DESIGN OF A COMBINED MICROWAVE AND HOT AIR DRYING SYSTEM FOR AGRICULTURAL PRODUCTS

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ABSTRACT
This work concerns the design of a combined microwave and a conventional hot air drying system for application in agricultural products. Storage stability of dry food products depend on the state at which the drying process is finished. Because of undesirable changes in the quality of dried food products due to high temperature beyond food optimum drying temperature of 60°C and long drying time, microwave heating capabilities were combined with the heating capabilities of the conventional hot air system to develop a time and cost effective food drying method. This will improve the quality of dried food and yet retain their rehydration abilities. The work observed the effect of microwave drying system, the effect of conventional hot air drying system, and the effect of both drying methods on food items. The Combined method not only solved the problem of non-uniform products drying and prolonged drying period, but also improves the drying efficiency and quality of dried grain food such as rice, beans, and maize.

KEYWORDS: Microwave drying, conventional hot air heating, hybrid drying, moisture contents

1. INTRODUCTION

Agricultural products such as grains, fruits and vegetables can last very long on preservation if they are properly dried (Adesina et al., 2019). Drying involves dehydration or removal of water contents from the products which can facilitate decomposing and damage. The process of drying brings about microbial stability and is indispensable in many food industry sectors because of the increased shelf-life of the product, reduced packaging cost, lower shipping weights and environmental advantages (Lewicki, 2006).

As a result of trial and error experience and research done over the years, today we have many drying options such as hot air dryers, compressed air dryers, infrared dryers, microwave dryers, vacuum dryers, Freeze-drying and desiccant dryers. Although all have the same core function of removing moisture from a material but no single one provides a complete solution to all drying requirements (Shaffer and Jamison, 2017).

According to Dehnad and Jafari (2012), the combination of microwave drying and the conventional hot air drying system has proved to be the best drying method for food items such as grains and tubers. The design was necessitated as a result of processes involved in dewatering and its adverse effect on food items. Evaporation of water at very high temperature beyond food optimum drying temperature of 60°C can cause chemical, physical and biological changes in food. Also, poor handling can bring about food contamination and reduce the nutritional quality. In this regard, there should be proper drying method selection for better food processing, moreover, drying where properly used can result in unique properties that are not achievable by other technological procedures. Today's consumer expectation for better quality, safety and nutritional value drives research and improvement of drying technologies (Xiaoyan et al, 2015).

The production of safe and nutritious food is the responsibility of the producer. Therefore, during designing of a dehydration process, the safety of food must be assured. The nutritional value and quality attributes must meet consumer expectations. In addition to these, their properties must agree with the requirements of further processing. The most important way to achieve these qualities and reduce the adverse influence of drying on food quality is to design carefully a hybrid process for drying the food items (Hussein et al., 2016).

2. DRYING SYSTEMS

The drying methods considered in this work are conventional hot air drying system, Microwave drying system and the combined Microwave and conventional hot air drying system (hybrid drying system).

2.1 Hot Air Drying

In conventional hot air drying, heat is transferred to the surface of the material by conduction, convection or radiation and into the interior of the material by thermal conduction. Moisture is initially flashed off from the surface and the remaining water inside the material diffuses to the surface. The diffusion rate is limited, requiring high external temperatures to generate the required temperature differences for proper drying (Jones, 2017). Drying of tuber and grains such as Rice, Beans and Maize using high temperature and for long period can result in reduced quality of the final dried products. The rate of grain drying is increased as the temperature of the drying air is raised. However, the grain will be damaged if the temperature is too high. Damage is more likely to occur when the grain is dry or nearly dry. As the grain becomes drier, the moisture release slows down and the grain temperature increases. By the time the grain is dry, it is possible that some of it will have reached the same temperature as the drying air. To prevent grain damage, it is important that the maximum air temperature does not exceed the maximum allowable temperature of the grain being handled. Temperature sensing should be properly done as the thermometer must be located to indicate the highest temperature in the air plenum (Friesen, 1980).

Figure 1 shows the schematic diagram of the hot air drying equipment, here the ambient air is passed through the air inlet for heating by a controlled heater system. The heated ambient air with very low moisture content is blown across the trays containing the product and this absorbs water molecules from the particles of the food items and carry them away following the air direction. (Maskan, 2000). Depending on the system design the air may be in vented or recycled. This design system is a vented method as hot air is vent out through the air outlet.

The major disadvantages of the hot air drying system are the low energy efficiency and lengthy period of drying time. Because of the low thermal heat conductivity of food materials in this period, heat transfer to the inner sections of the food during conventional heating is limited. The desire to eliminate this problem, prevent significant food quality loss and to achieve fast and effective thermal processing, resulted in the alternative option of combined or a hybrid method for food processing.

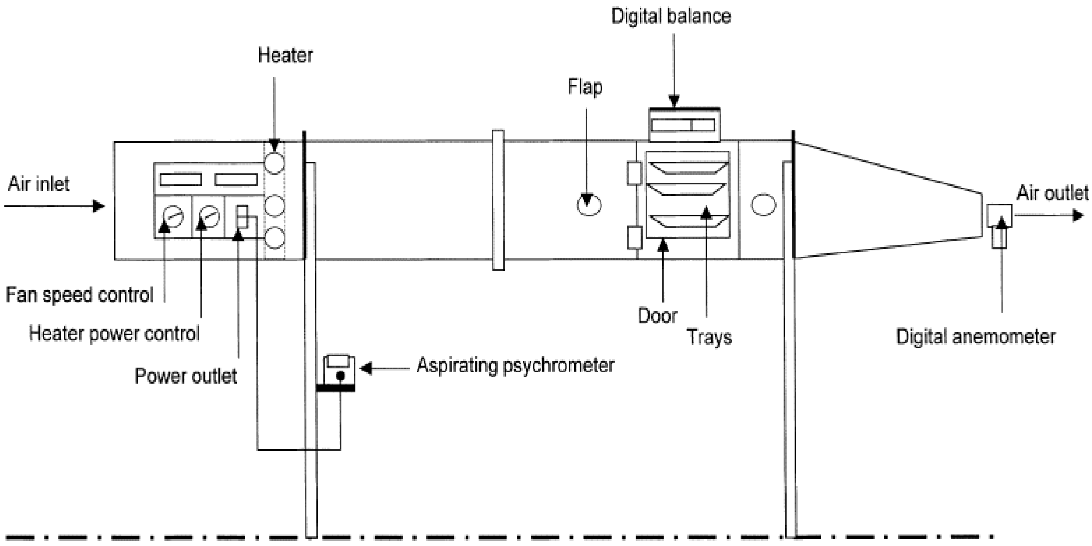

Figure 1: Schematic diagram of the hot air drying equipment. Source: (Maskan, 2000).

2.2 Microwave Drying

Microwaves are electromagnetic waves in the frequency range of 300 MHz to 300 GHz, with wavelength varying from 1 millimeter to 1 meter. They are not forms of heat but rather forms of energy that are manifested as heat through their interaction with materials. Microwave drying is rapid, more uniform and energy efficient as compared with conventional hot air drying system. Here the removal of moisture is accelerated and the transfer of heat to the solid is slowed down significantly due to the absence of convection. Because the waves can penetrate directly into the material, heating is volumetric (from the inside out) and provides fast and uniform heating throughout the entire product. Microwave penetrates into the object at the speed of light, so it allows rapid response (Okeke *et al.*, 2014).

The quick energy absorption of water molecules results in rapid evaporation of water which brings about higher drying rates of the food and creating an outward flux of rapidly escaping vapor. In addition to improving the rate of drying, this outward flux can help to prevent the shrinkage of tissue structure, which prevails in most conventional hot air drying techniques. Hence better rehydration characteristics may be expected in microwave dried products (Mohd *et al.*, 2013). Figure 2 shows a simple system of microwave oven consisting of a high power source, a wave guide feed, and the oven cavity. The source is generally a magnetron tube operating at 2.45GHZ. Although 915MHZ is sometimes used when greater penetration is desired, power output is usually between 500 and 1500W. The oven cavity has electrically large metallic walls. To reduce the effect of uneven heating caused by standing waves in the oven, a wave spreader, which is a metallic fan blade, is used to stir the electromagnetic wave inside the cavity for uniform wave distribution. Furthermore, to enhance more drying uniformity, the food items may be kept on a controlled rotating plate.

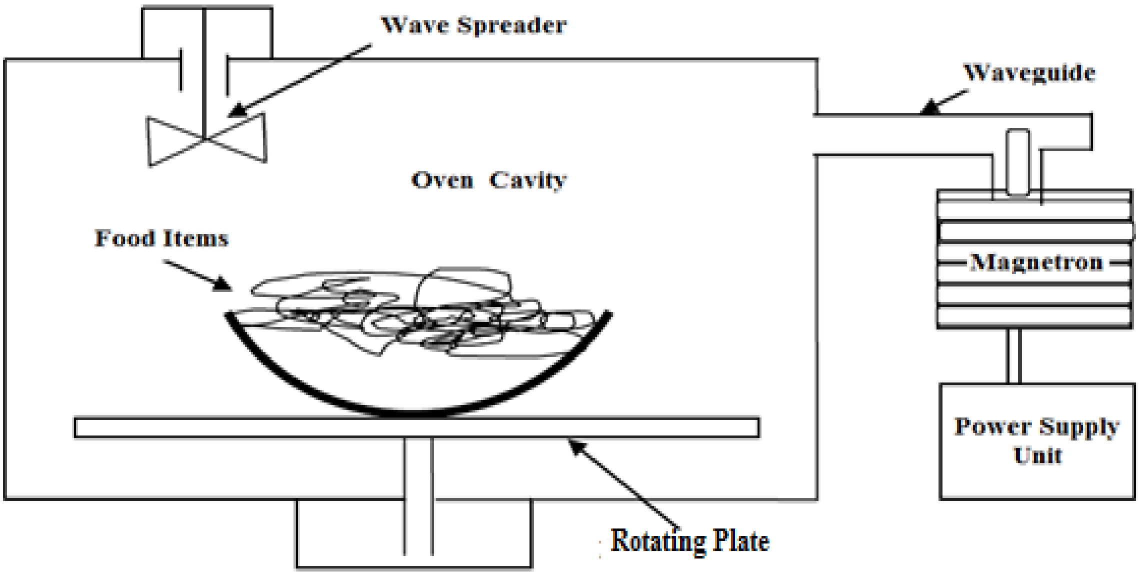

Figure 2: Structure of Microwave heating equipment. Source: (Okeke *et al*., 2014).

2.3 The Hybrid System

The hybrid drying system is the combination of the microwave and the conventional hot air drying equipment. The microwave energy in combination with conventional energy sources makes it possible to control the drying process and more precisely to obtain greater yields and better quality products in the shortest possible time. Drying control in the hybrid system is inevitable because of the several stages during drying of food materials which ranges from increasing rate at the beginning, constant rate period in the middle, and falling rate period at the end. Microwave-assisted combination drying is a rapid dehydration technique that can be applied to specific foods such as fruits and vegetables (Wang, 2008). Figure 3a shows the microwave effect on material, figure 3b shows the effect of hot air and figure 3c shows the combined effect of microwave and conventional hot air in the hybrid dryer on the same material.

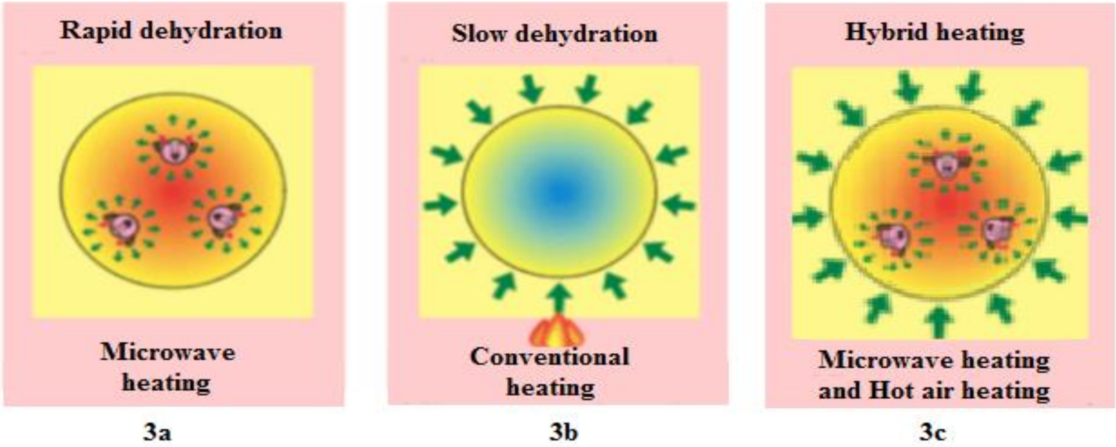

Figure 3: Product heating. Source: (Okeke *et al*., 2014).

3. METHODS

The design/structure of the hybrid drying system is shown in figure 4. The A section is the main system containing the heater B, which is expanded in section B. The magnetron tube is activated to operate at 2.45GHZ for domestic or 915MHZ for industrial microwaves. The wave spreader distributes the wave evenly throughout the oven cavity. The load cell may be motorized to enhance even microwave distribution. V_1, V_2 and V_3 are valves controlling the flow and direction of air movement. Turning ON valves 1, 2, and 3 and with help of the blower, fresh air enters the chamber and blows across the food trays in the oven cavity which is already under the influence of microwave heating. The valve V_2 is closed and the system of heater B is then put on to heat up the air, which is blown across the food trays through the inlet 1, outlet 2 and round through the chamber. The Anemometer in the vent of the heater monitors the air speed while the Psychrometer monitors the air humidity. If the air humidity is high due to moisture absorption, valve 1 is closed and the air is exuded by the help of the damper. With the help of the valves, blower and damper, the air can either be vented or recycled. The control of air temperature and humidity results in a well-controlled drying system which assures required product quality.

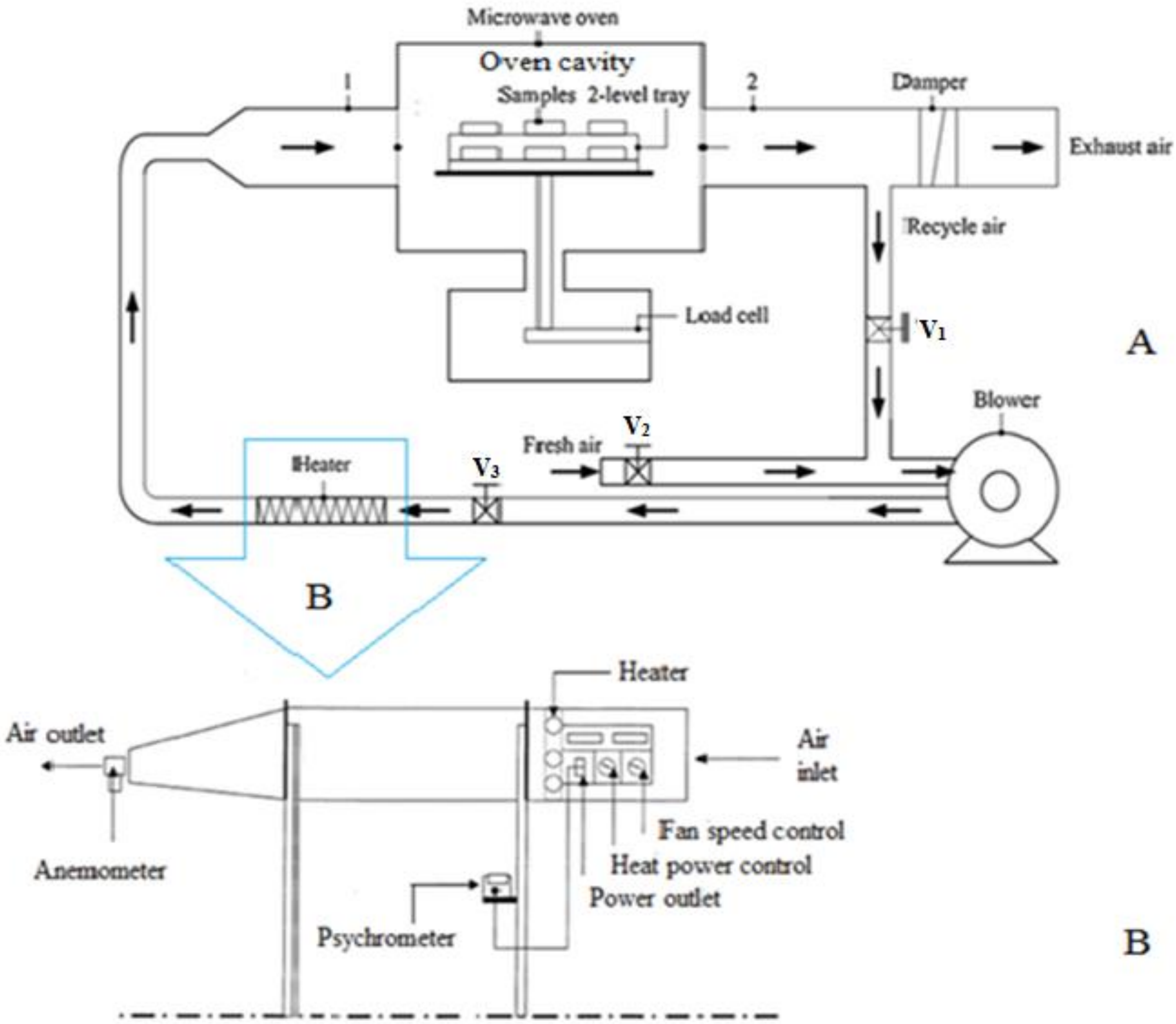

Figure 4: The Hybrid design for combined microwave and hot air drying system

3.1 Design Calculation of a Microwave and Hot Air Drying System for Agricultural Products.

The components of the system can be sourced locally. To conserve heat in the microwave in order to achieve temperature control, batts fiberglass was used as lagging and thermostat for the regulation. The microwave is expected to supply heat energy that will be relatively cheap. The power consumption is 500 – 1500 watts at 220 volts of 50Hz. The body of the microwave and hot air drying system was designed according to design specification.

3.2 Design Calculation of Heating Element

The design is based on a voltage of 220 volts with power consumption of 1500 watts.

Following ohm's law, we have that;

$$V = IR \qquad (1)$$

Where: V = Voltage in volts (V)

I = Current in ampere (A)

R = Resistance of heating element in ohm (Ω)

The resistance of the heating element can be obtained using the relationship

$$R = \frac{\rho L}{A} \qquad (2)$$

Where ρ = resistivity (Ωm)

L = length of wire (m)

A = Cross Sectional Area (m^2)

The power consumption P = IV (3)

Where I and V are as defined in equation 1

P = power consumption in watts (W)

From equation 1

$$I = {}^{V}/_{R} \qquad (4)$$

Substituting equation 1 into equation 3

$$P = IV = P = \left(\frac{V}{R}\right)V = \frac{V^2}{R} \qquad (5)$$

If we substitute the values given above into equation 5 we have that,

$$R = \frac{220^2}{1500} = 32.27\ \Omega$$

Also substituting the values into equation 4 we have that,

$$I = \frac{220}{32.27} = 6.8A$$

Therefore based on specification, the microwave electrical quantities are

$$P = 1500w,\ R = 32.27\Omega,\ I = 6.8A\ \text{and}\ V = 220V$$

3.3 Calculation of Electrical Heating

The values of electric heating is calculated using Joules law which is given by the equation.

$$H = I^2RT\ \text{Joules} \qquad (6)$$

Where H = Heat in Joules (J)

I = Current in ampere (A)

R = Resistance in ohms (Ω)

T = Time in seconds (s)

The heat H can be expressed in term of VIT or $\frac{V^2}{R}$ (Joules)

The mechanical equivalent of the heat produced can be expressed in calories. Since

1 calories = 4.2 Joules. Then, $H = \frac{I^2RT}{4.2}$ (7)

3.4 The Efficiency of the Microwave Oven

The efficiency of the microwave can be calculated as:

$$\eta = \frac{\text{Energy Absrbed}}{\text{Energy released}} \tag{8}$$

$$\eta = \frac{H_w + H_c + H_d}{H_r} \tag{9}$$

Where H_w = Heat used in raising temperature of the walls of the microwave oven.

H_c = Heat used in raising temperature of the container in calories.

H_d = Escape of heat due to opening of door.

H_r = Heat released by the microwave oven element and can be obtained as:

$$H_r = MxS(T_2 - T_1) \tag{10}$$

Where M = Mass of the element in kilogram

S = Specific heat capacity in joules per kilogram Kelvin ($JKg^{-1}K^{-1}$)

$T_2 - T_1$ = Change in temperature in seconds

Also, the Heat used in raising temperature of the microwave oven wall is given as:

$$H_w = \frac{KA}{t}(T_1 - T_2)w/m^o c \tag{11}$$

Where t = thickness of walls in (m)

A = area of wall in (m^2)

T_1 and T_2 = inside and outside temperatures respectively

K = thermal conductivity in Watts per meter-Kelvin

The heat absorbed by container (H_c) is obtained in that same way as heat absorbed by oven walls (H_w). Heat loss due to opening the door (H_d) is difficult to calculate because it depends on the operator's frequency of opening the oven door. However, it is assumed that the door is always kept closed.

Therefore, the relationship between heat produced electrically, the heat absorbed mechanically and useful heat can be determined with the expression:

$$\frac{VIT}{J} x\, \eta = M\, x\, S\, x\, (T_2 - T_1) \tag{12}$$

Electrical heat energy converted = Absorbed useful mechanical energy converted into heat energy.

Where V = voltage in volts

I = current in amperes
J = Joules
η = efficiency
M = mass of food item
S = specific heat
T = temperature

3.5 Dimension of the Microwave

The dimension of the microwave oven was chosen, taken into consideration the size of the agricultural product, number of the agricultural product to be dried. The microwave can dry a very large agricultural product at a given time.

3.6 The Outside Dimensions of the Microwave

L_o = length = 180cm (1.8m)

W_o = width = 150cm (1.5m)

H_o = height = 75cm (0.75m)

A lagging space of 10cm (0.1m) was made on all sides of the microwave to prevent heat loss.

3.7 The inside Dimensions of the Microwave

L_1 = length = 170cm (1.7m)

W_1 = width = 140cm (1.4m)

H_1 = height = 66cm (0.66m)

The volume of the microwave (drying compartment was calculated as:

Volume = length x width x height

$= (1.7 \times 1.4 \times 0.66) = 157.08cm^3$ or $1.5708m^3$

The remaining compartment was used to house the heating element and the control circuit.

4 RESULT AND DISCUSSION

In this design, the system will produce a maximum power of 1500W, when a voltage of 220V and a current of 1.68A is applied to the system. The designed system specification will generate a daily watt-hour of 18000Wh, when it is allowed to run in 12 hours. During drying, most of the changes incurred to the material by dehydration are disadvantageous to quality of the final product. However, the changes can be minimized by appropriate design of the drying process. Here the applications of microwave heating technology and the hot air conventional heating method for processing foods have been reviewed. The idea of combined fast microwave heating and the conventional hot air drying proved to be advantageous to drying agricultural tuber and grain products. The hybrid dryer technology approach offers distinct advantages in food drying and processing such as short processing time which will not exceed twelve hours. This will lead to high energy consumption efficiency and increase in production rate, as well as saving time and costs. With hybrid method, food properties such as color, ascorbic acid, shrinkage, and texture are maintained/preserved even after drying.

5. CONCLUSION

All agricultural products need to be stored to avoid scarcity due to season and climatic effect on agricultural harvest. For proper storage of these items, they need to be dried to dehydrate moisture that may facilitate decay. More importantly, proper drying prolongs preservation. However, the drying method adopted may affect the finished product.

The design of conventional hot air drying system and that of microwave heating system on grain food items were made. Also the design considered the effect of a combined microwave and hot air drying method. Theoretical evidence showed that the combined microwave and hot air drying method is more efficient and effective in drying grain food items and yet retain their rehydration abilities.

REFERENCES

Maskan M., (2000). Microwave/air and microwave finish drying of banana. Journal of Food Engineering, Volume 44, Pp71 -78.

Okeke C. A., Abioye A. E. and Omosun Y, (2014). Microwave Heating Applications in Food Processing. Journal of Electrical and Electronics Engineering. Volume 9, Issue 4. PP 29-34.

Lewicki P. P., (2006). Design of hot air drying for better foods. Trends in Food Science & Technology. Volume 17, Issue 4, Pp153–163.

Shaffer R. and Jamison J., (2017). Technology Bulletin, Conair Drying expert www.conairgroup.com. Pp1-5. Accessed on 03/07/2017.

Jones S., (2017). Comparing Microwave to Conventional Heating and Drying Systems. Marion Mixers. (http://www.chemicalprocessing.com/assets/wp_downloads/pdf/comparing-microwave-to-covnetional-heating-drying-systems-v2.pdf) Pp1-5. Accessed on 03/07/2017.

Friesen O.H., (1980). Heated-air grain dryers. A federal/provincial publication, Information Services, Agriculture Canada. Pp1-27.

Wang L., (2008). Energy Efficiency and Management in Food Processing Facilities. CRC Press Taylor & Francis Group, New York. Pp338-340.

Adesina J. M., Nameirakpam B., Dinabandhu S. and Yallappa R., (2019). Traditional methods of food grains preservation and storage in Nigeria and India. ELSEVIER article on Annals of Agricultural Sciences. Pp1-10.

Xiaoyan Z., Chao Z., Jiangchangmei L., Yubin W. and Yue M., (2015). Drying temperature affect the quality of dehydrated mint. 7th IEEE International Conference on Information Technology in Medicine and Education. Pp456-459.

Hussein J. B., Usman M. A. and Filli K. B., (2016). Effect of Hybrid Solar Drying Method on the Functional and Sensory Properties of Tomato. American Journal of Food Science and Technology, Vol. 4, No. 5, Pp141-148.

Dehnad D. and Jafari S. M., (2012). Combined microwave drying with other drying methods. The First Middle East Drying Conference: Shahid Chamran University of Ahvaz, Iran. Pp1-6.

Mohd R. T., Ida I. M., Chee L. N. and Pang S. N., (2013). Drying Kinetics, Rehydration Characteristics and Sensory Evaluation of Microwave Vacuum and Convective Hot Air Dehydrated Jackfruit Bulbs. Jurnal Teknologi (Sciences & Engineering) Pp51–57.