the effective moisture diffusion values. Nevertheless, the trend did not continue drying in straight line as the drying proceeded. The effective moisture diffusivity coefficient (D_{eff}) increased with an increase in hot air temperatures of 50, 60 and 70^{o}C at the thickness of 11.5 mm with the corresponding values of 5.70×10^{-9} m^2 s^{-1}, 7.15×10^{-9} m^2 s^{-1}and 7.42×10^{-9} m^2 s^{-1}. Figure 29 shows the variation of In(MR) versus drying time for the various thicknesses of 3, 11.5 and 20 mm dried at 70^{o}C. It was observed that D_{eff} increased with increase in sample thickness studied with the respective values of 0.56×10^{-9} m^2 s^{-1}, 7.42×10^{-9} m^2 s^{-1}and 24.32×10^{-9} m^2 s^{-1} in 3, 11.5 and 20 mm. The range of moisture diffusivities for the whole process of hot air drying ranged from 0.24×10^{-9} m^2 s^{-1} to 24.32×10^{-9} m^2 s^{-1} as it can be

represented in Table 13. The variation of In(MR) versus drying time for the various MW-powers of 270, 495 and 720 W at sample thickness of 11.5 mm is shown in Figure 30. Table 13 shows that D_{eff} similarly increased with increase in MW-power 56.3×10^{-9} m^2 s^{-1}, 134×10^{-9} m^2 s^{-1} and 180×10^{-9} m^2 s^{-}, respectively. The variation of In(MR) versus drying time for the various samples thicknesses of 3,11.5 and 20 mm at MW-power of 720 W is shown in Figure 31. It was evidenced in Figure 31 a similar decrease in sample thickness led to a decrease in $D_{eff,}$ 138×10^{-9} m^2 s^{-1} at 3 mm then at 11.5 mm was 180×10^{-9} m^2 s^{-1} and at 20 mm was 389×10^{-9} m^2 s^{-1}. The range of moisture diffusivities using MW-alone to dry ranged from 7.48×10^{-9} m^2 s^{-1} to 389×10^{-9} m^2 s^{-1} as shown in Table 13. The Deff obtained for MW-assisted and blanch-assisted are presented in the Appendix. The D_{eff} increased with increase in temperature and microwave pretreatment time as far as MW-assisted hot air drying method was concerned. D_{eff} for Blanch assisted increased with hot air temperatures and blanching time of moringa leaves.

The D_{eff} obtained for hot air, MW-alone, MW-assisted and blanch-assisted drying methods in the present study lies within the general range of $10^{-12} – 10^{-8}$ m^2s^{-1} for drying of food materials (Doymaz, 2010). The values of D_{eff} increased with an increase in temperature, as the hypothesis was started that the diffusion has governed the internal mass transfer. The highest mass transfer rate was obtained at 70°C for hot air drying while for microwave alone drying was achieved at 720 W. This was verified from the above values of effective moisture diffusivity. The D_{eff} for MW drying is about 16 times higher than for hot air drying. Studies done by Premi et al. (2010) on drumstick showed that D_{eff} for hot air drying was 2.40, 3.04, 3.21 and 3.89 ×

10^{-9} m^2s^{-1} at the temperatures of 50, 60, 70 and 80°C repectively. Their results are lower than the results obtained in the present study. The values of the correlation coefficients for hot air drying ranged from 0.8509 to 0.9768 while microwave drying ranged from 0.7874 to 0.9449. The values of correlation coefficient for hot air drying are relatively higher than those of microwave drying. The increase of D_{eff} with increase in hot air temperature and microwave powers might be due to the increase in heating energy, which would increase the activity of the water molecules leading to higher moisture diffusivity when the leaves were dried at higher hot air temperature and microwave power (Abano et al., 2011; Demir et al., 2004; Doymaz, 2010).

The moisture diffusivities values were used to fit Fick's second law of diffusion to estimate the activation energy (E_a) for moisture diffusion. The influence of hot air on effective moisture diffusivity for the various hot air temperatures and thicknesses studied is shown in Figure 32. The results of the fitting gave a regression coefficient (R^2) of 0.9128, 0.9884 and 0.8932 for the various hot air temperatures of 50, 60 and 70^{o}C at the thicknesses of 3, 11.5 and 20 mm respectively. The R^2 obtained for the various microwave powers waere 0.9918, 0.9796 and 0.9913 at the thicknesses of 3, 11.5 and 20 mm respectively (Figure 33). In the present study, the highest value of R^2 was obtained at the thickness of 11.5 mm and 3mm for hot air and MW-alone drying, respectively. There values of R^2 were generally high.

The activation energy is the energy needed to initiate internal moisture diffusion and indicates the temperature sensitivity of D_{eff}. The values obtained for the activation energy of moisture diffusion for hot air drying were 14.457kJ/mol, 14.491 kJ/mol and 28.580 kJ/mol for the thicknesses of 3, 11.5

and 20 mm, respectively. The hot air activation energy obtained in the present study are higher than those of 5.54 kJ/mol for okra (Dadalı, Apar, & Özbek, 2007), 13.6 kJ/mol for pandanus leaves (Rayaguru & Routray, 2011). However, the E_a values obtained in this study are lower than those by other researchers. Doymaz (2005) obtained 51.26 kJ/mol for okra drying within the temperature range of 50 to 70^{o}C while Erbay and Icier (2010) reported 42.80 kJ/mol for red pepper. The results of the activation energy obtained in this study are within the general range of 12.7-110 kJ/mol reported by Aghbashlo and Samimi-Akhijahani (2008) for most agricultural and food materials.

The E_a determined for microwave alone drying were 243.63 W/mm, 51.237 W/mm and 25.030 W/mm at the thickness of 3, 11.5 and 20 mm respectively. There values are higher than 13.52W/mm for 2min, 17.48W/mm for 3 min and 8.58W/mm for 4min reported for mango drying by Abano (2016). However, these values are higher than the activation energy values of 14.945W/mm reported by Darvishi (2012) for drying of potato slices.

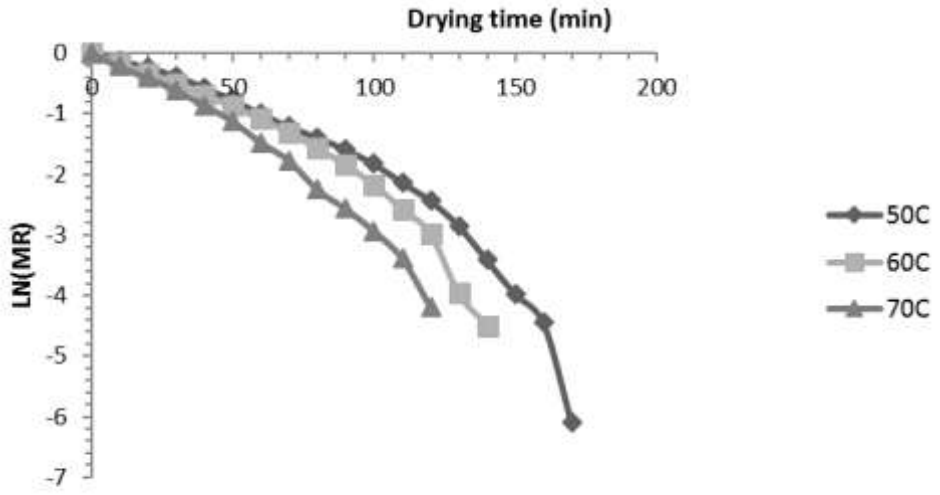

Figure 25: Variation of In(MR) versus drying time for the various selected hot air temperatures and thickness of 11.5 mm.

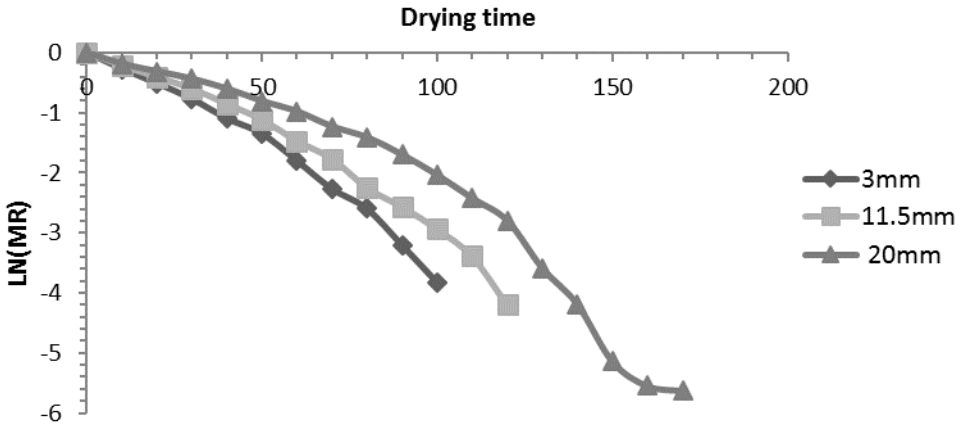

Figure 26: Variation of In(MR) versus drying time for the various selected sample thicknesses at 70^{o}C.

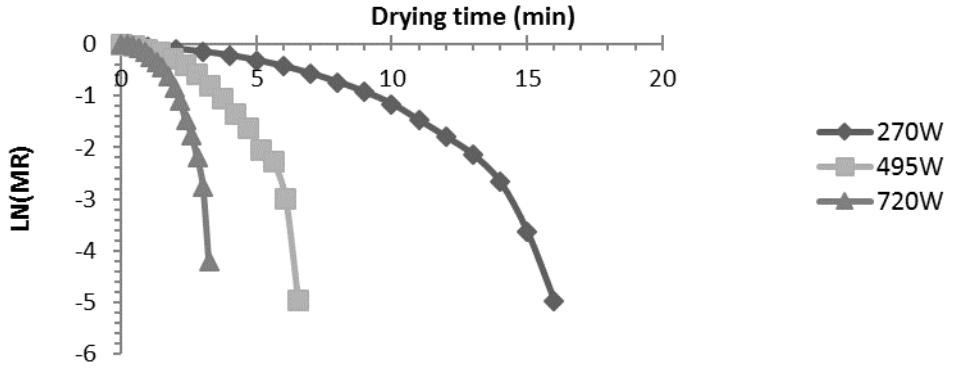

Figure 27: Variation of In(MR) versus drying time for the various microwave powers studied at sample thickness of 11.5 mm.

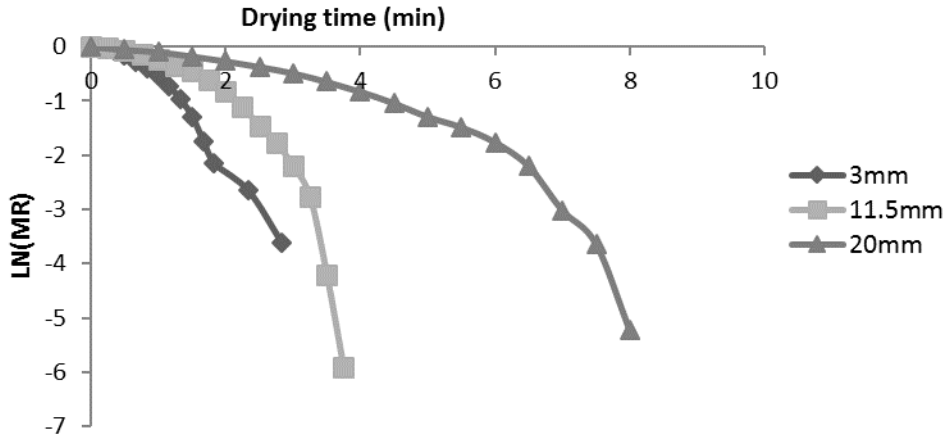

Figure 28: Variation of In(MR) versus drying time for the various samples thicknesses studied at MW-power of 720 W.

Table 11: The Effect of Temperature and Sample Thickness on the Effective of Moisture Diffusivity and R^2 for Hot air and Microwave alone Drying

	Hot air alone				Microwave alone			
RUN	T (^oC)	L^* (mm)	D_{eff} ($m^2 s^{-1}$)	R^2	L^* (mm)	MP (Watts)	D_{eff} ($m^2 s^{-1}$)	R^2
1	70	3	0.56×10^{-9}	0.9762	11.5	495	134×10^{-9}	0.7874
2	70	20	24.32×10^{-9}	0.9259	3	270	3.83×10^{-9}	0.7598
3	70	11.5	7.42×10^{-9}	0.9699	20	270	113×10^{-9}	0.8390
4	60	11.5	7.15×10^{-9}	0.9232	20	720	389×10^{-9}	0.8208
5	60	11.5	9.09×10^{-9}	0.9231	3	495	156×10^{-9}	0.9308
6	50	11.5	5.70×10^{-9}	0.9518	11.5	270	56.3×10^{-9}	0.8038
7	50	3	0.49×10^{-9}	0.9728	11.5	720	180×10^{-9}	0.9449
8	60	3	0.24×10^{-9}	0.9768	11.5	495	111×10^{-9}	0.9126
9	60	11.5	0.50×10^{-9}	0.8847	11.5	495	124×10^{-9}	0.8027
10	50	20	14.1×10^{-9}	0.9581	3	720	$138x 10^{-9}$	0.7608
11	60	20	15.7×10^{-9}	0.8509	20	495	7.48×10^{-9}	0.8972

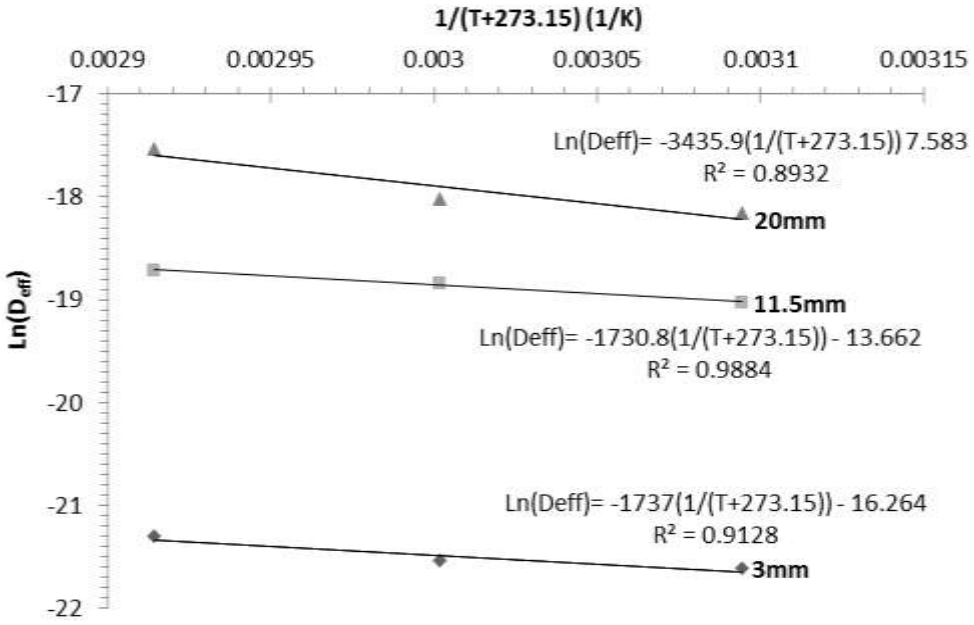

Figure 29: Influence of ln(D_{eff}) against 1/(T+273.15) (1/K)for the various hot air temperatures and sample thicknesses.

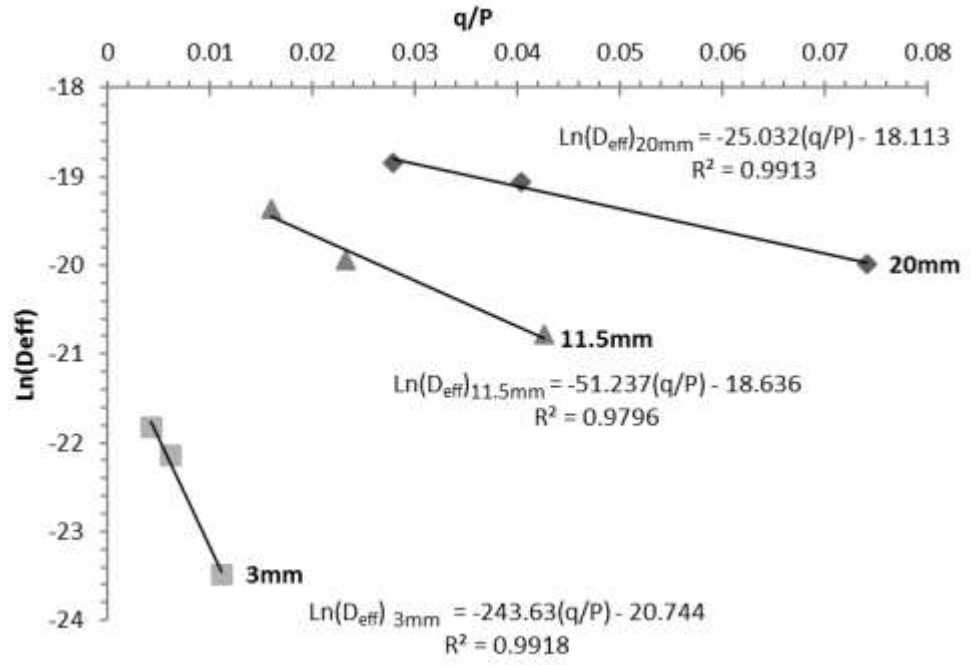

Figure 30: Variation of ln(D_{eff}) against q/P for the various microwave powers and sample thicknesses.

Mathematical Models for Fitting of Drying Curves of Moringa Leaves

Non-linear regression analysis was used to determine the appropriate mathematical model for drying moringa leaves. The dimensionless moisture

ratio was plotted against drying time for the pretreatments, thicknesses and drying temperatures. The data were fitted to the drying models of Page, Henderson and Pabis, logarithmic and Midilli et al.

The results of fitting of the experimental data of the samples dried using hot air alone at temperatures of 50 and 70^{o}C for various sample thicknesses of 3, 11.5 and 20 mm are presented in Tables 14 and 15 for each temperature. Experimental data for the samples dried using microwave alone at various microwave powers of 27 and 720 W at the selected sample thicknesses are shown in Table 16 and 17 respectively. The samples dried using blanch-assisted are shown in Table 18 and 19 at various temperatures of 50 and 70 ^{o}C individually. Table 20 and 21 present the fitting of microwave-assisted hot air drying at various microwave powers of 270 and 720 W for temperatures of 50, 60 and 70^{o}C.

The tables mentioned give the models values of the estimated constants with their corresponding statistical R^2, χ^2, and RMSE values characterizing each fitting. It was observed in Table 14 and 15 that the values of drying rate constant (k) decreased with increase in sample thickness for hot air drying method at 50 and 70^{o}C. This implies that drying rate potential decreased with increase in sample thickness. From the studies done by Abano and Amoah (2015) it was reported that there was an increase in the constant (k) with increase in microwave pretreatment time. This implied that drying rate potential increased with increase in microwave pretreatment time.

The results of this study show that the experimental data fitted the four models. The correlation coefficients obtained are in the range of 0.9560-0.9991 for hot air, 0.8795-0.9995 for microwave alone, 0.9642-1 for blanch-

assisted and 0.9121-0.9988 for microwave-assisted hot air drying. The thin-layer drying models tested could suitably describe the various drying methods of moringa leaves. The four models presented high R^2 with low χ^2 and RMSE.

Midilli et al.'s model most appropriately described the drying behavior for moringa leaves in all the experimental data because of its highest correlation coefficient (R^2), lowest (chi square χ^2) and mean square error (RMSE). It therefore indicated a good predicting capacity for the drying methods tested over the entire duration of the drying process. The correlation coefficients obtained for Midilli et al.'s model are in the range of 0.9922-0.9991, 0.9913-0.9995, 0.9912-1, and 0.9932-0.9988 for hot air, Mw-alone, blanch-assisted hot air drying and MW-assisted hot air drying, respectively. This defines the profile of the moisture ratio of moringa leaves dried using all the various drying methods in the present work. Of all the four drying methods examined on Midilli et al. model blanch-assisted had the highest correlation coefficient. Demir et al. (2004) and Premi et al. (2010) on drumstick and bay leaves respectively they reported Verma model was the best model to represent the drying behaviour of leaves in a convective type dryer.

Figures 34, 35, 36, and 37 show the fitting of various drying methods of experimental and simulated points to the Midilli et al. model. It was evident that experimental data were close to the simulated data. Studies done by Abano, Ma, Qu and Teye (2011) on garlic slices reported similar results for the controlled samples. Among the models tested in their study, Midilli et al. model had the highest values of R^2, lowest χ^2 and RMSE values. Further, the studies done by Doymaz, (2011) on thyme reported results similar to those obtained in the present study.

Table 12: The Fitness of Different Models at 50 ^{o}C for Hot Air Alone Drying

Model name	L*	Model constants				R^2	X^2	RMSE
Page								
	3	k = 0.002	n = 0.143			0.9840	0.0022	0.0467
	11.5	k =0. 004	n = 1.329			0.9989	0.0001	0.0108
	20	k = 0.007	n = 1.182			0.9921	0.0008	0.0281
Henderson and Pabis								
	3	k = 0.028	a = 1.085			0.9560	0.0060	0.0623
	11.5	k = 0.018	a = 1.078			0.9847	0.0048	0.0376
	20	k = 0.016	a = 1.059			0.9881	0.0012	0.0348
Logarithmic								
	3	k = 0.025	a = 1.132	c = -0.060		0.9613	0.0058	0.0762
	11.5	k = 0.015	a =1.164	c = -0.123		0.9956	0.0005	0.0224
	20	k = 0.014	a = 1.092	c = -0.052		0.9912	0.0009	0.0307
Midilli et al.								
	3	k = 0.002	a = 0.976	n = 1.715	b= 0.000	0.9853	0.0024	0.0494
	11.5	k = 0.005	a = 0.996	n = 1.280	b= 0.000	0.9994	0.0001	0.0082
	20	k = 0.009	a = 1.014	n = 1.135	b= -6.226 E-005	0.9922	0.0009	0.0297

Table 13: The Fitness of Different Models at 70 ^{o}C for Hot air Alone Drying

Model name	L*	Model constants				R^2	X^2	RMSE
Page								
	3	k = 0.016	n = 1.151			0.9965	0.0004	0.0200
	11.5	k = 0.010	n = 1.218			0.9963	0.0004	0.0204
	20	k = 0.006	n = 1.259			0.9931	0.0007	0.0269
Henderson and Pabis								
	3	k = 0.029	a = 1.023			0.9922	0.0009	0.0300
	11.5	k = 0.025	a = 1.038			0.9882	0.0013	0.0365
	20	k = 0.019	a = 1.045			0.9820	0.0019	0.0435
Logarithmic								
	3	k = 0.023	a = 1.089	c = -0.089		0.9991	0.0001	0.0105
	11.5	k = 0.019	a = 1.117	c = -0.109		0.9977	0.0003	0.0165
	20	k = 0.015	a = 1.117	c = -0.108		0.9947	0.0006	0.0243
Midilli et al.								
	3	k = 0.022	a = 0.995	n = 1.147	b= -0010	0.9991	0.0001	0.0117
	11.5	k = 0.012	a = 0.988	n = 1.146	b= 0.000	0.9985	0.0002	0.0141
	20	k = 0.006	a = 0.968	n = 1.236	b= 0.000	0.9968	0.0004	0.0194

Table 14: The Fitness of Different Models at 270 W for MW-alone Drying

Model name	L*	Model constants				R^2	X^2	RMSE
Page	3	k = 0.006	n = 2.382			0.9898	0.0016	0.0400
	11.5	k = 0.011	n = 2.034			0.9949	0.0007	0.0262
	20	k = 0.011	n = 1.862			0.9944	0.0008	0.0100
Henderson and pabis								
	3	k = 0.139	a = 1.168			0.8795	0.0190	0.1378
	11.5	k = 0.130	a = 1.159			0.9155	0.0115	0.1072
	20	k = 0.101	a = 1.126			0.9288	0.0102	0.1010
Logarithmic								
	3	k = 0.000	a = 199.915	c = -198.827		0.9873	0.0022	0.0471
	11.5	k = 0.016	a = 4.930	c = -3.876		0.9989	0.0015	0.0392
	20	k = 0.017	a = 3.510	c = -2.472		0.9944	0.0009	0.0298
Midilli et al.								
	3	k = -0.172	a = 0.0995	b= -0.169	n = 0.603	0.9961	0.0008	0.0274
	11.5	k = 0.011	a = 0.975	b= -0.005	n = 1.960	0.9995	0.0001	0.0085
	20	k= -1.593E-012	a = 1.032	n = 1.055	n = 8.246	0.9979	0.0004	0.0194

Table 15: The Fitness of Different Models at 720 W for MW-alone Drying

Model name	L*	Model constants				R^2	X^2	RMSE
Page	3	n = 1. 988	k = 0.576			0.9973	0.0004	0.0196
	11.5	n = 2.157	k = 0.273			0.9963	0.0005	0.0231
	20	n = 1. 873	k = 0.065			0.9956	0.0006	0.0243
Henderson and pabis								
	3	a = 1.152	k = 0.843			0.9374	0.0089	0.0945
	11.5	a = 1.177	k = 0.653			0.9097	0.0132	0.1149
	20	a = 1.152	k = 0.276			0.9335	0.009	0.0949
Logarithmic								
	3	a = 1.445	k = 0.514	c = -0.337		0.9654	0.0024	0.07016
	11.5	a = 3.831	k = 0.105	c = 2.755		0.9845	0.0024	0.0493
	20	a = 1.967	k = 0.096	c = -0.901		0.9874	0.0018	0.0426
Midilli et al.								
	3	a = 0.980	k = 0.555	b= 0.003	n = 2.090	0.9978	0.0004	0.0191
	11.5	a = 0.984	k = 0.247	b= -0.017	n = 2.093	0.9990	0.0002	0.0124
	20	a = 0.060	k = 0.177	b= -0.006	n = 1.827	0.9986	0.0002	0.0141

Table 16: The Various Drying Models for Blanch-assisted Hot Air Drying at 50 ^{o}C

Model name	t*	Model constants				R^2	X^2	RMSE
Page								
	1	k = 0.006	n = 1.224			0.9939	0.0006	0.0250
	2	k = 0.005	n = 1.246			0.9864	0.0014	0.0368
	3	k = 0.021	n = 1.005			0.9927	0.0007	0.0263
Henderson and pabis								
	1	k = 0.016	a = 1.044			0.9847	0.0016	0.0395
	2	k = 0.015	a = 1.045			0.9747	0.0025	0.0503
	3	k = 0.021	a = 0.991			0.9935	0.0006	0.0248
Logarithmic								
	1	k = 0.010	a = 1.210	c = -0.212		0.9993	0.0001	0.0082
	2	k = 0.007	a = 1.385	c = -0.406		0.9982	0.0002	0.0137
	3	k = 0.018	a = 1.036	c = -0.066		0.9967	0.0003	0.0183
Midilli et al.								
	1	k = 0.993	a = 0.010	n = -0.001	b= 1.053	0.9993	0.0001	0.0085
	2	k = 1.001	a = 0.017	n = -0.002	b= 0.847	0.9988	0.0001	0.0115
	3	k = 1.002	a = 0.037	n = -0.001	b= 0.816	0.9991	0.0003	0.0095

Table 17: The Various Drying Models for Blanch-assisted Hot Air Drying at 70 ^{o}C

Model name	t*	Model constants				R^2	X^2	RMSE
Page	1	k = 0.025	n = 1.102			0.9991	0.0001	0.0100
	2	k = 0.016	n = 1.294			0.9904	0.0012	0.0344
	3	k = 0.018	n = 1.373			0.9957	0.0006	0.0236
Henderson and pabis								
	1	k = 0.037	a = 1.015			0.9972	0.0003	0.0173
	2	k = 0.044	a = 1.057			0.9788	0.0026	0.0513
	3	k = 0.58	a = 1.058			0.9772	0.0030	0.0548
Logarithmic								
	1	k = 0.033	a = 1.041	c = -0.038		1.0000	0.0000	0.0000
	2	k = 0.036	a = 1.132	c = -0.095		0.9868	0.0018	0.0424
	3	k = 0.040	a = 1.208	c = -0.185		0.9932	0.0010	0.0194
Midilli et al.								
	1	k = 0.029	a = 0.998	n = 1.048	b= 0.000	1.0000	0.0000	0.0000
	2	k = 0.016	a = 0.992	n = 1.273	b= 0.000	0.9912	0.0133	0.0365
	3	k = 0.018	a = 0.986	n = 1.334	b= -0.001	0.9974	0.0004	0.0207

Table 18: The Various Drying Models Fitted for MW-assisted Hot Air Drying at 270 W

Model name	T	Mw*	Model constants				R^2	X^2	RMSE
Page									
	50	2	k = 0.0.33	n = 1.128			0.9889	0.0014	0.0376
	60	1	k = 0.013	n = 1.227			0.9915	0.0010	0.0316
	60	3	k = 0.063	n = 0.941			0.9894	0.0012	0.0340
	70	2	k = 0.063	n = 0.880			0.9859	0.0014	0.0373
Henderson and pabis									
	50	2	k= 0.050	a = 1.013			0.9857	0.0018	0.0428
	60	1	k= 0.032	a= 1.026			0.9825	0.0021	0.0454
	60	3	k = 0.050	a = 0.074			0.9894	0.0012	0.0340
	70	2	k = 0.039	a = 0.954			0.9837	0.0016	0.0401
Logarithmic									
	50	2	k = 0.036	a = 1.128	c = -0.144		0.9948	0.0007	0.0270
	60	1	k = 0.020	a = 1.206	c = -0.218		0.9985	0.0002	0.0133
	60	3	k = 0.045	a = 1.002	c = -0.042		0.9915	0.0002	0.0133
	70	2	k = 0.036	a = 0.971	c = -0.027		0.9848	0.0016	0.0399
Midilli et al.									
	50	2	k = 0.049	a = 0.997	n = 0.938	b= -0.002	0.9954	0.0007	0.0265
	60	1	k = 0.021	a = 0.985	n = 1.042	b= -0.001	0.9981	0.0003	0.0158
	60	3	k = 0.088	a = 1.007	n = 0.783	b= -0.002	0.9957	0.0005	0.0234
	70	2	k = 0.097	a = 1.018	n = 0.705	b= -0.001	0.9932	0.0008	0.0274

Table 19: The Various Drying Models Fitted for MW-assisted Hot Air Drying at 720 W

Model name	T	Mw*	Model constants				R^2	X^2	RMSE
Page									
	50	2	k = 0.698	n = 0.409			0.9943	0.0005	0.0213
	60	1	k = 0.141	n = -0.740			0.9870	0.0013	0.0362
	60	3	k = 1.646	n = 0.207			0.9976	0.0002	0.0129
	70	2	k = 0.779	n = 0.507			0.9833	0.0013	0.0357
Henderson and pabis									
	50	2	k = 0.314	a = 0.954			0.9045	0.0076	0.0874
	60	1	k =0.056	a = 0.899			0.9816	0.0018	0.0430
	60	3	k = 0.631	a = 0.999			0.9719	0.0020	0.0447
	70	2	k = 0.433	a = 0.935			0.9121	0.0001	0.0357
Logarithmic									
	50	2	k = 0.434	a = 0.914	c = 0.070		0.9534	0.0041	0.0640
	60	1	k = 0.056	a = 0.901	c = -0.003		0.9816	0.0020	0.0447
	60	3	k = 0.759	a = 0.961	c = 0.039		0.9918	0.0006	0.0252
	70	2	k = 0.602	a = 0.902	c = 0.075		0.9524	0.004	0.0632
Midilli et al.									
	50	2	k = 0.774	a = 1.000	n = 0.324	b= -0.001	0.9977	0.0002	0.0149
	60	1	k = 0.194	a = 0.993	n = 0.560	b= -0.002	0.9984	0.0002	0.0135
	60	3	k = 1.918	a = 1.000	n = 0.100	b= -0.001	0.9988	0.0001	0.0100
	70	2	k = 0.852	a = 1.000	n = 0.358	b= -0.006	0.9869	0.0012	0.0350

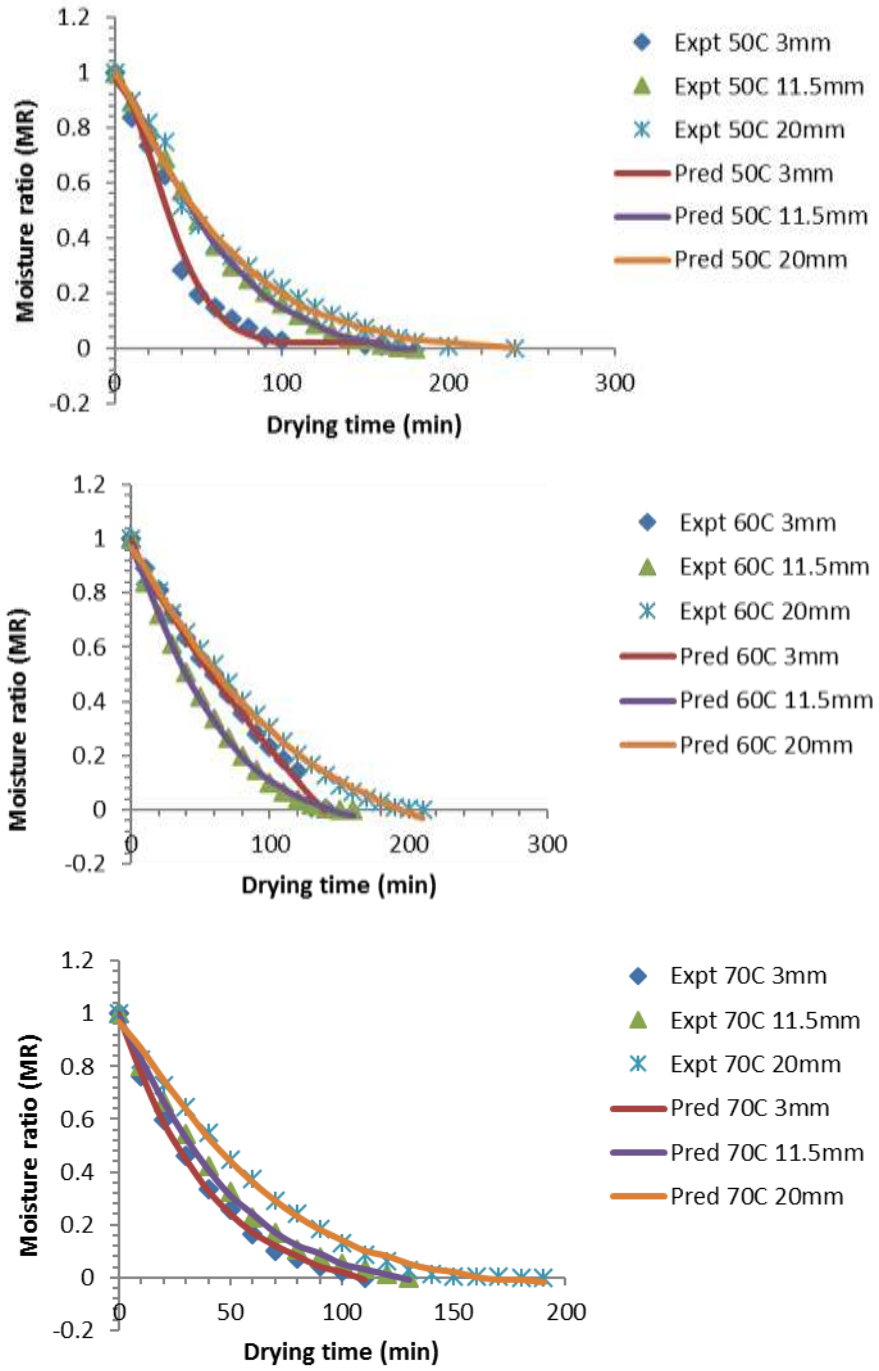

Figure 31: Fitting of hot air alone drying experimental and predicated data to the Midilli et al. model at various temperatures and thicknesses.

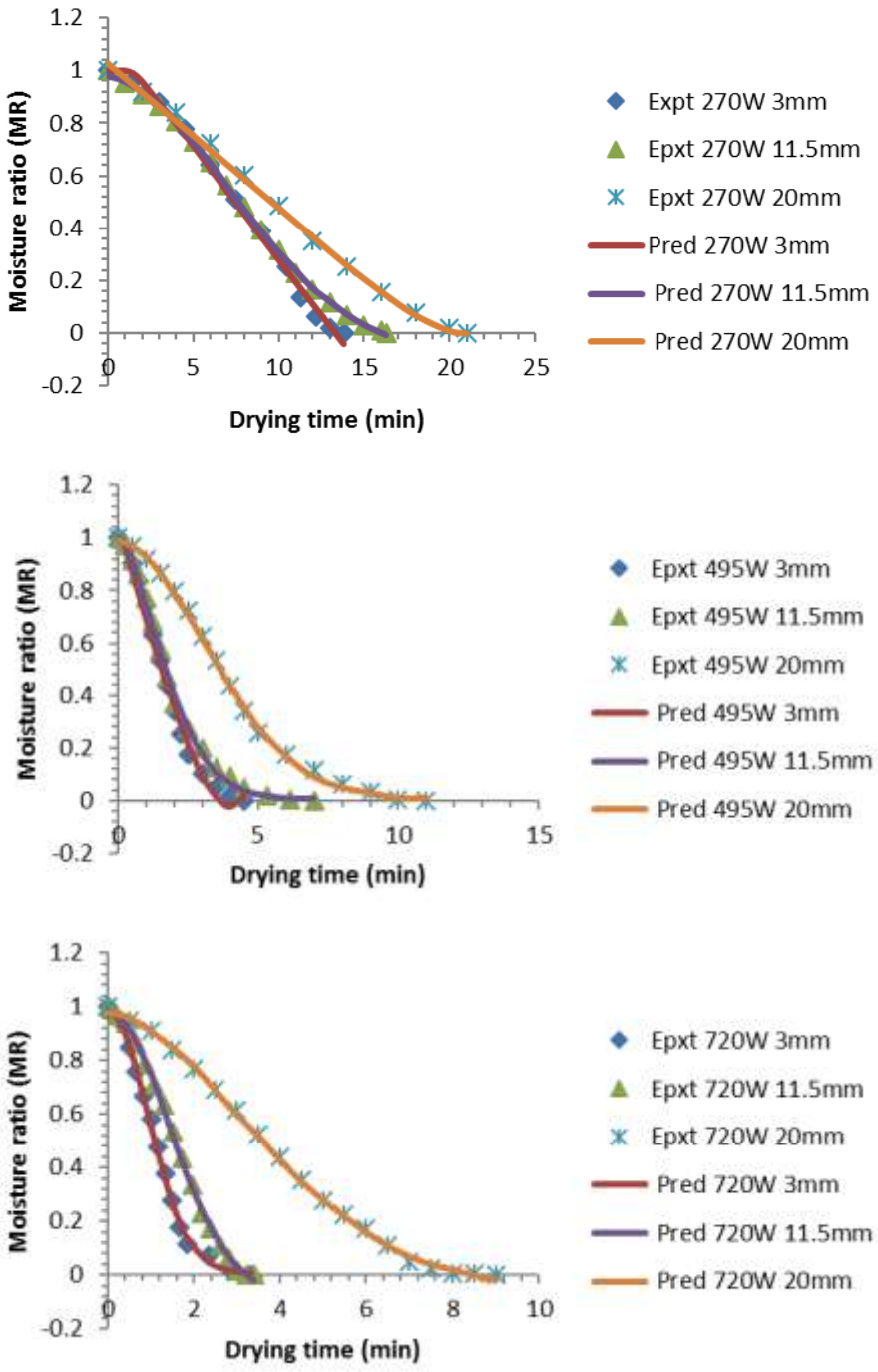

Figure 32: Fitting of microwave alone drying experimental and predicated data to the Midilli et al. model at different microwave powers and thicknesses.

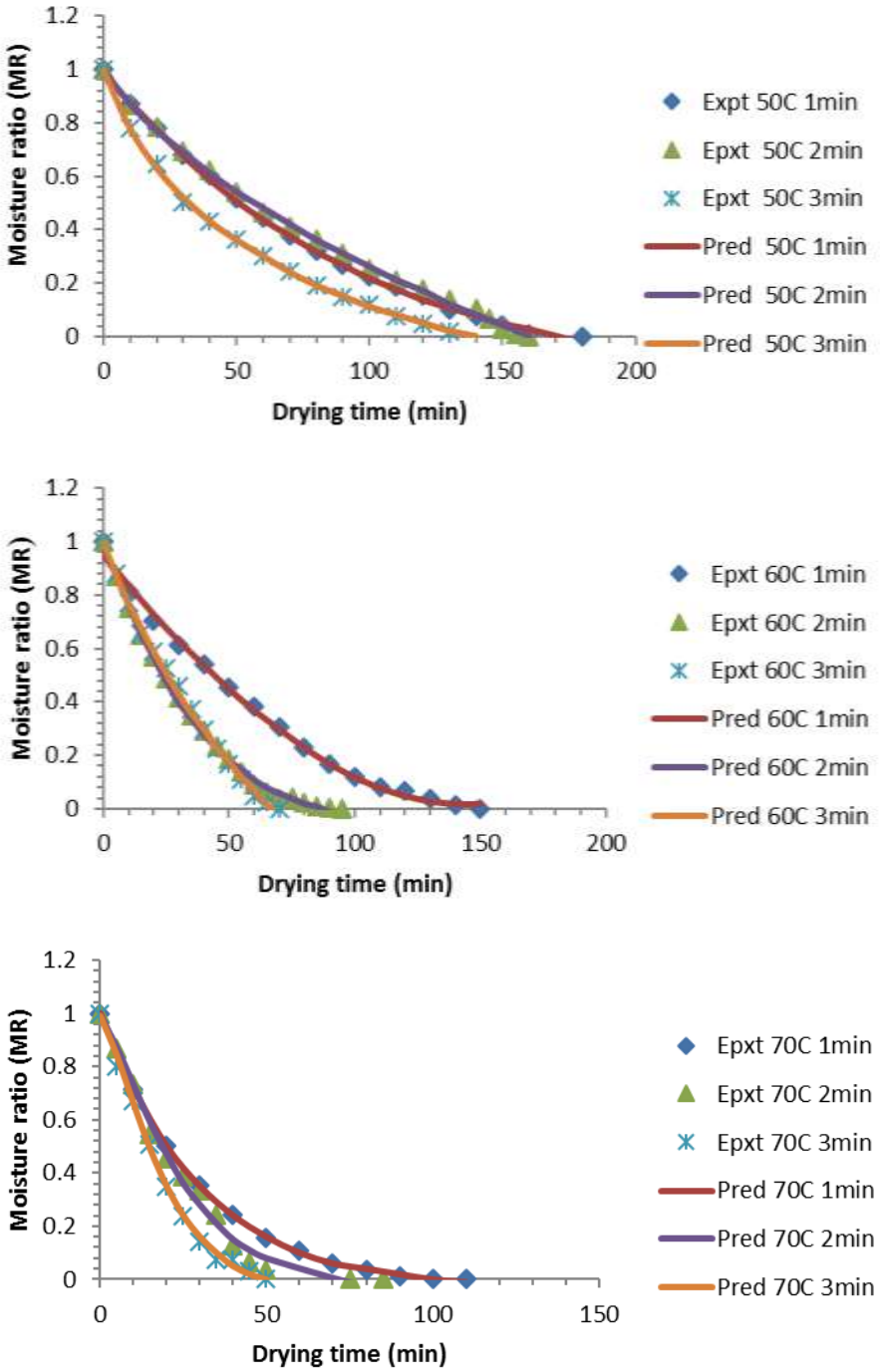

Figure 33: Fitting of blanch-assisted hot air drying experimental and predicated data to the Midilli et al. model at various temperatures and blanching time.

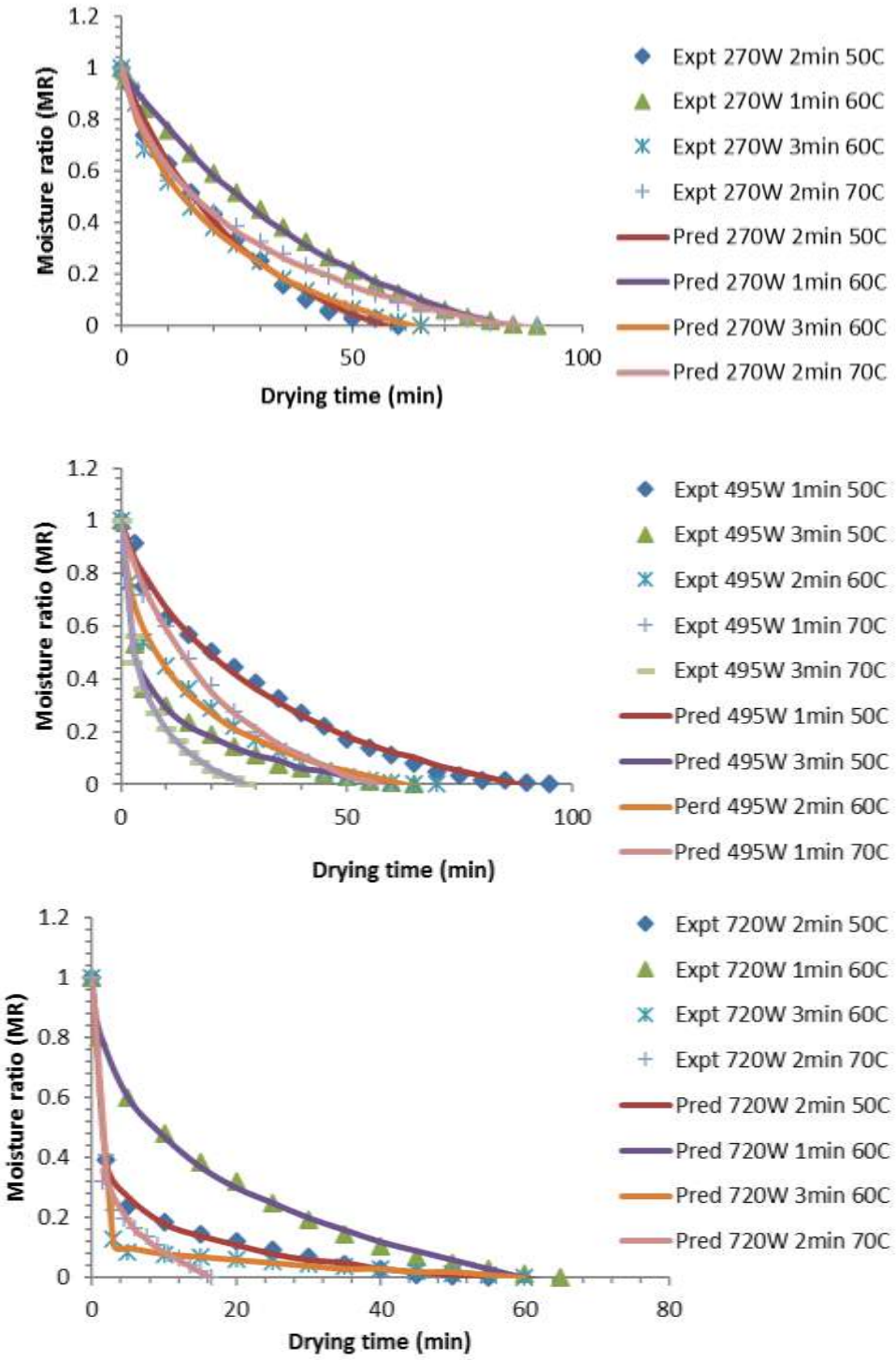

Figure 34: Fitting of Mw-assisted hot air drying experimental and predicated data to the Midilli et al. model at different microwave powers, temperatures and thicknesses.

Quality Attributes AA, TP, FL, AOA and BI

Effect of Various Drying Conditions on Ascorbic Acid Content (AA)

The contents of ascorbic acid obtained using sun, shade and solar were 3.863, 3.433 and 3.645 mg/g respectively. According to the results obtained by these methods of drying, the content of AA reduced compared to the fresh moringa leaves (5.815 mg/g). This confirms the research results Kiremire et al. (2010) and Ndawula et al. (2004) that sun drying causes loss of vitamins through oxidation because of the exposure of the solar radiation for a long period without protection against the sun's ultraviolet rays which causes photo degradation of the carotenoids. Further, other researchers Kendall et al. (2004), Yadav and Sehgal (1995) reported the loss of nutrients from vegetables during sun, shade and solar drying. Studies by Kiremire et al. (2001) also indicated that sun drying method results in the greatest cause for the loss of b-carotene and vitamin C contents. Initial and final values would have been more meaningful related.

The results of AA content using hot air drying are shown in (Table 5). Table 6 clearly shows that as the sample thicknesses increased it led to a decrease in the ascorbic acid content. The ascorbic acid content ranged from 2.918- 4.199 mg/g. The results obtained in this study, agree with the results obtained by Sreelatha and Padma (2009). In their study they also discovered that ascorbic acid for matured leaves averaged 6.60±0.01 mg/g and that for tender leaves was 5.81±0.01mg/g. This also confirms that the moringa leaves used in the present study are tender leaves. The increase in hot air temperature led to the decrease in ascorbic acid content is shown in Figure 38. Table 6 shows that the linear effect of hot air temperatures gave significant model

terms for AA content. The reduction of vitamin C content in dried moringa leaves could be attributed to the fact that ascorbic acid is very sensitive to high temperatures. On the contrary, the main effect of sample thickness, the quadratic effect of hot air temperature and sample thickness gave insignificant model terms. This is in agreement with results of the study by Mrad, Boudhrioua, Kechaou, Courtois and Bonazzi (2012) whereby AA content decreased as air temperature increased in the range of 30–70^{o}C and this was attributed to the occurrence of irreversible oxidative reactions during drying. A similar degradation in ascorbic acid content was reported by Erenturk, Gulaboglu and Gultekin (2005) for drying of rosehip within the temperature range of 50–80^{o}C.

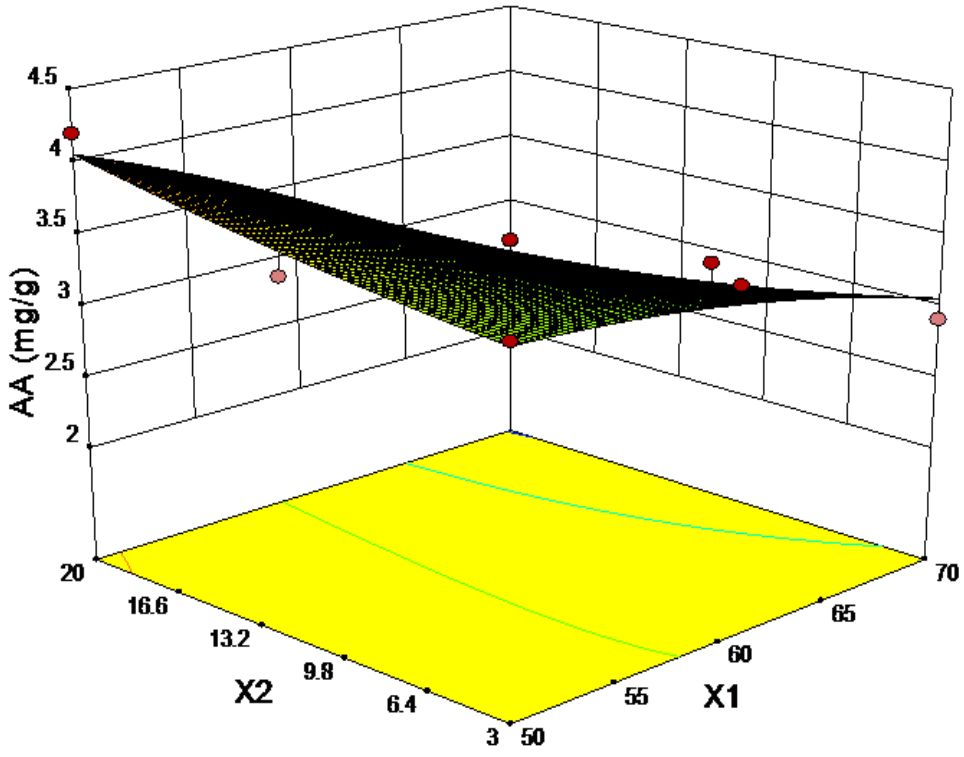

Figure 35: Effect of drying temperature (X1) and thickness (X2) on ascorbic acid.

The effect of microwave alone drying on ascorbic acid of moringa leaves is illustrated in Figure 39. The linear effect of microwave power and

their quadratic terms were significant on the ascorbic acid content. However, the linear effect of sample thickness and the interaction effect of microwave powers and sample thickness were insignificant on model terms as it is given in Table 8. It was evident that a decrease in sample thickness led to a reduction in ascorbic acid content. Sample thickness has been reported to significantly affect the retention of ascorbic acid content for drying of okra slices (Adom, Dzogbefia, & Ellis, 1997), onion slices (Adam, Mühlbauer, Esper, Wolf, & Spiess, 2000) and tomatoes by Abano et al. (2011).

As the microwave power increased from 270 to 720 W there was a reduction in ascorbic acid content of moringa leaves due to the destruction of vitamin C by the electromagnetic waves that microwave drying process contains. Losses of ascorbic acid during the microwave have been reported by Abano and Amoah (2015) on white yam cubes, Zheng and Lu (2011) reported the reduction of ascorbic acid during microwave drying of green asparagus. Sokhansanj and Jayas (1995) also found the loss of ascorbic content during the drying of food stuffs that was between 10 % and 50 %. From Table 7, the initial ascorbic acid content of moringa leaves (5.815 mg/g) and ranged between (2.274 and 3.989 mg/g) after drying. The loss of ascorbic acid content in this study ranged from 31.4 to 60.9 %, thus a significant decrease of such an important nutrient.

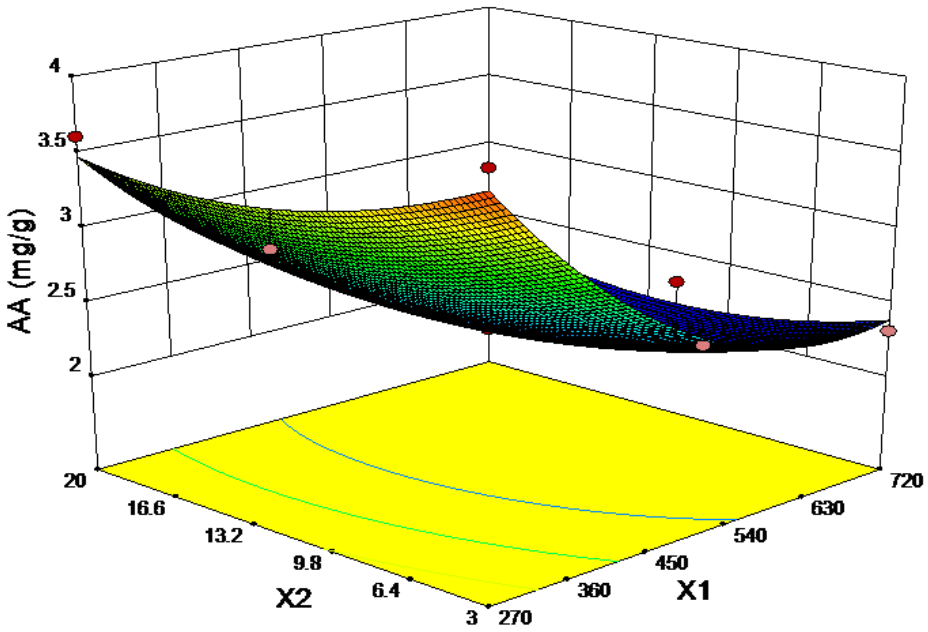

Figure 36: Effect of microwave power (X1) and thickness (X2) on ascorbic acid.

The effect of blanching time on ascorbic acid content is shown in Figure 40. Ascorbic acid content ranged from 2.025 to 3.491mg/g during blanch-assisted hot air drying method Table 9. The increase in blanching time and hot air temperatures induced the loss of ascorbic acid content in moringa leaves (Table 9). This might be due to the fact that ascorbic acid is very soluble in water and highly vulnerable to heat (Nagy & Smoot, 1977). The resent results agree with the results reported by Oboh (2005) where blanching of the vegetables caused a significant decrease ($p<0.05$) in the vitamin C content of the vegetables. The highest level of decrease occurred in *Telfairia occidentalis* where blanching caused 82.4 % loss in the vitamin C content, while in *Ocimum gratissimum* caused 47.5 % loss in Vitamin C content. In the present study, the percentage decrease in ascorbic acid content ranged from 40 to 65.2 %. The difference in the percentage range might be due to the fact that in the present study steam blanching was used whereas in Oboh`s study water

blanching was used. However, the study done by Kendall et al. (2004) recommended water blanching over steam blanching because water blanching achieves a more even heat penetration than the steam blanching. But in the present study it was observed that steam blanching retained AA content. Therefore, steam blanching is recommended for the retention of ascorbic acid.

Table 10 shows the coefficient of model terms and their significances as far as blanch-assisted hot air drying method. The linear effect of temperature and the interaction between blanching time and temperature gave significant model terns on ascorbic acid content. The linear effect of blanching time gave insignificant model terms. The fitting of Ascorbic acid content gave R^2 of 0.9271 which is relatively high. Losses of ascorbic acid during blanching before drying have been reported by Achinewhu (1983) for some tropical vegetables. The researchers stated that during handling and processing of vegetables the loss of ascorbic acid content were 32.0–68.0 %. As a result of heat and blanching might have degraded most of the ascorbic acid in the vegetables, water would have washed away the vitamin C during the course of blanching.

The reduction of ascorbic in the present study acid agrees with the results obtained by Leng, Gouado and Ndjouenkeu (2011). They reported that after blanching and drying of *Dioscorea schimperina*, there was more than 50 % loss of ascorbic acid content. Enemo, Ekpunobi, Nnubia and Onuegbu (2010) reported high losses of ascorbic acid content in *Solanum gilo* and *Gnetum africanum*. They reported that blanching and drying of the samples reduced ascorbic acid by 92.29 % and 96.29 %, respectively.

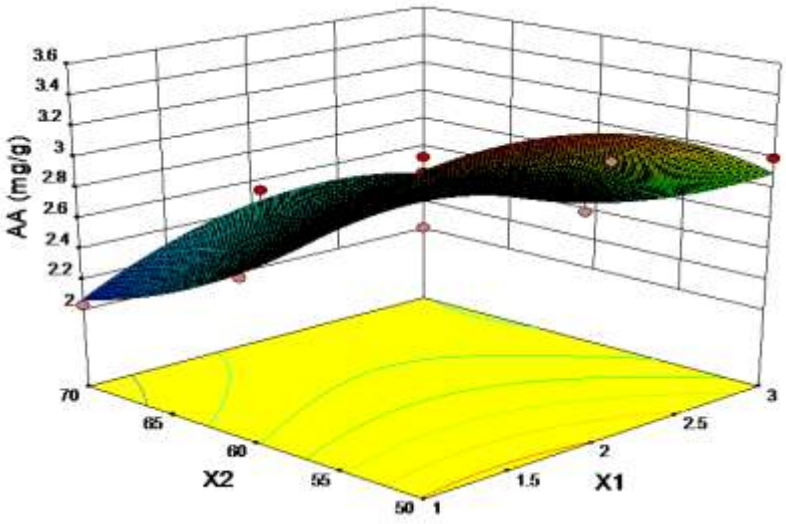

Figure 37*:* Effect of blanching time (X1) and temperature (X2) on ascorbic acid.

The effect of microwave power and microwave pretreatment time at the various hot air temperatures of 50, 60 and 70^{o}C on the ascorbic acid content of moringa leaves is shown in (Figure 41 A-C). High temperatures and microwave powers caused more reduction of the ascorbic acid content and it ranged from (2.231-3.501 mg/g) after the drying process as observed in Table 11. The reduction of ascorbic acid agrees with results obtained by Zheng and Lu (2011) for microwave pretreatment time on the content of ascorbic acid in different parts of green asparagus. The main effect of temperature and quadratic term models effect were significant on ascorbic acid content (Table 12). While the interaction effects of hot air temperature, MW- power plus MW-pretreatment time and their quadratics effects gave insignificant model terms on ascorbic acid content. This might be due to the fact that ascorbic acid is very sensitive to high temperatures. Likewise, Abano and Amoah (2015) reported 88 % loss of vitamin C of white yam as a result of using microwave drying. Tagawaa (2012) reported the decrease of ascorbic acid in okra fruit when microwave was involved in the drying process, the AA reduction was

between 43 % and 63 %. Mrad et al. (2012) observed 70 % reduction of AA in pears dried at 70 ^{o}C.

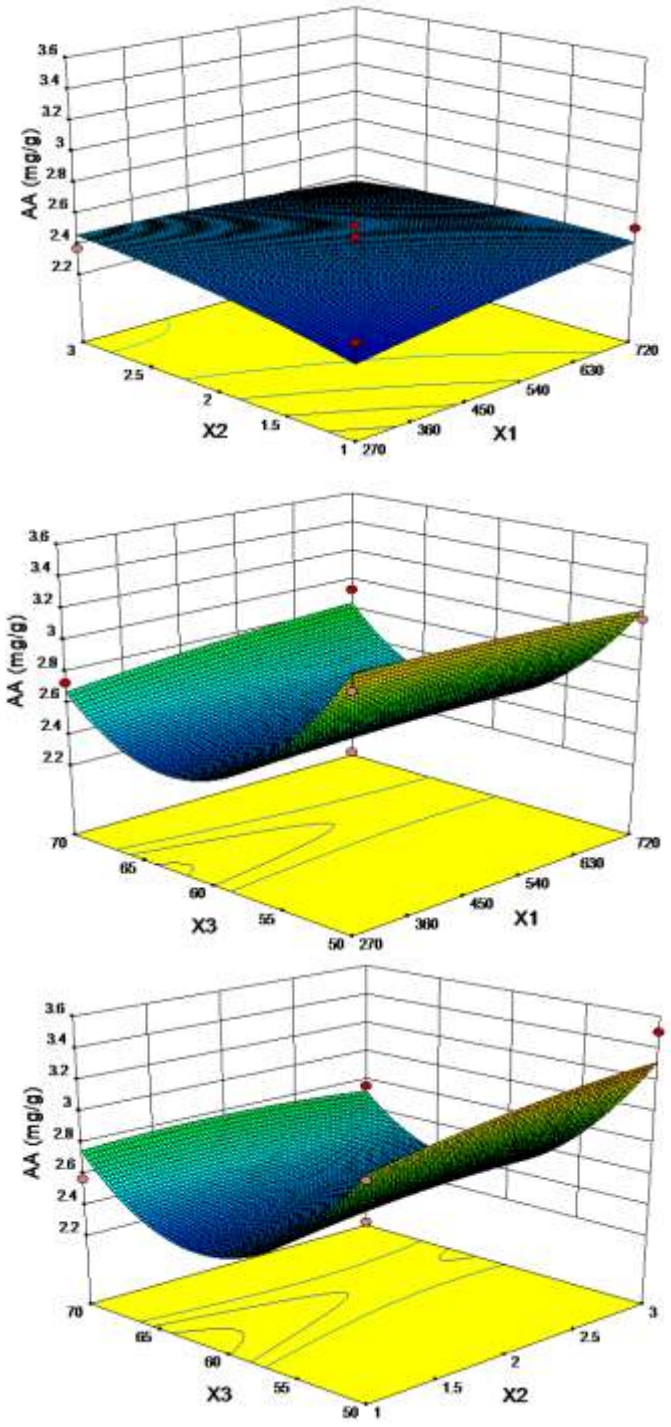

Figure 38: The effects of (A) microwave power (X1) and microwave time (X2), (B) microwave power (X1) and temperature (X3), (C) microwave time (X2) and temperature (X3) on ascorbic acid.

Effect of various Drying Conditions on Total Phenolics Content (TP)

The phenolic compounds may contribute directly to antioxidative action Awika, Rooney, Wu, Prior, & Cisneros-Zevallos (2003) hence its importance to this study. The TP content of the fresh leaves was 0.013 mg/g, as compared to the following ranges of values from 0.03-0.043, 0.026-0.035 and 0.087-0.296 mg/g of DW for hot air, microwave alone and microwave-assisted hot air drying conditions respectively as shown in Tables 5, 7 and 11. The R^2 values for hot air drying, MW-alone were 0.9756, 0.6656 and 0.9724 respectively. The results obtained using solar, sun and shade drying were 0.037, 0.032 and 0.026mg/g of DW respectively. From Figure 42, it was observed that the increase in temperature and sample thickness led to the reduction of TP content. TP gave significant model terms in Table 6 and 12 for the sample dried using hot air alone and microwave-assisted respectively. The linear effect of temperature, thickness and the quadratic effect of sample thickness gave significant model terms for TP content while the interaction effect of temperature and sample thickness were insignificant model terms (Table 6) on TP content.

On the contrary, the linear effect of MW-power, sample thickness and their quadratic effect model terms were insignificant on TP content as it listed in Table 8. As the microwave powers increased from 270 to 720 W, sample thicknesses from 3 to 20 mm resulted in the reduction of TP content as it is shown in Figure 43.

The increase in microwave power and microwave pretreatment time decreased the content of TP, likewise the increase of microwave powers and temperature decreased the content of TP. Furthermore, the increase in

microwave power and temperature dramatically reduced the phenolic content (Figure 44 A-C). This implies that temperature had the highest effect on the TP content of moringa leaves dried using microwave-assisted hot air drying. From Table 12 It was observed that the linear effect of microwave pretreatment time, temperature and their interactions, and the quadratic effect of temperature were significant model terms

The results obtained for present study for the selected drying methods lie within the range of values reported by Iqbal and Bhanger (2006). In their study they confirmed the strong effect of temperature on the content of TP. The TP content of the leafy vegetables ranged from 0.1 to 0.3 g/100 g. However, the values obtained in tise present work were generally higher than what Yang, Lin, and Mau (2002) reported for some varieties of commercial mushrooms (0.01–0.02 g/100 g). The higher constant of TP in moringa leaves this makes it useful for medicinal purposes. Oboh (2005) studied the content of TP of some green leafy vegetables and reported the values of 0.1 g/100 g and 0.2 g/100 *Structium sparejanophora* and *Vernonia amygdalina* respectively. However, the TP content of *Vernonia amygdalina* is also slight lower than the results obtained in this work.

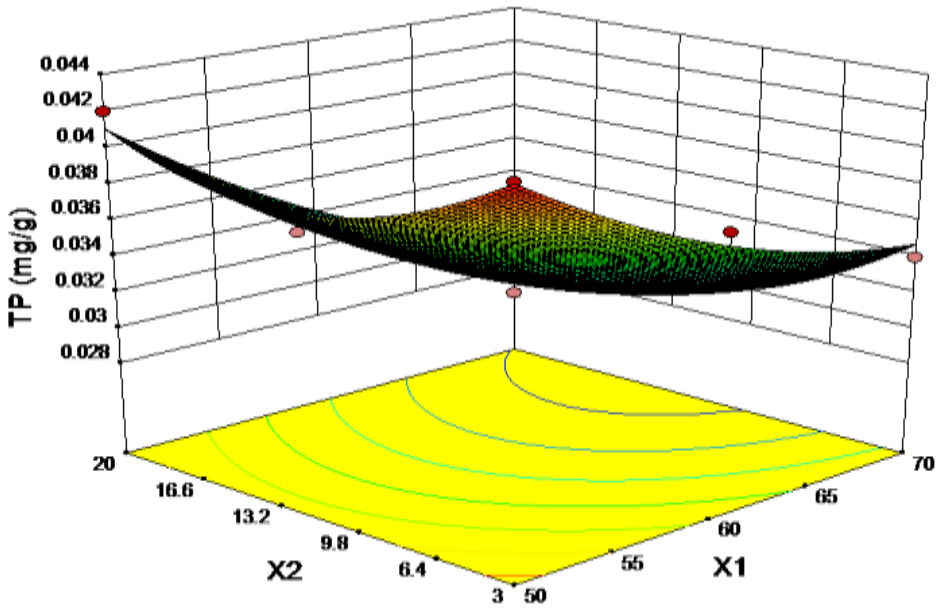

***Figure 39*:** Effect of hot air temperatures (X1) and thicknesses (X2) on total phenolic using hot air alone drying.

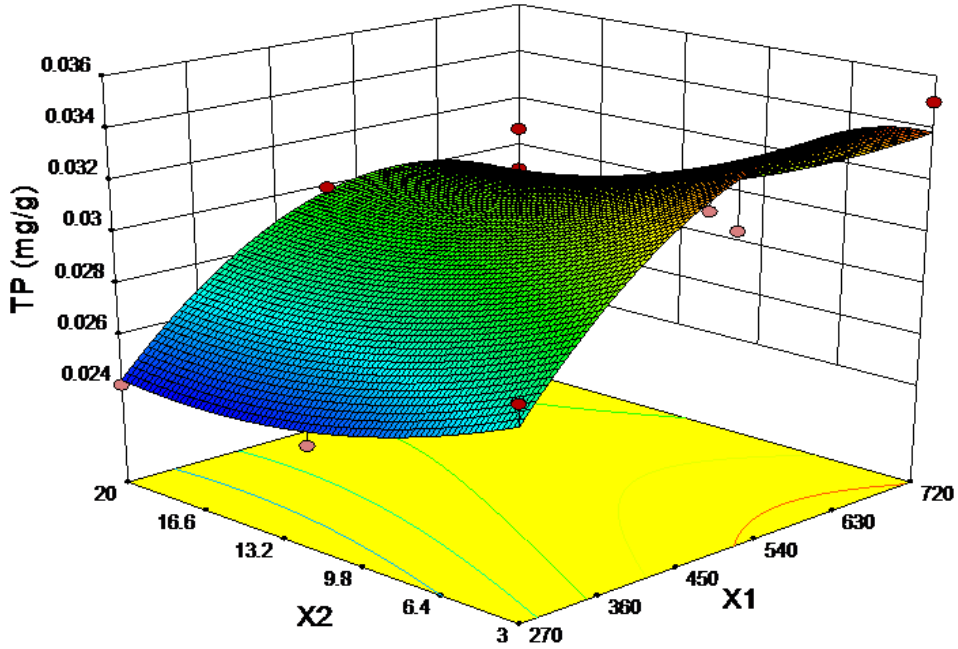

***Figure 40*:** Effect of microwave power (X1) and thickness (X2) on total phenolic using microwave alone to drying.

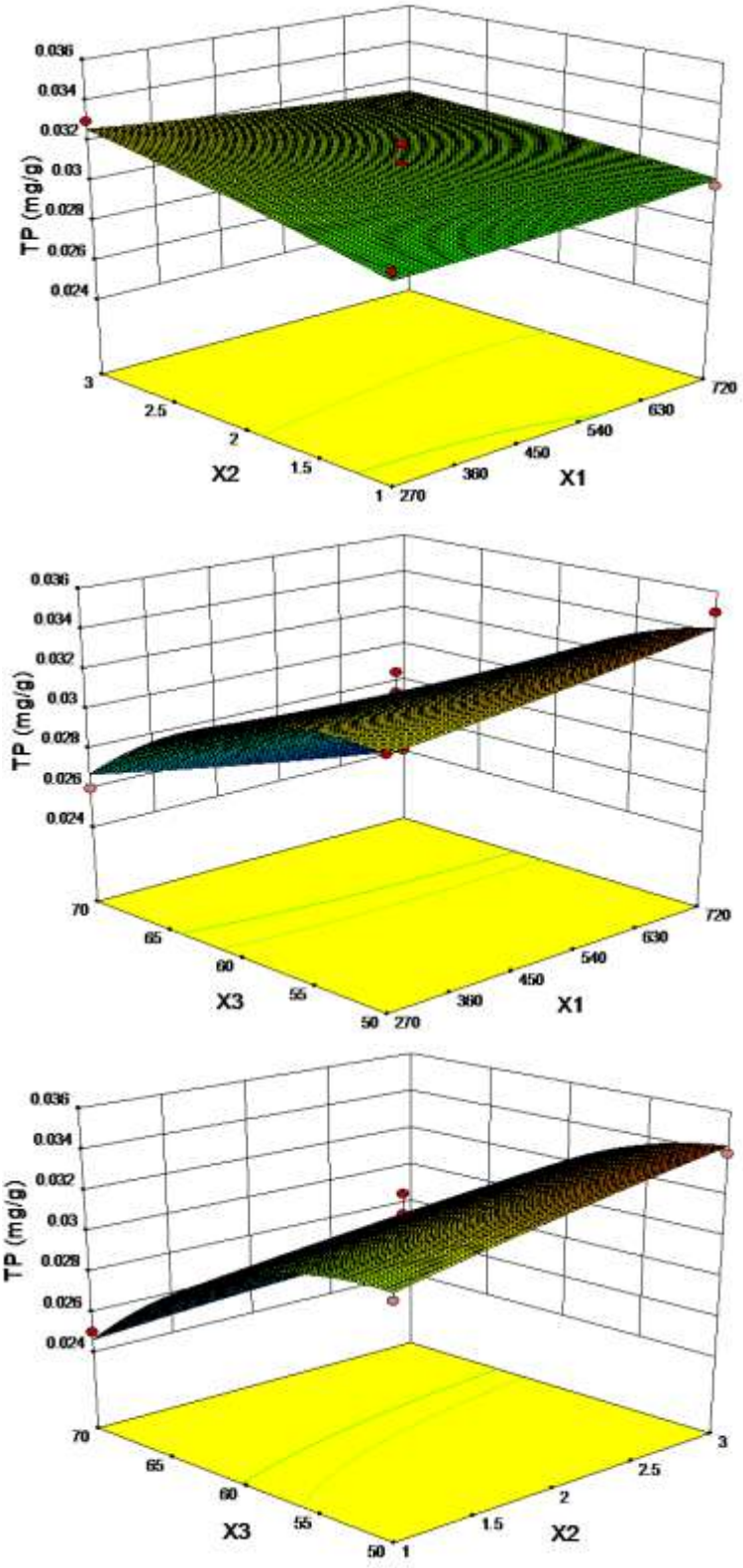

Figure 41: The effects of (A) microwave power (X1) and microwave time (X2), (B) microwave power (X1) and temperature (X3), (C) microwave time (X2) and temperature (X3) on total phenolic using microwave-assisted hot air drying.

Effect of various Drying Conditions on Flavonoids (FL)

Determination of flavonoids was done for fresh and dried moringa leaves using hot air, microwave and microwave-assisted hot air drying. Flavonoids contribute a great deal to the antioxidant properties of plant food product (Tai et al., 2010). The flavonoids content for fresh moringa leaves was 0.056 mg/g and ranged from 0.085-0.174, 0.07-193 and 0.087-0.296 mg/g, for sample thickness dried by hot air, microwave and microwave-assisted hot air drying respectively (Tables 5, 7 and 11). The FL obtained for solar, sun and shade drying were 0.116, 0.086 and 0.056 mg/mg, respectively. The main effect of temperature and sample thickness were significant model terms on flavonoids content while their quadratic effect gave insignificant model terms on flavonoids content (Table 6). The increase in hot air temperature and sample thickness resulted in the reduction of flavonoids content (Figure 45).

However, the content of flavonoids in the samples dried using microwave alone increased when the microwave power as well as sample thickness increased (Figure 46). The linear effect of microwave power and sample thickness were significant model terms as observed in (Table 8). In microwave-assisted hot air drying, temperatures, gave significant model terms (Table 12). The main effect of temperature was significant while the main effect of microwave power and pretreatment time and their quadratic model terms were insignificant on the flavonoids of dried moringa leaves. The results obtained in the present study agree with the results obtained by Zhishen, Mengcheng and Jianming (1999) on mulberry leaves of 19 varieties of species. They reported that mulberry fresh leaves contained more flavonoids than those dried using hot oven. Garba and Kaur (2014) reported that higher flavonoids

content were recorded at drying air temperature of 50°C for control and pretreated samples of black carrot compared to air temperature of 40 and 60°C that were also studied. Also Lemus-Mondaca, Ah-Hen, Vega-Gálvez, Honores, & Moraga, (2015) confirmed that flavonoids content was higher at 50°C for Stevia rebaudiana Leaves dried at temperatures ranging from 30 to 80°C. In ths present study the highest values of flavonoids content were obtained at hot air temperature of 50°C. As the hot air temperatures increased from 50 to 70°C there was a decrease in flavonoids content of moringa leaves.

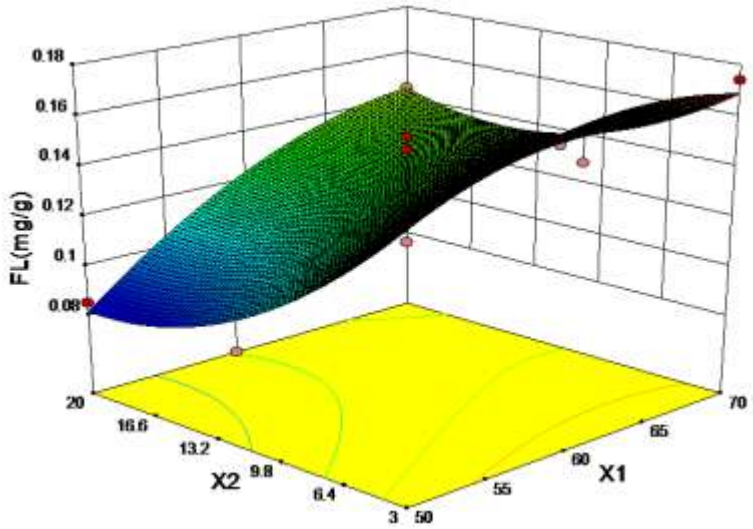

Figure 42: Effect of drying temperatures (X1) and the thicknesses (X2) on flavonoids using hot air alone.

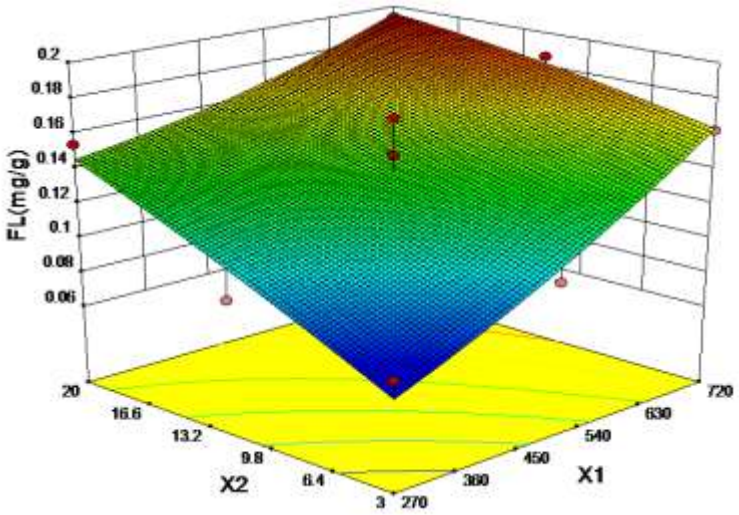

Figure 43: Effect of microwave power (X1) and the thicknesses (X2) on flavonoids using microwave alone to dry.

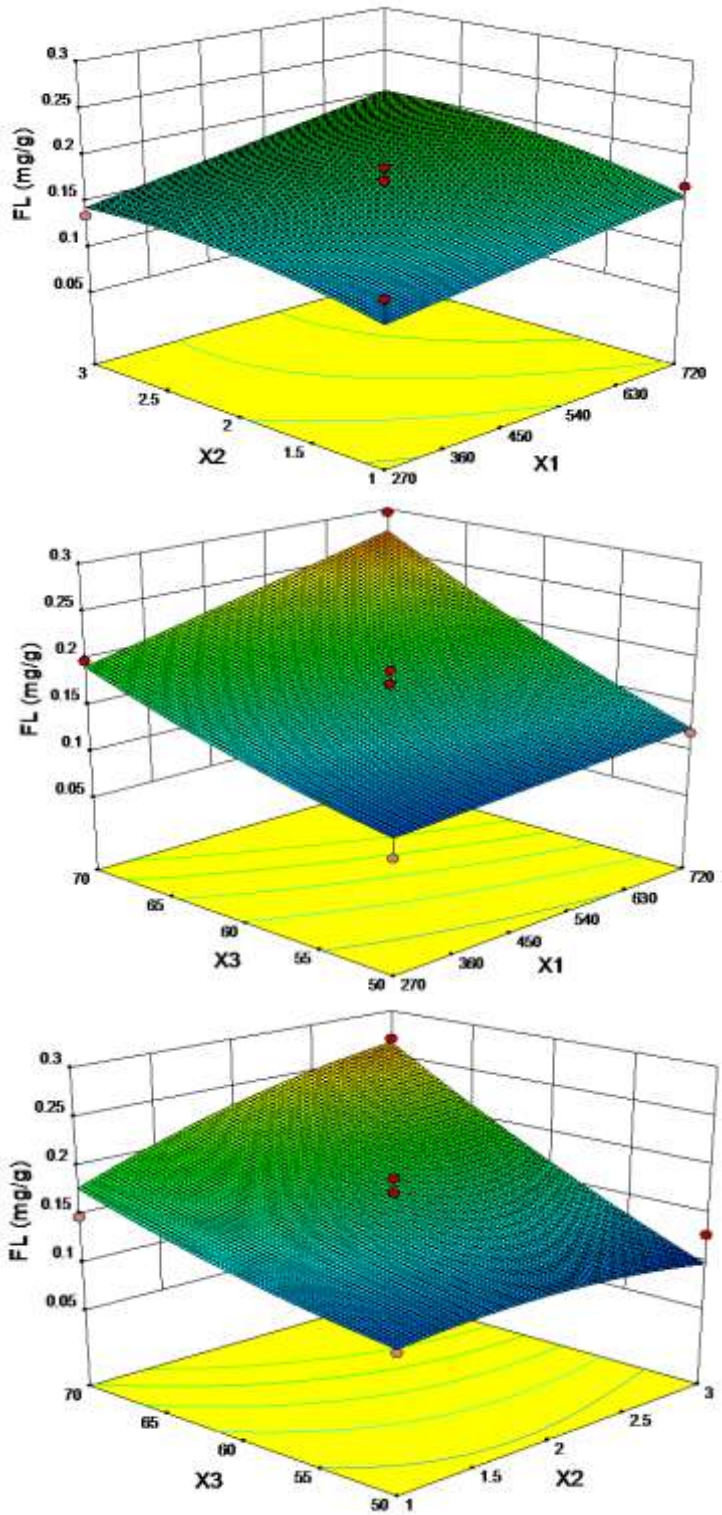

Figure 44: The effects of (A) microwave power (X1) and microwave pretreatment time (X2), (B) microwave power (X1) and temperature (X3), (C) microwave pretreatment time (X2) and temperature (X3) of flavonoids using microwave-assisted hot air drying.

Effect of various Drying Methods on Antioxidant Activity (AOA)

The initial AOA content of fresh moringa leaves was 79.909 % of inhibition. The consecration of AOA for samples dried using sun, shade and solar were 68.879, 68.770 and 85.343 % of inhibition, respectively. The low retention of nutrients and antioxidant activity in direct sun and shade dried leaves might have been caused by enzymatic processes (Mueller-Harvey, 2001). The findings of Kiremire et al. (2010) are in good agreement with the results obtained in this study. In their study, it was reported that solar radiation reflects the UV exposure, which may be associated with free radical formation and singlet oxygen production. Studies done by Zheng and Wang (2001) on strawberry showed that environmental temperature strongly alters antioxidant properties.

Table 5 lists the range of AOA concentrations for samples dried using hot air alone (70.069-81.013 % of inhibition). The decrease in temperature and thickness increased the concentration of AOA (Figure 48). The quadratic effect of sample thickness gave significant model terms on AOA. The R^2 obtained using hot air drying alone on AOA was 0.6636 (Table 6). The results of this study are in good agreement with the findings of Siddhuraju and Becker (2003) of freeze-dried leaves of *Moringa oleifera* Lam

The main effect of sample thickness gave significant model terms (Table 8). The increase in microwave power and decrease in sample thickness resulted in reduction in the free radical scavenging ability of moringa leaves (Figure 49). The results of AOA obtained for fresh leaves and dried samples ranged from 57.209 to 72.927 % of inhibition (Table 7). The results of this study agree with those reported by Demarchi, Ruiz, Concellón and Giner

(2013). They found out that retention of antioxidant capacity decreased with increasing dehydration temperature as the temperatures increased from 50 to 70^{o}C.

The results of the free radical scavenging ability of blanch-assisted samples ranged from 50.812-71.509 % of inhibition (Table 9). The results obtained might be due to the fact that dried moringa leaves are rich in antioxidant compounds (Iqbal & Bhanger, 2006; Santos, Argolo, Coelho, & Paiva, 2005). The result indicated that free radical scavenging ability of moringa leaves was affected by blanching time and hot air temperature. The increase in blanching time decreased AOA of moringa leaves (Figure 50). The quadratic effect of temperature and blanching time are significant model terms on the free radical scavenging ability (Table 10). The results obtained in this study disagree with the results reported by Oboh (2005) which started that there were no changes in the scavenging ability between the blanched and unblanched samples. The loss in free radical scavenging ability ranged from 5.8 % loss in *Telfairia occidentalis* to 51.5 % loss in *Ocimum gratissimum,* which indicated in his study that blanching drastically reduce the free radical scavenging ability of some tropical green leafy vegetables.

Microwave-assisted hot air drying results of AOA ranged from 59.645-76.672 % of inhibition (Table 11). Microwave-assisted hot air drying gave insignificant model terms on AOA as observed in Table 12. The results obtained in this present work disagree with the studies of Siddhuraju and Becker (2003). They reported that all the moringa leaves dried using microwave powers from 150 to 900 W showed a significant increase in AA.

As the microwave power, microwave pretreatment time and temperature increased led to a decrease in AA (Figure 51).

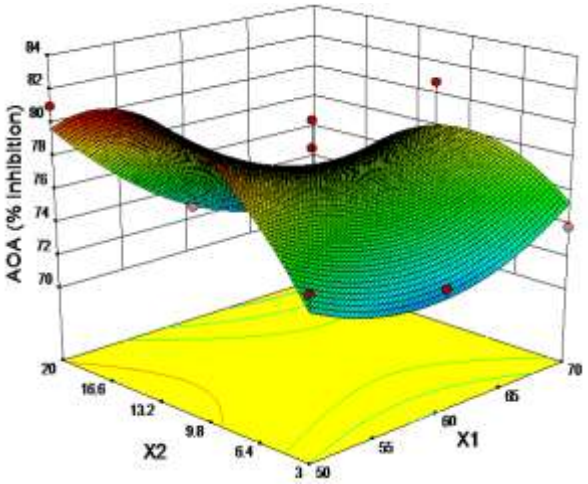

Figure 45: Effect of drying temperature (X1) and the thickness (X2) on AOA.

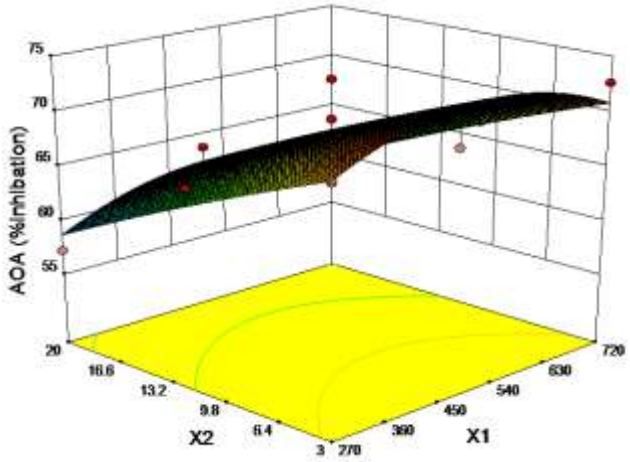

Figure 46: Effect of microwave power (X1) and the thicknesses (X2) on AOA.

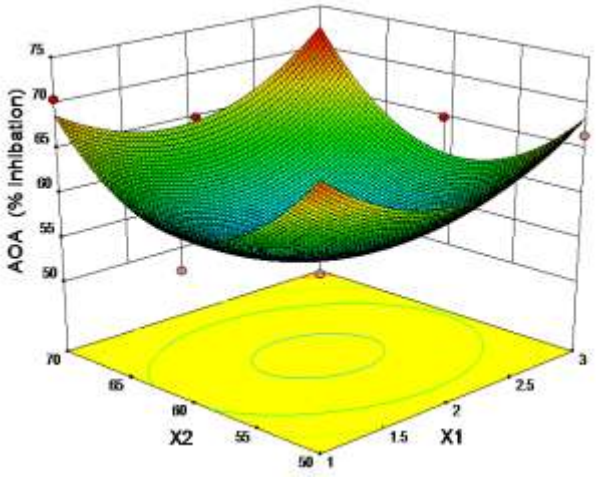

Figure 47: Effect of blanching time (X1) and temperature (X2) on AOA.

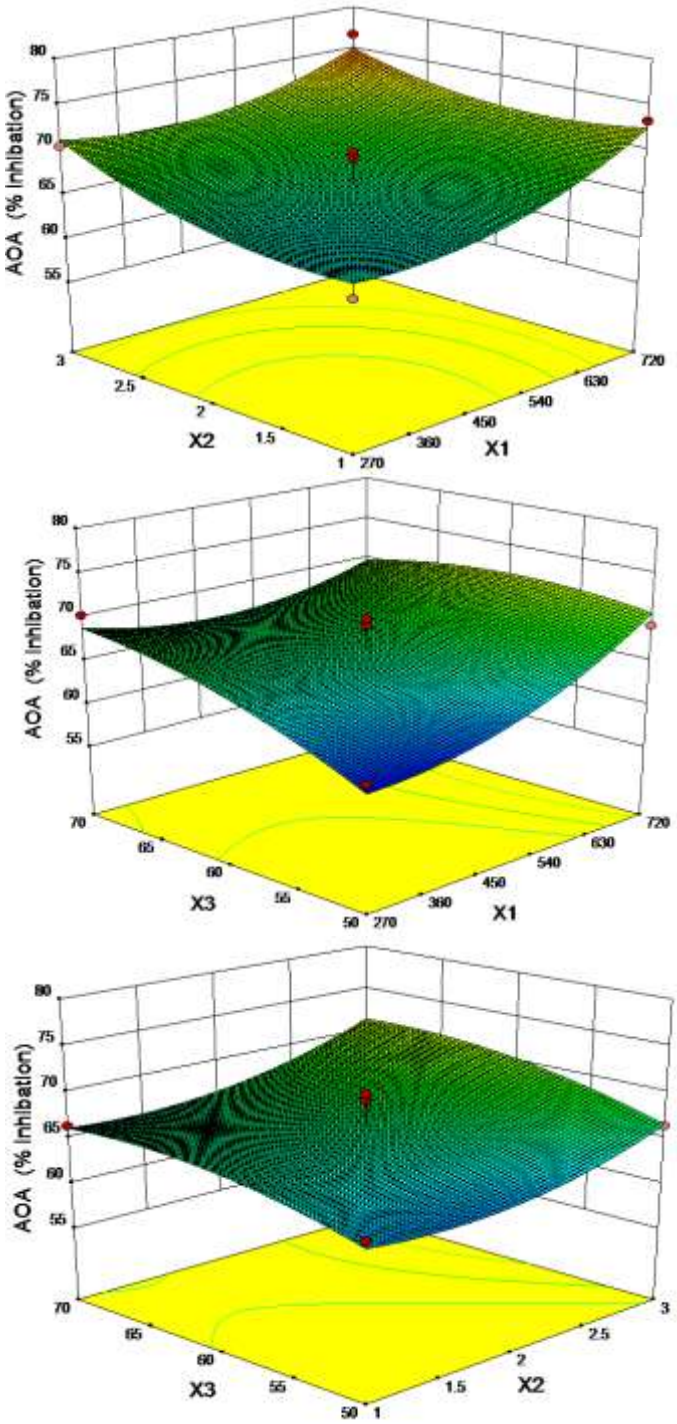

Figure 48: The effects of (A) microwave power (X1) and microwave time (X2), (B) microwave power (X1) and temperature (X3), (C) microwave time (X2) and temperature (X3) on AOA.

Influence of Blanching Time and Air Temperature on both Enzymatic and Non-enzymatic browning of Moringa Leaves

Both enzymatic and non-enzymatic reactions were observed in moringa leaves. The brown pigment formation in dried moringa leaves was due to non-enzymatic browning. The browning index absorbance of fresh moringa leaves was 1.010 Abs unit. The results obtained for solar, sun and shade drying on enzymatic browning were 2.127, 2.672 and 1.788 Abs unit, respectively while for blanch-assisted hot air dried samples ranged from 1.724 to 2.516 Abs unit as listed in Table 9. Non enzymatic browning is a quality indicator in dried agricultural products. It is not a desirable indictor in dried moringa leaves and some food processing units.

The linear effect of blanching time gave significant model terms on browning index (Table 10) with R^2 of 0.7834. The influence of blanching time and hot air drying temperatures on the development of non-enzymatic browning in moringa leaves is shown in (Figure 52). The browning index increased with increase in blanching time and drying temperatures. This shows that the moringa leaves were affected by blanching time and drying temperatures. This agrees with the studies done by Abano and Amoah (2015) on white yam where the browning index increased with both microwave pretreatment time and temperature from 0.012 in the fresh yams to 0.112 Abs after drying at 90°C and microwave pretreatment time of 5 min. Non-enzymatic browning is caused by the amount of nitrogenous constituents and reducing sugars, nitrogenous constituents and organic acids, and sugars and organic acids (Cernîşev, 2010).

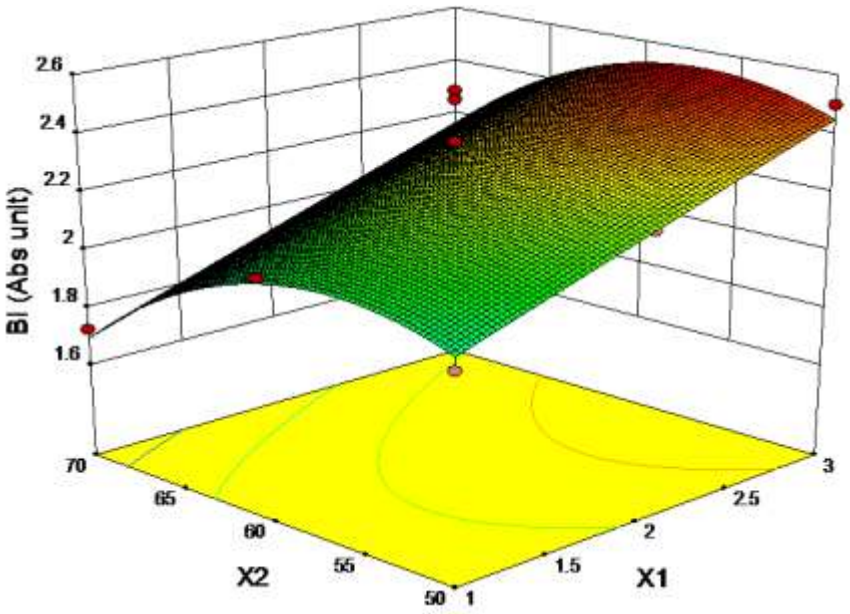

Figure 49: Effect of blanching time (X1) and hot air temperature (X2) on browning index.

Energy Consumption

The energy consumption was determined for various drying methods studied using the optimized results. The energy consumption values obtained for hot air alone, microwave alone, blanch-assisted and microwave-assisted hot air drying were 5.41, 0.04, 1.77 and 0.19 kW/h, respectively. Hot air drying method had the highest energy consumption compared to the microwave alone, blanch-assisted and microwave-assisted hot air drying. Hot air drying method was used as the standard to calculate the percentage of energy consumption of the study. The percentage difference for microwave alone, blanch-assisted hot air and microwave-assisted hot air were 99.26 %, 67.28 % and 96.49 % respectively.

Reduction in energy consumption was observed in microwave alone and microwave-assisted hot air as compared to that of blanch-assisted hot air. One of many reasons might be that the drying time was longer under hot air drying hence it resulted in an increase in energy consumption while using

microwave alone drying shortened the drying time. It could also be due to the higher energy efficiency of microwave as compared to the conventional method. Similar results have been reported by Abano (2016) and Darvishi (2012) for mango and potatoes slices, respectively. Abano found that energy efficiency percentage of mango was 29.7 % while Darvishi reported that maximum drying efficiency of potato slices was 62.4%. However the maximum energy efficiency in this present work was 99.26 %. This value is higher than that for mango and potato slices. Studies done by Mullin (1995) and Thuéry (1992) reported energy decrease in bread baking while using microwave alone and the energy consumption was reduced by 50%.

Optimization of the Drying Parameters

The optimal conditions for drying of moringa leaves were done with Design Expert 9 version: 9.0.6.2. It was established using the concept of the overall desirability index. The maximum predicted DT, AA, TP, FL and AOA were 162.17 min, 3.632 mg/g, 0.042 mg/g, 0.135 mg/g and 76.313% of inhibition, respectively for the hot air drying conditions. The simulated values were closer to their corresponding experimental values of 240 min, 4.199 mg/g, 0.043 mg/g, 0.175 mg/g, and 81.013 % of inhibition. Microwave alone drying the maximum predicted DT, AA, TP, FL and AOA were 4.813 min, 2.613 mg/g, 0.034mg/g, 0.11mg/g and 73.797 % of inhibition, respectively. The simulated values were closer to their corresponding experimental values of 19.5 min, 3.989 mg/g, 0.035 mg/g, 0.193 mg/g, and 72.9273% of inhibition. For the blanch-assisted hot air drying the maximum predicted DT, AA, BI and AOA were 53.096 min, 2.49 mg/g, 2.067 Abs unit and 67.653% of inhibition, respectively. The simulated values were close to their corresponding

experimental values of 200 min DT, 3.491 mg/g AA, 2.516 Abs units BI, and 71.509 % of inhibition. However, in microwave-assisted hot air drying the maximum predicted DT, AA, TP, FL and AOA were 42.833 min, 2.699 mg/g, 0.028 mg/g, 0.22 mg/g and 74.46 % of inhibition, respectively. The simulated values were closer to the corresponding experimental values of 95 min, 3.501 m/g, 0.035 mg/g, 0.296 mg/g, and 76.672 % of inhibition respectively.

The overall desirability for hot air, microwave alone, blanch-assisted and microwave-assisted hot air drying were obtained as 0.65, 0.55, 0.62 and 0.58, respectively on the quality of dried moringa leaves. The results were predicted with 95 % confidence in the range of the independent variables and gave optimal hot air temperature of 50 ^{o}C and thickness of 4.79 mm for hot air drying condition. For microwave alone, the drying conditions was 501.1 W with sample thickness of 3 mm. In blanched-assisted hot air drying, the temperature of 70^{o}C and blanching time of 2.58 min. Microwave-assisted hot air drying situations had a temperature of 70°C, microwave power of 270 W and microwave pretreatment time of 3 min. The surface plot of the desirability for the optimum parameters of hot air, microwave alone, blanch and microwave-assisted hot air drying are shown in Figures. 53, 54, 55 and 56 respectively.

At this optimum condition the experiment was repeated to confirm the predicated results. The results were 162.17 min, 3.632 mg/g, 0.042 mg/g, and 0.135 mg/g and 76.318 % of inhibition for DT, AA, TP, FL and the AOA respectively. The confirmed results of microwave alone drying are as follows: DT was 4.8 min, AA was 2.613 mg/g, TP was 0.034 mg/g, FL was 0.11 mg/g and the AOA was 73.797 % of inhibition. Blanch-assisted hot air drying

method confirmation results were as follows: DT was 53.096 min, AA was 2.49 mg/g, BI was 2.067 Abs Unit and the AOA was 67.244 % of inhibition. For microwave-assisted hot air drying method were as follows: DT was 42.833min, AA was 2.699 mg/g, TP was 0.028 mg/g, FL was 0.22 mg/g and AOA 74.46 % of inhibition after the experiment was repeated.

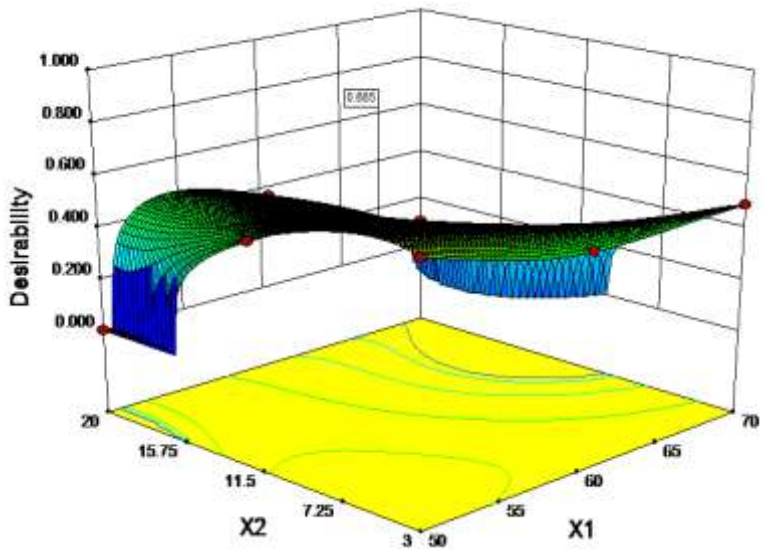

Figure 50: A 3-D plot showing the effect of drying temperatures (X1) and the thicknesses (X2) on desirability index for the optimal drying conditions using hot air alone drying method.

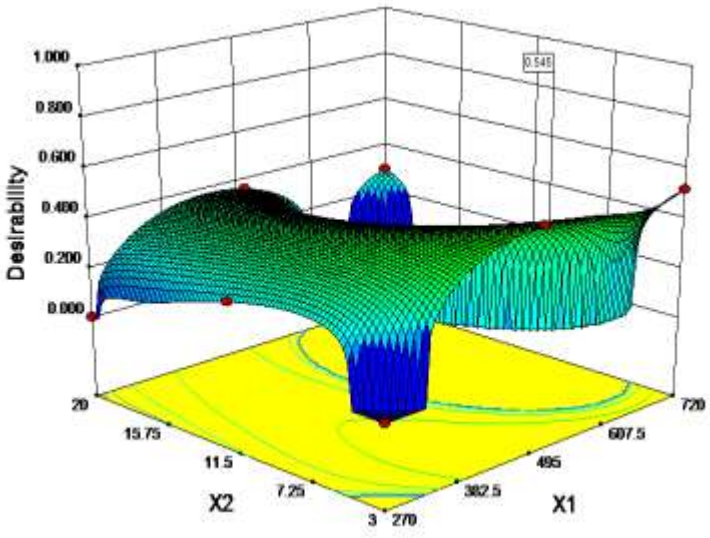

Figure 51: A 3-D plot showing the effect of microwave powers (X1) and the thicknesses (X2) on desirability index for the optimal drying conditions using MW-alone to dry.

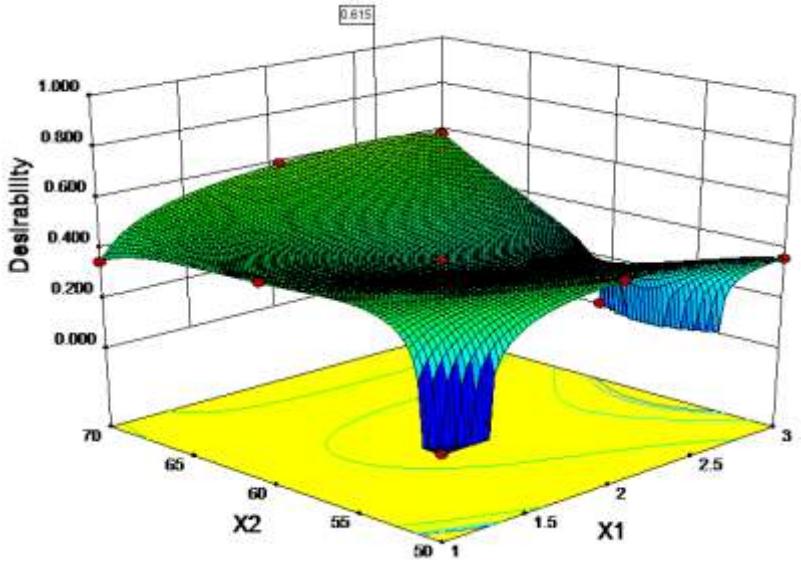

Figure 52: A 3-D plot showing the effect of hot air temperatures (X1) and blanching time (X2) on desirability index for the optimal drying conditions for blanch-assisted.

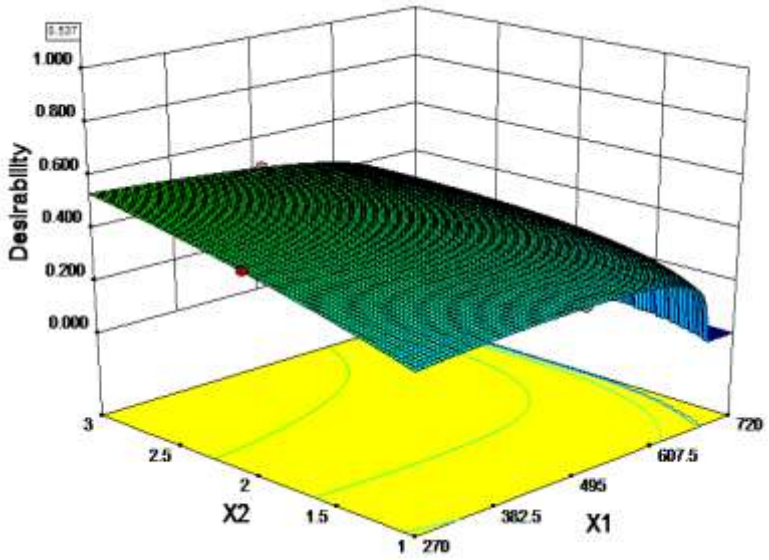

Figure 53: A 3-D plot showing the effect of microwave powers (X1) and microwave time (X2) on desirability index for the optimal drying conditions for MW-assisted.

Effects of Drying Methods on Rehydration Kinetics of Dried Moringa Leaves

Rehydration studies of dried moringa leaves was performed at a temperature of 60^{o}C for the various drying conditions solar, shade, microwave alone, hot air, blanch-assisted, microwave-assisted and direct sun drying.

According to Singh et al. (2008), rehydration at high temperatures occurs rapidly because temperature has effect on the cell wall and tissue. This was also confirmed by Doymaz (2011) for thyme. The thyme was rehydrated at different temperatures of 20, 40 and 60^{o}C and the rapid rehydration ratio occurred at 60^{o}C. The various drying methods studied gave different moisture uptake during rehydration process. The hot air, MW-alone, Blanch-assisted and Mw-assisted were rehydrated using the optimized conditions. The moisture content of dried moringa leaves versus rehydration time is shown in Figure 57.

It can be seen that all curves for the various drying methods studied for the rehydration process had the same rehydration behavior at the beginning. The samples had high water absorption rate at the beginning. The amount of moisture absorbed increased with rehydration time but at a decreasing rate up to saturation level. The most possible cause for the high water uptake at the initial of reconstitution was due to the filling in capillaries on the surface of the samples. As water absorption continues, the soaking rate starts to decline due to the filling of free capillaries and intercellular spaces with water.

In the present study hot air and MW-alone dried samples exhibited the highest rehydration rates and faster water absorption rate compared to other drying methods used. The highest rehydration ratio was 4.83 followed by 4.44 for hot air and MW-alone drying, respectively while the lowest was 4.27 for shade and blanch-assisted drying. Solar, MW-assisted and sun drying obtained 4.49, 4.42 and 4.44 respectively. The results obtained can be justified with the study done by Maskan (2001) on kiwifruits. The rehydration characteristics of kiwi fruits dried using microwave, conventional and combined microwave-hot

air system were compared and reported that MW-assisted and hot air alone dried kiwifruits gave higher rehydration capacities compared to other drying methods. Therefore, in the present study MW-alone and hot air gave the best quality of the dried moringa leaves compared to other drying methods studied. Other researchers (Askari, Emam-Djomeh, & Mousavi, 2006; Nindo, Sun, Wang, Tang, & Powers, 2003; Therdthai & Zhou, 2009) who worked on apple slices, asparagus and mint leaves, respectively found that different drying methods affect rehydration rates. According to Feng and Tang (1998) difference in rehydration rates may be due to changes in the structure of the samples caused by the drying methods used to dry the agricultural materials.

The difference in rehydration ratios range was small observed in Figure 58. Researchers such as Therdthai and Zhou (2009) found that microwave vacuum drying at 1920W and 2240W yielded significantly higher rehydration rates than the hot air drying at 60 and 70^{o}C. The results obtained in the present study might be due to the fact that microwave powers used are lower than those used by Therdthia and Zhou for mint leaves. While Nindo et al. (2003) found that microwave-assisted gave the highest rehydration ratio of asparagus the difference between the lowest and the highest is negligible.

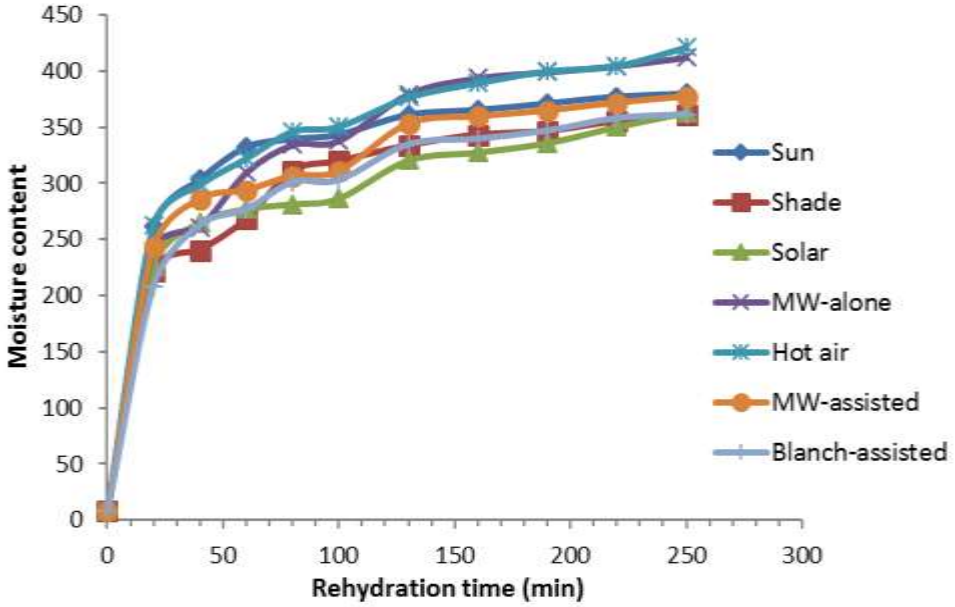

Figure 54: Rehydration rate curves of moringa leaves at various drying methods.

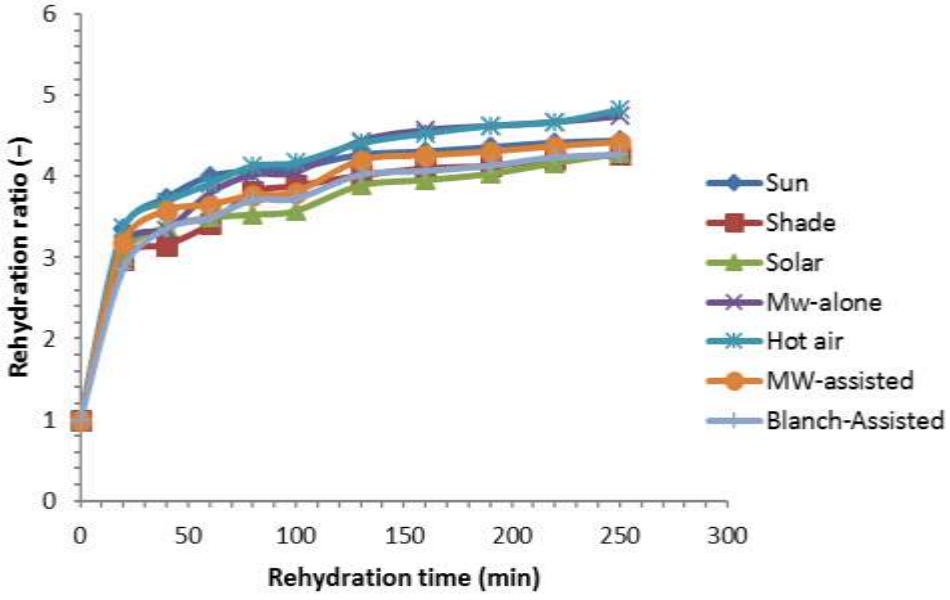

Figure 55: Rehydration ratio of the various drying method

Results Obtained on the Fitting Data for the Rehydrated Moringa Leaves

The values of constant A and B for Peleg`s model were obtained for the rehydration data for each drying method used in the study. The R^2 obtained was 0.9667, χ^2 was 17.685 and for the RMSE was 5.05619. All the different

drying methods studied obtained similar values of R^2, χ^2 and RMSE while constants A and B gave different values. Constant A ranged from 0.258 to 1.342 while constant B ranged from 0.2058 to -4.4792 as it is listed in Table 22. The Sun drying has the lowest constant A and this shows its good fit with a value more close to zero. Weibull model gave the highest value of R^2 of 0.9882, the lowest χ^2 value of 13.6637 and RMSE of 3.6964. Studies have been reported on rehydration kinetics for different foods and reported the good fit obtained by Weibull model for quince (Marabi & Saguy, 2004) and carrot of (Noshad et al., 2012). The kinetic constants of first-order and exponential association models (K and H) are listed in Table 22.

The lowest value of K was 0.003 and was obtained by sun, MW-assisted, hot air and MW-alone drying. Hot air drying method attained the highest R^2 of 0.9713 with the lowest χ^2 of 199.1884 and RMSE of 14.1134 compared to all the other drying methods studies. It was observed that the lowest values of H were obtained by MW-alone and hot air drying method. The highest values of R^2 were observed with lower χ^2 and RMSE. MW-alone attained R^2 of 0.9798, χ^2 of 140.6108 and RMSE of 11.8579 while hot air obtained R^2 of 0.9808, χ^2 of 133.2649 and RMSE of 11.5440. It is evident that hot air drying obtained the highest coefficient compared to the other methods of drying studied. Therefore, the model of Weibull, first order kinetic and exponential association best describes the drying process for hot air and MW-alone drying

Table 20: Values of Parameters the Models used for Different Drying Methods

Model names	Temperatures	Model constants		R^2	X^2	RMSE
Peleg`s	Sun	A = 0.258	B = -2.929	0.9967	17.685	5.05619
	solar	A = 0.853	B = -0.219	0.9967	17.685	5.05619
	shade	A = 0.174	B = -4.792	0.9967	17.685	5.05619
	Mw-assisted	A = 0.710	B = -0.455	0.9967	17.685	5.05619
	Mw-alone	A = 1.342	B = 0.208	0.9967	17.685	5.05619
	Hot air	A = 0.903	B = -0.155	0.9967	17.685	5.05619
	Blanch- assisted	A = 0.986	B = -0.061	0.9967	17.685	5.05619
Weibull equation	Sun	A = 1.378	B = 248.779	0.9977	17.685	4.2054
	solar	A = 1.402	B = 235.573	0.9974	20.2383	4.4992
	shade	A = 1.404	B = 234.173	0.9973	20.5603	4.5344
	Mw-assisted	A = 1.382	B = 246.525	0.9977	18.0718	4.2511
	Mw-alone	A = 1.342	B = 274.257	0.9981	14.34	3.7868
	Hot air	A = 1.334	B = 281.349	0.9982	13.6637	3.6964
	Blanch- assisted	A = 1.404	B = 234.172	0.9973	20.5603	4.5344
First-order kinetic	Sun	k = 0.003		0.9655	239.909	15.489
	solar	k = 0.004		0.9624	261.3645	16.1668
	shade	k = 0.004		0.9620	263.8557	16.2436
	Mw-assisted	k = 0.003		0.9650	243.327	15.5989
	Mw-alone	k = 0.003		0.9702	206.8773	14.3832
	Hot air	k = 0.003		0.9713	199.1884	14.1134

Table 20: Cont'd

	Blanch- assisted	k = 0.004	0.9622	262.8557	16.2128
Exponential association equation	Sun	H = 0.004	0.9751	172.7495	13.1434
	solar	H = 0.004	0.9721	194.0714	13.9309
	shade	H = 0.004	0.9717	196.5676	14.0293
	Mw-assisted	H = 0.004	0.9746	176.1243	13.2712
	Mw-alone	H = 0.003	0.9798	140.6108	11.8579
	Hot air	H = 0.003	0.9808	133.2649	11.5440
	Blanch assisted	H = 0.004	0.9717	196.5676	14.0203

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

In summary, the study was conducted on "The drying kinetics and quality of moringa leaves using microwave alone, solar, sun, shade, hot air, microwave and blanch-assisted hot air drying methods". The effects of solar, sun, shade, hot air, microwave alone, microwave and blanch-assisted hot air drying were investigated on the drying rate, moisture diffusivity, activation energy for moisture removal and quality attributes such as ascorbic acid, total phenolics, antioxidant activity, non-enzymatic browning and flavonoids of moringa leaves. A thin layer drying model for the different drying methods was established. The optimal drying condition of moringa leaves was determined for all the various drying methods used in the study. The rehydration studies and kinetics were investigated for the all the drying methods used in the present study

Conclusions

From the results the following conclusions can be drawn:

1. Hot air drying method gave the best results in minimizing the losses of quality parameters studied compared to the other drying methods used while MW-alone drying was superior in enhancing the drying rate and drying time.
2. An increase in temperature led to a decrease in relative humidity for sun, shade and solar drying conditions.
3. The drying time reduced by 42 %, as the sample thickness decreased from 20 to 3 mm and substantial savings in drying time was achieved when the

hot air temperature was increased to 70^{o}C and sample thickness reduced to 3 mm.

4. The increase in microwave power, hot air temperature and blanching time reduced the drying time of the moringa.
5. The D_{eff} of moringa leaves increased with an increase in hot air temperatures. The thin layer drying models used in the study Midilli et al. model was chosen to be the most suitable drying model to describe the drying behaviors for moringa leaves.
6. The increase in temperature, MW-power, MW pretreatment time, blanching time and a decrease in sample thickness reduced dramatically the retention of AA, TP, AOA and FL while the browning index increased with increase in blanching time and drying temperatures.
7. Reduction in energy consumption was achieved using microwave alone with 99.26 % efficiency.
8. The optimal conditions for processing quality moringa leaves was found to be 50^{o}C and thickness of 4.79 mm for hot air drying condition, As for microwave alone drying conditions was 501.1 W and 3 mm thickness. Blanched-assisted drying was 70^{o}C and 2.58 min blanching time. And for microwave-assisted drying at 70°C, microwave power of 270 W and microwave time of 3 min.
9. Rehydration studies for hot air and MW-alone drying methods gave the best fit of Weibull model, first order kinetic and exponential association equation model while MW assisted drying method gave the best fit for peleg's model.

Recommendations

1. In order to obtain best quality of the dried moringa leaves therefore the leaves should be dried using the following conditions 50^{o}C at the thickness of 4.79 mm and drying it for 167.17 min using hot air drying condition, As for microwave alone drying conditions would be dried using 501.1 W and with 3 mm thickness for 4.8 min. Blanched-assisted drying the samples would be blanched for 2.58 min and died at 70^{o}C for 53.098 min. And for Microwave-assisted drying would be best at 70°C using microwave power of 270W and the microwave pretreatment time would be 3 min and dried for 42.833 min
2. From the study it was recommended for the farmer to use hot air alone or microwave alone depending on his or her interests after drying, if the famer is more interested in drying moringa leaves faster, MW-alone is the best drying method but if he or she is interested in quality attributes after the drying of moringa leaves, hot air alone drying method is the most applicable one.
3. Studies should be done on Verma et al.'s drying model and be compared to Midilli et al.'s model in order to understand which model best fits drying of moringa leaves.
4. Further studies should be carried out on storage of the optimized results of moringa leaves and determination of microbial load should be performed.

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APPENDICES

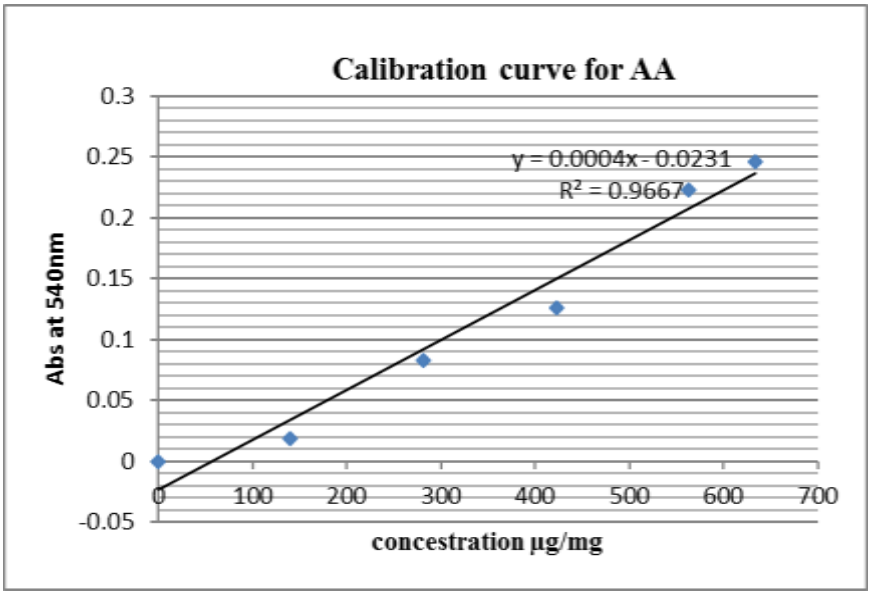
APPENDIX A

Table A1: *Effect of Temperature and Pretreatment Time on Effective Moisture Diffusivity and Their Coefficient of Determination*

RUN	T	MP(Watts)	PT	Deff(min^2/s)	R^2
1	70	495	3	2.05×10^{-9}	0.9843
2	70	720	2	3.13×10^{-9}	0.9393
3	60	495	2	1.05×10^{-9}	0.9256
4	50	270	2	0.836×10^{-9}	0.8914
5	70	270	2	1.009×10^{-9}	0.9393
6	60	270	1	0.447×10^{-9}	0.9913
7	60	495	2	9.47×10^{-9}	0.9647
8	60	270	3	0.947×10^{-9}	0.9469
9	60	495	2	1.25×10^{-9}	0.9205
10	50	495	1	0.771×10^{-9}	0.9255
11	60	720	3	0.869×10^{-9}	0.7881
12	60	720	1	0.961×10^{-9}	0.9689
13	50	495	3	1.08×10^{-9}	0.9632
14	50	720	2	37.5×10^{-9}	0.9170
15	70	495	1	1.05×10^{-9}	0.9735

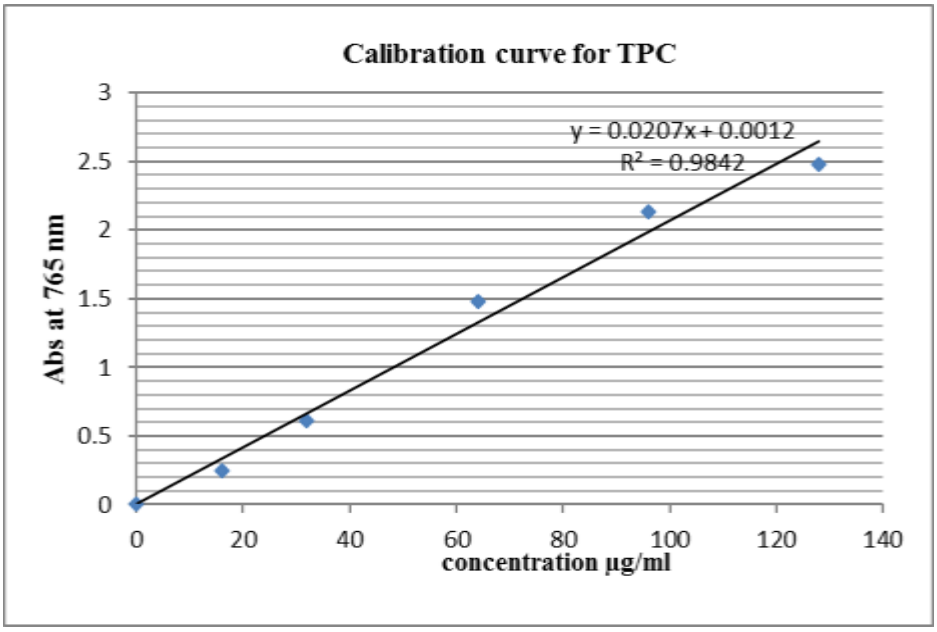
Table A2: *Effect of Temperature and Blanching Time on Effective Moisture Diffusivity and Their Coefficient of Determination*

Run	Temp	Bt	Deff (min^2/s)	R^2
1	70	1	0.833×10^{-9}	0.9114
2	60	3	0.663×10^{-9}	0.9090
3	60	2	0.672×10^{-9}	0.9720
4	70	3	1.16×10^{-9}	0.9702
5	60	1	0.407×10^{-9}	0.9285
6	60	2	0.819×10^{-9}	0.9406
7	60	2	0.606×10^{-9}	0.9270
8	50	1	0.287×10^{-9}	0.9572
9	50	2	0.278×10^{-9}	0.8858
10	50	3	0.0403×10^{-9}	0.9312
11	70	2	1.24×10^{-9}	0.9100

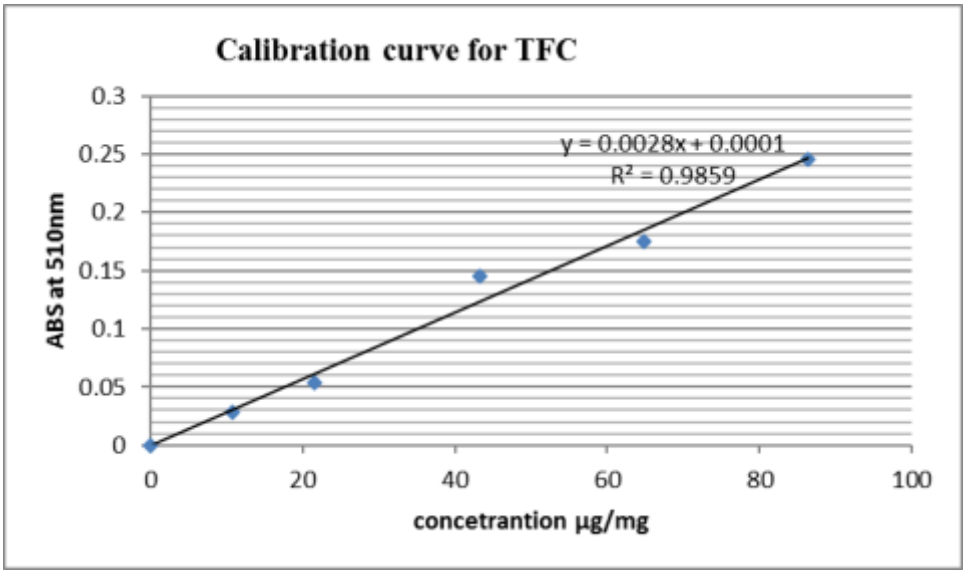


APPENDIX B

Graph of standard calibration curve for ascorbic acid.



Appendix B2: Graph of standard calibration curve for total phenolic content.



Appendix B3: Graph of standard calibration curve for total flavonoid content.

APPENDIX C

Table C1: *The Fitness of Different Models at 60^{o}C for Hot air Drying*

Model name	L*	Model constants				R^2	X^2	RMSE
Page								
	3	k = 0.003	n = 1.387			0.9819	0.0019	0.0439
	11.5	k = 0.007	n = 1.257			0.9951	0.0005	0.0231
	20	k = 0.003	n = 1.288			0.9897	0.0011	0.0324
Henderson and pabis								
	3	k = 0.015	a = 1.065			0.9588	0.0044	0.0662
	11.5	k = 0.020	a = 1.048			0.9842	0.0017	0.0416
	20	k = 0.013	a = 1.050			0.9746	0.0026	0.0510
Logarithmic								
	3	k = 0.004	a = 2.169	c = -1.181		0.9971	0.0003	0.0183
	11.5	k = 0.015	a = 1.145	c = -0.136		0.9975	0.0003	0.0169
	20	k = 0.008	a = 1.263	c = -0.271		0.9980	0.0002	0.0145
Midilli et al.								
	3	k = 0.011	a = 1.001	n = 0.859	b= -0.003	0.9971	0.0004	0.0191
	11.5	k = 0.009	a = 0.984	n = 1.168	b= 0.000	0.9981	0.0002	0.0152
	20	k = 0.001	a = -0.001	n = -0.010	b= 1.286	0.9990	0.0001	0.0105

Appendix C2

Table C2: *The Fitness of Different Models at 495W for MW-Alone Drying*

Model name	L*	Model constants				R^2	X^2	RMSE
Page	3	k = 0.302	n = 1.852			0.9994	0.0001	0.0088
	11.5	k = 0.284	n = 1.630			0.9977	0.0003	0.0183
	20	k = 0.64	n = 1.848			0.9986	0.0002	0.0141
Henderson and pabis								
	3	k = 0.591	a = 1.146			0.9462	0.0076	0.0873
	11.5	k = 0.514	a = 1.134			0.9692	0.0045	0.0673
	20	k = 0.254	a = 1.148			0.9475	0.0075	0.0868
Logarithmic								
	3	k = 0.324	a = 1.509	c = -0.417		0.9782	0.0033	0.0577
	11.5	k = 0.402	a = 1.233	c = -0.129		0.9800	0.0031	0.0561
	20	k = 0.149	a = 1.444	c = -0.963		0.9768	0.0036	0.0598
Midilli et al.								
	3	k = -0.004	a = 1.063	b= -0.367	n = 3.176	0.9913	0.0015	0.0381
	11.5	k = 1.010	a = 0.294	b= 1.622	n = 0.002	0.9977	0.0004	0.0196
	20	k = 0.058	a = 0.988	b= 0.000	n = 1.907	0.9986	0.0002	0.0152

Appendix C3

Table C3: *The Various Drying Models for Blanch-assisted Drying at 60^{o}C.*

Model name	t*	Model constants			R^2	X^2	RMSE
Page	1	k = 0.008	n = 1.192		0.9890	0.0011	0.0338
	2	k = 0.014	n = 1.237		0.9946	0.0006	0.0236
	3	k = 0.009	n = 1.349		0.9841	0.0018	0.0421
Henderson and pabis							
	1	k = 0.019	a = 1.026		0.9815	0.0019	0.0439
	2	k = 0.034	a = 1.050		0.9851	0.0016	0.0394
	3	k = 0.034	a = 1.059		0.9642	0.004	0.0632
Logarithmic							
	1	k = 0.012	a = 1.180	c = -0.199	0.9972	0.0003	0.0175
	2	k = 0.025	a = 1.139	c = -0.129	0.9978	0.0002	0.0158
	3	k = 0.014	a = 1.601	c = -0.611	0.9979	0.0003	0.0183
Midilli et al.							
	1	k = 0.995	a = -0.001	n = -0.014 b= 1.281	0.9972	0.0003	0.0183
	2	k = 0.017	a = 0.986	n = 1.144 b= -0.001	0.9984	0.0003	0.0137
	3	k = 0.997	a = 0.022	n = -0.004 b= 0.961	0.9979	0.0003	0.0165

Appendix C4

Table C4: *The Various Drying Models Fitted for MW-assisted Drying at 495W*

Model name	T	Mw*	Model constants				R^2	X^2	RMSE
Page									
	50	1	k = 0.039	n = 0.979			0.9859	0.0014	0.0377
	50	3	k = 0.359	n = 0.548			0.9900	0.0008	0.0277
	60	2	k = 0.150	n = 0.745			0.9880	0.0011	0.0338
	70	1	k = 0.046	n = 1.056			0.9928	0.0009	0.0303
	70	3	k = 0.319	n = 0.711			0.9855	0.0013	0.0357
Henderson and pabis									
	50	1	k = 0.035	a = 0.975			0.9864	0.0014	0.0370
	50	3	k =0.103	a = 0. 863			0.9200	0.0062	0.0784
	60	2	k = 0.063	a = 0.902			0.9777	0.0021	0.0463
	70	1	k = 0.054	a = 0.991			0.9921	0.0010	0.0316
	70	3	k = 0.168	a = 0.921			0.9618	0.0034	0.0580
Logarithmic									
	50	1	k = 0.029	a = 1.026	c = -0.074		0.9911	0.0009	0.0307
	50	3	k = 0.160	a = 0.872	c = 0.065		0.9440	0.0047	0.0683
	60	2	k = 0.064	a = 0.900	c = 0.004		0.9776	0.0023	0.0480
	70	1	k = 0.044	a = 1.056	c = -0.083		0.9973	0.004	0.0191
	70	3	k = 0.203	a = 0.905	c = 0.046		0.9690	0.0030	0.0548
Midilli et al.									
	50	1	k = 0.061	a = 1.002	n = 0.796	b= -0.001	0.9942	0.0006	0.0254
	50	3	k = 0.421	a = 1.001	n = 0.450	b= -0.001	0.9950	0.0005	0.0213
	60	2	k = 0.188	a = 1.000	n = 0.626	b= -0.001	0.9955	0.0005	0.0224
	70	1	k = 0.059	a = 0.987	n = 0.923	b= -0.002	0.9973	0.0004	0.0200
	70	3	k = 0.365	a = 0.999	n = 0.549	b= -0.003	0.9896	0.0011	0.0333