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Effects of Different Drying Condition on Microstructure and Drying Characteristics of Ginger

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Abstract: Ginger and its products have marked its importance in most households and industries in Nigeria. Ginger is always harvested with high moisture content and because of this, it is highly perishable. Farmers have tried various means to reduce moisture content to acceptable limit for proper handling. Drying methods that are being used may affect the major essential ingredients if not properly controlled. This study investigates effects of three different drying methods (open sun, solar dryer and electric dryer) on the microstructure of ginger sliced into 10 mm thickness longitudinally. Solar intensity, humidity, temperature (inner ginger and carbinet), weight reduction initial and final moisture content, drying time and microstructure (before and after drying for the three methods) were measured. The average solar intensity was found to be 168.52 W/m^2. The average drying temperatures and weight reduction for open sun, solar and electric dryers are 45^{o}C, 51^{o}C and 58^{o}C and 0.329 kg, 0.339 kg and 0.341 kg respectively. Also the final moisture contents are 19, 12 and 10% for sun drying, solar drying and electric dryer respectively. It took the average time of 12 h, 6 days and 9 days to dry ginger to safe moisture content in electric, solar and open sun dryer. The physical appearance for the drying products of the three dryer shows that open sun drying was better. Microscopic evaluation of the dried products show that electric drying method has the highest bond breaking capacity and consequently least essential nutrient trapping ability followed by solar and open sun. Electric dryer was faster and less contaminated, therefore, it saves energy and can be used for mass production if properly managed.

Keyword: Solar Energy, Electric, Dryer, Microstructure, Sun, Ginger

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I. INTRODUCTION

Ginger (Zingiber officinale) is a tropical spice and is cultivated in countries such as India, China, Japan, Indonesia, Australia, Nigeria and West Indies islands[1]. In Nigeria, it is grown majorly in states such as Gombe, Nasarawa and Kaduna state which is responsible for about 95% of the country's total production [2]. It is usually planted at the start of the year and it is generally harvested after 9-11 month of planting. Ginger grown in different parts of the country (Nigeria) varies considerably in its intrinsic properties and its suitability for processing. The important quality parameters of ginger are its fibre content, volatile oil content and non-volatile ether extract. It has constituent elements such as oleoresin, moisture (water) and essential oils such as zingiberene, limonene, linalool, geraniol and nerolidol which were obtained from gas chromatography [3]. Ginger and its products are useful to both households and industries and have varied applications in culinary preparation, bakery products, toiletry products, perfume industries, meat products, wine, and soft drinks making, spice and medicinal purposes [4].

Harvested ginger is mostly fresh but the market-embraced form of ginger is dried ginger. It comes in various forms such as powdered, candied and crystallized. Fresh ginger harvested from the farm undergoes a moisture reduction process known as drying. Drying reduces the moisture content of ginger to about 7-12% so that yeast, bacteria and mould cannot grow up and spoil it, during storage[5,6,7] It also reduces the cost of packaging, handling and transportation. Drying occurs as a result of vaporization of moisture in fresh ginger. Drying is regarded as a simultaneous heat and mass transfer energy intensive operation used as a food preservation technique. Adequate drying helps to preserve the flavour, texture, and colour of the food, which leads to a better quality product. Olaoye *et al.*, (2014) [8]studied effects of geometry on drying rate properties of ginger (peeled and unpeeled, rectangular and cylindrical shape) under open sun, solar and hybrid dryers and found that cylindrical shape retain more oil than rectangular shape. [5]Eze and Agbo (2011) found out that solar dried unpeeled ginger contain 7.0% moisture which was within the standard (6-9%) acceptable limits as compare to open dried ginger attaining 17% moisture content. Heat may be supplied by convection, conduction, radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field.

However, over 85% of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium and over 99% of its applications involve removal of water [9].

There are various post-harvest methods of moisture removal from ginger and it can be classified into two; traditional and modern methods. Traditionally, open air drying is the most common method for post-harvest preservation (for most farmers in Nigeria) because it is a natural occurring method for the conservation of the qualities of the plant material. However, due to methodical defects such pest infestation, scale of production, drying duration etc., new techniques of drying became necessary. Modern methods are commercial energy based drying techniques of moisture removal. It provided solutions to the aforementioned difficulties encountered in the use of traditional methods. These techniques employs drying processes such as forced convective drying, fluidized bed drying, heat pump drying, microwave drying, freeze drying etc. to dry agricultural products to a safe moisture content.

With the introduction of post-harvest modern techniques comes need for quality control of ginger product obtained from each of these methods. Rate of dehydration is an important quality parameter for dried products. During these processes different microstructure can be obtained showing changes to the cell structure [10]. Therefore, to have knowledge of what happens, there is the need to do microstructural examination of the dried products under different drying methods with the aid of microscope.

The objective of this study is to determine the drying characteristics of ginger samples dried using different drying methods, to investigate the effects of the methods on physical appearance of the products, and to analyse the effects of drying methods on ginger microstructure using microscope.

II. METHODOLOGY

Material preparation

8.50 kg fresh and mature ginger used was procured from Waso market, Ogbomoso, Oyo State, Nigeria. It was washed in cold water to remove soil and dust particles, after which the fingers washed ginger rhizomes, was sliced with knives longitudinally to a uniform thickness of 10 mm. Initial moisture content of batch of ginger bought was determined using oven method and it was found to be 78.3% wet basis. The sample was divided into three for the three experimental procedures.

Physical properties (such as colour, texture, surface roughness etc.) of fresh sliced ginger were observed before the commencement of drying.

Experimental procedure

Drying was performed through three methods which are open sun drying, solar dryer and electric dryer. Both solar dyer and electric dryer were locally fabricated. In the experiment 0.45 kg of samples were placed in the open sun, solar dryer and electric dryer. Moisture loss of the sample was recorded as a result of weight reduction at one hour interval using digital balance with 0.01 g precision. The three drying process was repeated three times and continue until the moisture content of the samples is constant. The air flowing inside the solar dryer was due to natural convection process while the air flow in electric dryer was due to forced convection (fan). The temperature inside the electric drying chamber was regulated using a pyrometer.

Drying chamber and ambient temperatures, relative humidity, air flow rate and weight reduction were measured using mercury thermometer, thermo-hygrometer, hot wire anemometer and weighing balance respectively. Also the internal temperature of ginger was measured using type K thermocouple attached to twelve channel temperature recorder (model: BTM- 4208SD) and incident solar energy was measured during solar drying by solar power meter (model: SPM-1116SD, ±0.4%+ 1^{o}C accuracy).

Mathematical calculation for dryer and drying parameters

(1) Amount of moisture to be removed from a given quantity of ginger (W_w) is given by [11] as:

$$W_w = \frac{W_g\left(M_i - M_f\right)}{100 - M_f} \tag{1}$$

Where, W_g =Initial mass of wet ginger (kg), M_i = Initial moisture content (%)

M_f = Final moisture content (%). The moisture content on wet basis (Mi) and on dry basis (Mf) are given by [12,13]

$$M_i = \frac{m_i - m_f}{m_i} \tag{2}$$

$$M_f = \frac{m_i - m_f}{m_f} \tag{3}$$

Final relative humidity or equilibrium relative humidity ERH (%) was determined as follows according to [14]:

$$ERH = 100a_w \tag{4}$$

$$a_w = 1 - \exp\left[-\exp\left(0.914 + 0.5639\ln M\right)\right]$$

$$M = \frac{M_f}{100 - M_f}$$

Where,
a_w = water activity and M = moisture content kg_w/kg_s (dry basis)
(2) Quantity of heat needed to evaporate water from ginger is given by [14,15] as:

$$Q = W_w \times h_{fg} \tag{5}$$

Where,
Q = Amount of energy required for drying process (kJ)
W_w = Mass of water (kg)
h_{fg} = latent heat of evaporation
but,

$$h_{fg} = 4.186 \times 10^3\left(597 - 0.56\left(T_{pr}\right)\right) \tag{6}$$

Where,
T_{pr} = Product temperature (^{0}C)
The total heat energy, E (kJ) required to evaporate water was calculated as follows:

$$E = m(h_f - h_i)t_d$$

Where E = total heat energy, kJ
m = mass flow rate of air, kg/hr
h_f and h_i = final and initial enthalpy of drying and ambient air respectively, kJ/kg dry air
t_d = drying time, hrs
Enthalpy of moist air in drying air at temperature T is given as [16]

$$h = 1006.9T + w\left(2512131.0 + 1552.4T\right)$$

Microstructure Analysis

An electric microscope (XJL-17) was used to observe the effect of different drying methods on microstructure of ginger samples. Microstructural studies may improve the understanding of drying mechanisms and the knowledge of food properties. Observing what happens at the microscopic level during drying results not only on qualitative information, but also on quantitative data suitable to modelling. Understanding the relationship between food microstructure and food perceived characteristics is of increasing importance to produce attractive food products [17].

III. RESULTS AND DISCUSSION

Comparative studies of effects of different drying methods on drying rate

From figures 1 and 2 mass reduction and moisture ratio with time during ginger drying for sun, solar and electric dryer can be seen. It was observed that for both figures the rate of moisture ratio and mass reduction is faster in electric dryer followed by solar and the least is the sun. This is as a result of almost constant heat supplied and air movement leading to moisture transport out of dryer in electric dryer at constant rate unlike both solar and open sun. The average drying temperatures and weight reduction for open sun, solar and electric dryers are 45^{o}C, 51^{o}C and 58^{o}C and 0.329 kg, 0.339 kg and 0.341 kg respectively. Also the final moisture contents are 19, 12 and 10% for sun drying, solar drying and electric dryer respectively from initial moisture content of 78.3 %. It took the average time of 12 h, 6 days(40h) and 9 days(53h) to dry ginger to safe moisture content in electric, solar and open sun dryer. The final moisture content after drying for both solar and electric dryer is within the acceptable limit which is 7-12 %. From the results electric dryer will be better for mass production at lower moisture constant and short time.
From figure 3, it could be seen that rate of drying is faster in electric dryer followed by solar and the least is open sun. It could also be seen from solar dryer result that the drying rate was not constant but rise and fall as a result of fluctuations in the intensity of the sun. Figure 4 show the internal temperature during ginger drying in electric dryer, it shows rise in temperature after about 300s this is as a result of temperature development in the ginger and increases as heating of moisture in the ginger, it reaches the peak of 45^{o}C before falling and the falling is as a result of decrease in moisture inside the ginger.

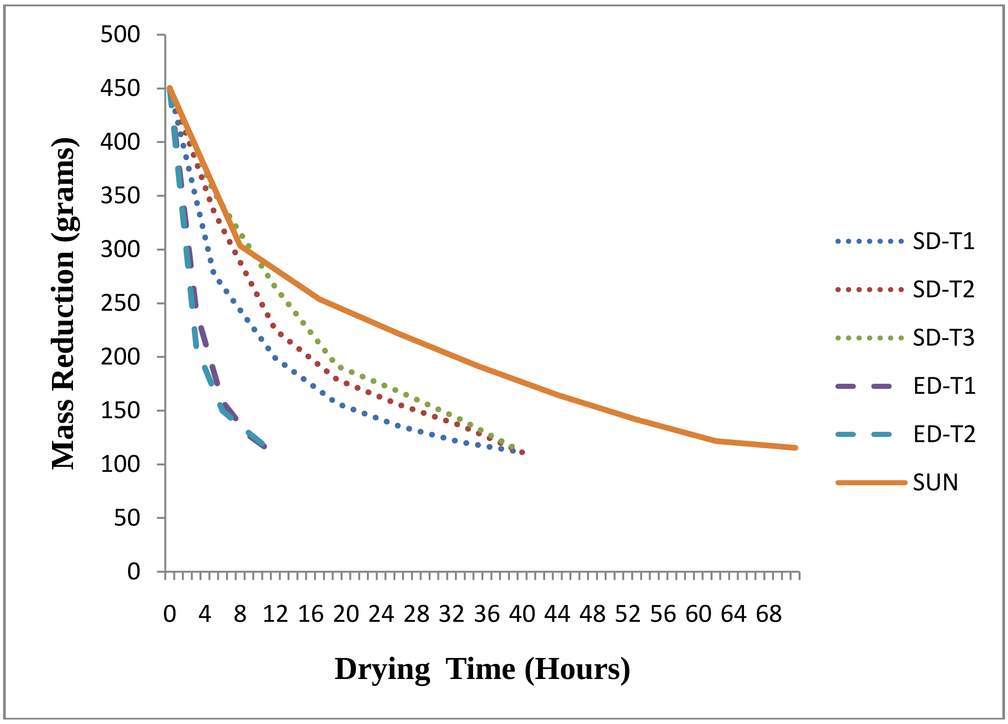

Figure 1: Graph of Mass Reduction against Time

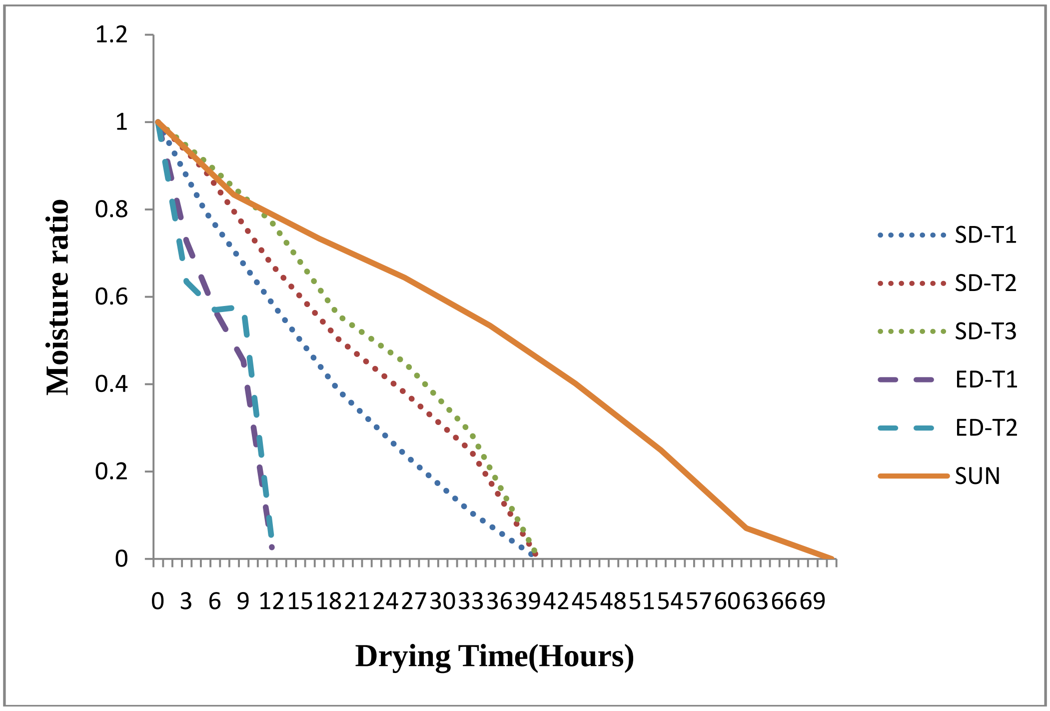

Figure 2: Graph of Moisture Ratio against Drying Time.

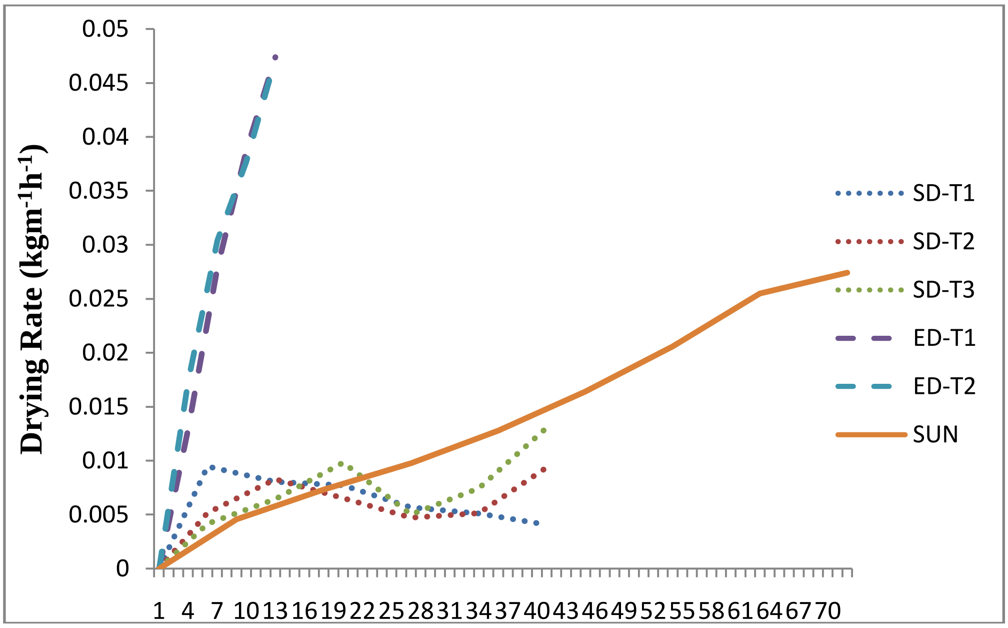

Figure 3: Graph of Drying Rate of Each Method of Drying

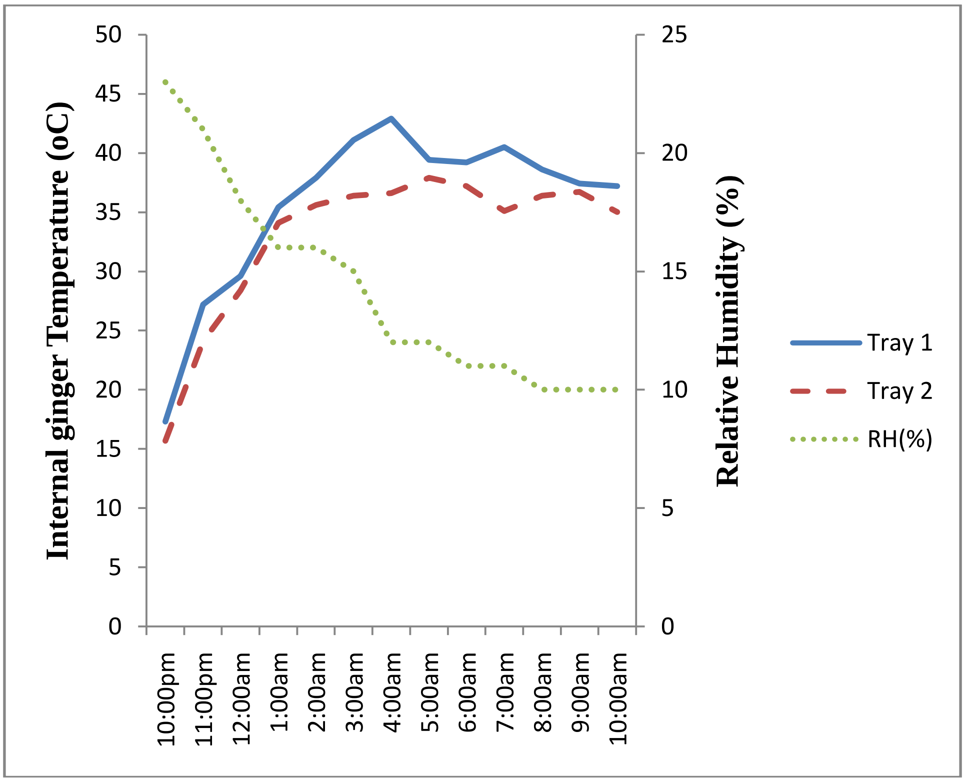

Figure 4: Graph of Electric Ginger Temperature and Relative Humidity against Time

Table 1: Electric Dried Ginger Experimental Results

Time	**Internal Ginger Temperature(^{0}C)**		**Mass (grams)**		**Relative Humidity**
	Tray 1	Tray 2	Tray 1	Tray 2	RH(%)
10:00pm	17.3	15.7	450	450	23
11:00pm	27.2	24.1			21
12:00am	29.6	28.4			18
1:00am	35.4	34.1	242.1	209.1	16
2:00am	41.1	36.4			16
3:00am	36.4	21.6			15

4:00am	42.9	36.6	158.2	149.5	12
5:00am	39.4	21.4			12
6:00am	39.2	37.2			11
7:00am	40.5	35.1	126.5	128.9	11
8:00am	38.6	36.4			10
9:00am	37.4	36.7			10
10:00am	37.2	35.0	108.9	109.2	10

Physical observation

From plate 1, fresh ginger sample obtained was found to be yellowish with its cells neatly arranged. Having a comparative physical examination, it was discovered that electric dried ginger had the most ruptured surface and bending stress. Furthermore, electric dried ginger had a rough evaporation surface and the lowest particle density which could be attributed to short drying time and minimal handling of the material during the experiment

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Plate 1a: Fresh ginger rhizome Cross section

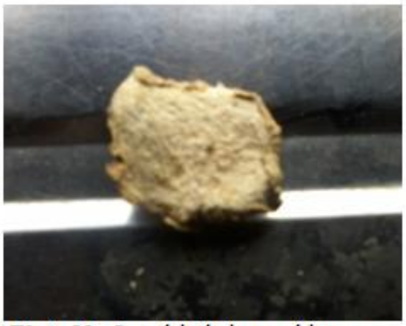

Plate 1b: Sun dried ginger rhizome

Plate 1c: Solar dried ginger rhizome

Plate 1d: Electric dried ginger rhizome

Histological Changes

Plate 2a reveals the cross sectional micrograph of freshly harvested sliced ginger rhizome. The essential oils have a grain-like structure and the bonding between oily cells and moisture was observed to be stable. Drying initiated the breaking of bonds to permit the escape of moisture and a re-bonding of the oil and starch cells was needed to preserve the essential nutrients which accounts for the clustering of oil and starch cells at different regions of plates 2b, 2c and 2d.

A comparative view of the micrographs reveals that electric method of drying had the highest bonding breaking capacity which attributed to its drying characteristics moisture removal capacity. However, the consequential effect of this simply means that electric drying has the least essential nutrient trapping ability.

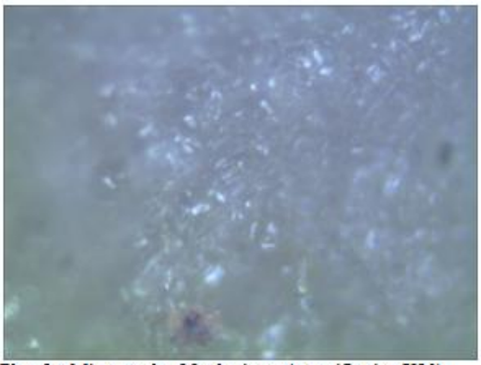

Plate 2a: Micrograph of fresh ginger (magnification X20)

Plate 2b: Micrograph of sun dried ginger (magnification X20)

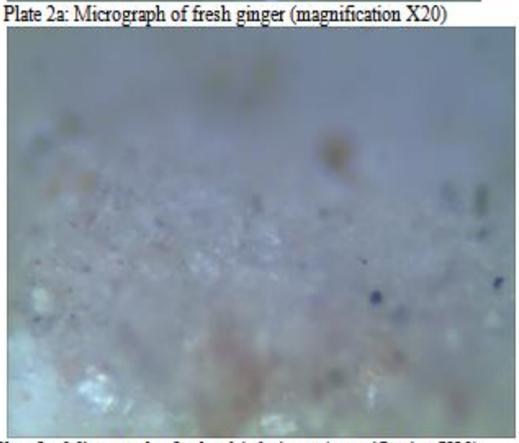

Plate 2c: Micrograph of solar dried ginger (magnification X20)

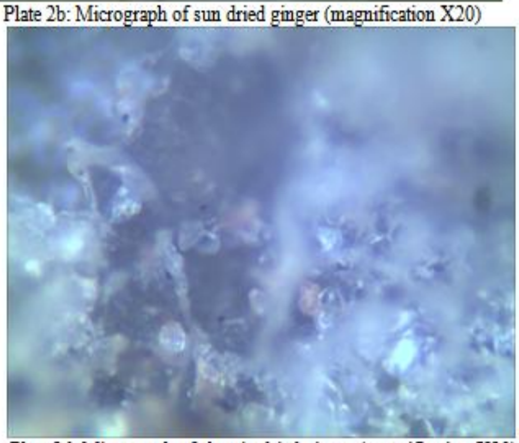

Plate 2d: Micrograph of electric-dried ginger (magnification X20)

IV. CONCLUSION

Ginger is a condiment that has its uses in medicine and industries. Improper drying has a great impact in affecting the major constituents of ginger as most of it will be evaporated at high temperature. Also when drying is done unhygenically it will affect the acceptability in the market. Drying rate in electric dryer is the fastest way of drying out of the three followed by solar and open sun is the least. The fast rate of drying in electric dryer affect the microstructure of the ginger more that the other mode of drying. Both electric and solar dried products shrink the same way by the open sun was a little better. Environmental impact affects the final product of the open sun dried products. The scanning microscope images revealed that electric dryer has the highest bond breaking capacity and this causes deformation in the microstructure of the ginger.

However, drying period in electric dryer was found to be 12 h, followed by solar (40 h) and the least open sun (53 h). Electric dryer saves time more than the other forms of dryers and its drying process could be controlled properly unlike the two other that depends on the availability of the sun.

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