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# Investigation of the Effect of Sample Geometry on Drying Energy Requirement of Plant-Based Food Materials

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## ABSTRACT

Drying is a simultaneous heat and mass transfer phenomena; primarily remove water to extend the shelf life of food materials. Over the course of drying, food quality deteriorates significantly along with taking huge energy. From the literature, it is found that both food properties and drying conditions affect the energy consumption criteria. However, there is a very limited number of research found that conducted investigation on the effect of sample geometry on energy requirement to dry. In this study, three typical shapes with a constant volume of selected food materials have been investigated to attain a correlationship between sample geometry and energy requirements. The amount of energy requirement during drying of Brinjal, Carrot, and Radish varies significantly with the variation of sample geometry. The minimum energy was required for sliced samples of selected food materials; whereas, cylindrical shaped samples took higher energy. The minimizing amount of energy also reduces the environmental pollution and GHG (Green House Gas). It can be concluded that sample compactness remarkably affects the energy requirement.

Keywords: Plant-based food material, food drying, energy requirement, sample geometry, environment pollution

## 1. Introduction

Generally, the different plant-based food materials contain about 80-90% moisture. The micro-organism growth is higher due to this higher amount of moisture content. Every year 1.3 billion tonnes of fruits and vegetables are wasted due to the lack of maintaining appropriate preserving techniques [1, 2]. There are lots of food preserving techniques within which drying technique is crucial because, it prevents the growth of yeasts, mold, and bacteria [3]. But drying technology is energy intensive. Approximately 15% of industrial energy is consumed by the drying process. On the other hand, the food quality also depends on the simultaneous heat and mass transfer during drying [4, 5]. In addition to sample properties and drying conditions, sample size and shape influence quality and energy requirement. However, there is an insignificant amount of research are reported in connection with the effect of sample shape and size on the quality and energy requirement during drying.

Energy requirement during drying of the sliced agricultural product was reviewed in which it was found that the minimum amount of energy requirement during drying of sliced shaped plant-based food materials are between 4.22 and 24.99 MJ/kg water removed [6]. The effect of aspect ratio and shape on effective moisture diffusivity and drying kinetics of potatoes, green beans and peas were analyzed where the diffusion coefficient and drying constant for potatoes, beans and peas were found in descending order [7]. The quality of dried foods and the amount of energy requirement during drying was studied where it was found that the energy consumption of the Infrared-Hot Air settings was lower that's why the thermal efficiency was higher compared to the Hot Air or Infrared-Cold Air settings [8]. Drying characteristics, energy requirement and drying efficiency during drying of potato slices was studied in which it was found that the maximum and minimum specific energy requirement for potato drying were 5.882 (MJ/kg water) and 4.645 (MJ/kg water) [9]. The energy consumption of main types of food drying like infrared drying, microwave drying, hot air convective drying, vacuum drying and convective dryer with microwave pretreatment were investigated where it was found that during pomegranate drying the maximum and minimum amount of energy was required for vacuum and microwave dryer. On the other hand, for infrared drying, the drying time increased with air velocity which results in the larger amount of energy consumption [10]. It is crucial to dry foods with low cost, minimum energy and less time [11, 12].

However, there is no comprehensive study that investigated the effect of the shape of the sample associated with the energy consumption of the plant-based food materials during drying. In this study, authors thoroughly investigated the effect of different shape on the drying energy requirements and correlate with environmental pollution.

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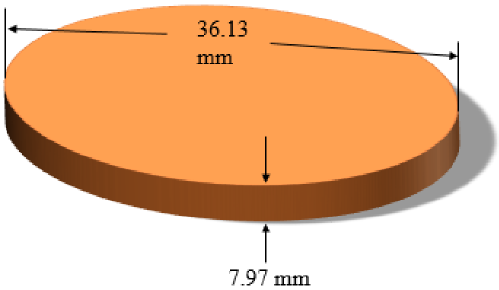
## 2. Materials and methods

### 2.1 Materials

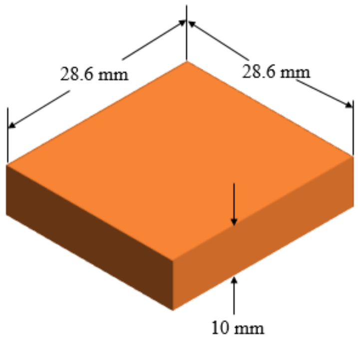
Different types of plant-based food materials like Brinjal, Carrot, and Radish were collected from the local market in Rajshahi, Bangladesh. The initial moisture content of the fresh food materials was measured by oven drying method [13]. The initial mass of the Brinjal, Carrot and Radish samples were about 4.5 gm, 9 gm, and 8.5 gm respectively. The samples were dried in a convective dryer at 60 ± $2^0$ C until the weight did not change between two weight intervals. Physical properties of the food material samples such as average diameter, thickness, and mass were slightly different for slice, rectangular and cylindrical shape respectively.

### 2.2 Sample Preparation and Drying Method

The samples were stored in a refrigerator at 4°C before using for the drying experiment. The convective dryer in which the experiment was performed was started about 30 min before drying experiments to achieve steady-state conditions before each drying run. At the start of each experiment, the materials were washed and cut into slices with 7.97 mm thick and 36.13 mm in diameter, rectangular shapes with 10 mm thick and 28.6 mm length, and cylindrical shapes with 19.18 mm height and 23.3 mm in diameter that are placed each sample on each separate tray. The slice, rectangular and cylindrical shape sample with their dimensions are shown in Fig.1. The experiment was performed at the temperature around 60°C and a constant air velocity of 0.7 m/s. During the experiment, the relative humidity of the inlet air was around 57%. Air flowed perpendicularly to drying surfaces of the samples. During the drying process, the tray was taken out at 30-min interval and weighed using a digital electronic balance. The measurement range of the balance was 0–100 gm with an accuracy of 0.01 gm. All the dimensions of the samples were measured 30-minute time interval by digital slide calipers. All weighing and measuring processes were completed within 30 seconds during the drying process. The experiments were replicated thrice, and the average of the moisture content at each value was used for constructing the drying curves.




(a)

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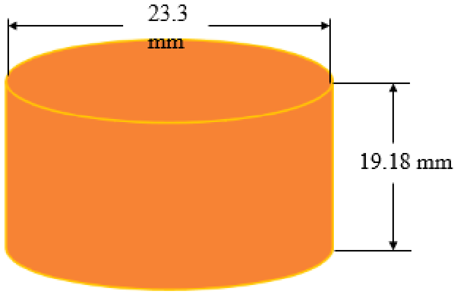



(c)

**Fig.1** Types of samples used in this experiment are (a) slice; (b) rectangle; (c) cylinder

In this experiment, a simple convective dryer was used shown in Fig.2. A hygrometer was used to measure the humidity inside the drying chamber. The dryer was run by electric energy. It consists a heater and a fan. The heater converts the electric energy into heat energy and the fan transfer the atmospheric air into the drying chamber at a certain speed.

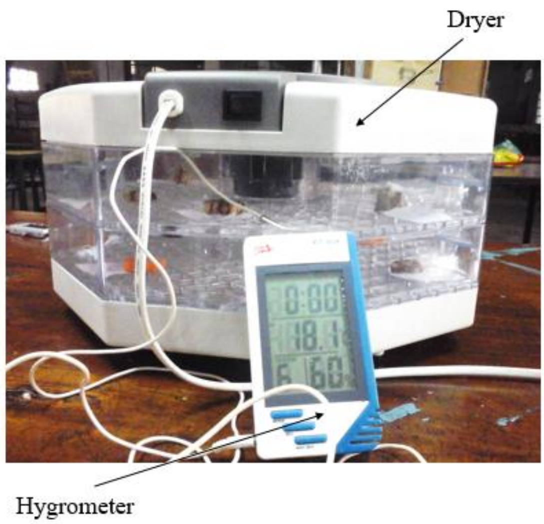



**Fig.2** Convective dryer used in this experiment

### 2.3 Energy Calculation of Convective Drying

In convective drying, total energy consumption is the summation of energy required for drying samples and blowing air, which is described by the equation (1) [14]:

$$E_t = \rho_a A v c_a \Delta T * D_t \qquad (1)$$

Where, $\rho_a$ is air density (kg/m$^3$), $E_t$ is total energy consumption (kWh), $v$ is air velocity (m/sec), A is cross-sectional area of container in which sample is placed (m$^2$), $\Delta T$ is a temperature difference between inlet and outlet air (°C), $c_a$ is specific heat (kJ/kg °C), $D_t$ is the total drying time of each sample (h) [15].

In this experiment, the air density, cross-sectional area of the dryer, air velocity, specific heat capacity, and the temperature difference between input and output remains the same. In convective drying, the condition $\rho_a A v c_a \Delta T$ can be represented by the energy consumption of the dryer $E_c$. So, the equation (1) can be written as

$$E_t = E_c * D_t \text{ kWh}$$
$$E_t = 3.6 E_c * D_t \text{ MJ}$$

Energy requirement for 1 kg sample

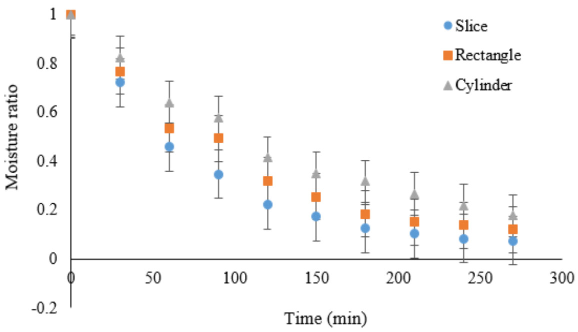
$$e_t = \frac{3.6(E_c * D_t)}{C} \text{ MJ/kg} \qquad (2)$$

Where, C is the capacity of the dryer (1 kg)

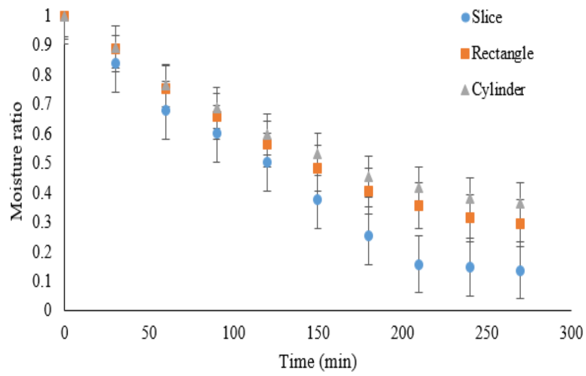
## 3. Results and discussion

### 3.1 Drying Kinetics

Moisture ratio variation with drying time for different plant-based food materials like Brinjal, Carrot, and Radish are shown in Fig.3. These figures also hold the pattern of minimizing moisture ratio with drying time for slice, rectangular and cylindrical shape food sample. The rate of moisture transfer is faster for slice sample instead of the rectangular and cylindrical sample because of having more surface area of the sliced sample. That's why the time required for drying is also minimized and a large amount of energy can be saved by using slice sample during drying of plant-based food material.




(a)

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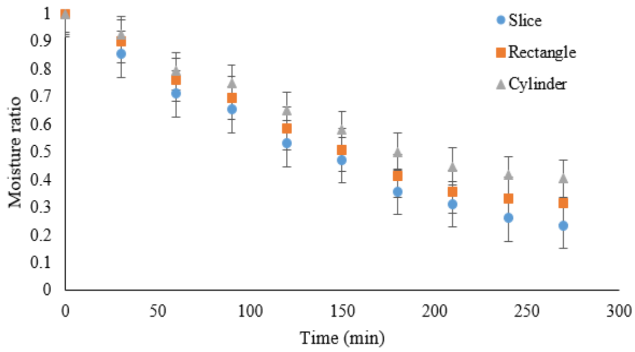



(c)

**Fig.3** Variation of moisture ratio with drying time for (a) Brinjal; (b) Carrot; and (c) Radish

### 3.2 Energy Consumption

The amount of energy savings can be represented by Table 1. Energy consumed by the dryer for slice sample is 14.4±0.72, 16.2±0.81 and 16.63±0.83 MJ/kg of water for Brinjal, Carrot, and Radish respectively. The amount of energy required for the rectangular and cylindrical sample are also shown in the table. Table 1 clearly shows that energy requirement for slice sample is lower than the rectangular and cylindrical sample for obtaining the same amount of moisture content. For microwave and convective hybrid solar dryers, the minimum energy requirement for drying sliced crops range from 4.22 – 24.99 and 5.21 – 90.4 MJ/kg of water removed respectively [16].

According to the common heat transfer sense, with the increased surface area, the rate of heat transfer is increased. Using slice sample instead of the rectangular or cylindrical sample gives more surface area to transfer heat. It also gives the better appearance and color. The percentage of energy savings for slice sample compared to the rectangular and cylindrical sample are 35.75%, 32.67%, 33.12% and 63%, 57.11%, 57.36% for Brinjal, Carrot, and Radish respectively. Only the change of shape without changing the other drying perimeter like temperature, humidity, moisture content etc. gives the remarkable amount of energy saving which is the key focus of this paper.

Surface area to volume ratio of the samples is another important criteria for measuring drying kinetics and amount of energy savings. The higher surface area to volume ratio ($mm^{-1}$) implies larger heat and mass transfer rate because of getting a larger surface area for the same volume. The surface area to volume ratio for slice sample is 0.361 $mm^{-1}$. On the other hand, the values are 0.339 $mm^{-1}$ and 0.275 $mm^{-1}$ for the rectangular and cylindrical sample. As a result, the amount of energy required for slice sample during drying is lower than rectangular and cylindrical sample because of the above-mentioned reason.

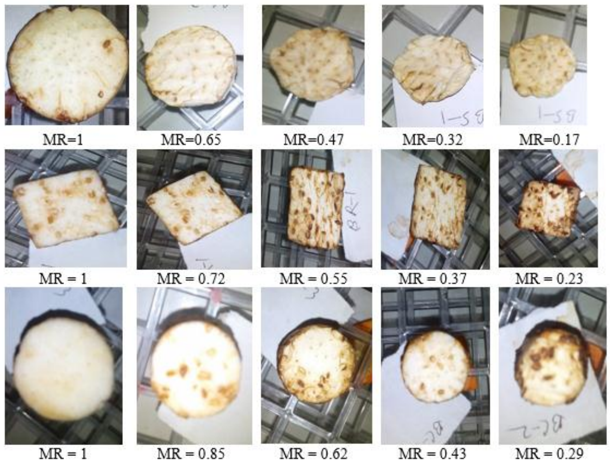
**Table 1** Energy requirement during drying for different sample of porous plant-based food materials

| Food materials | Energy requirement (MJ/kg of water) | | |
|---|---|---|---|
| | Slice | Rectangle | Cylinder |
| Brinjal | 14.4±0.72 | 19.55±0.98 | 23.47±1.17 |
| Carrot | 16.2±0.81 | 21.49±1.07 | 25.45±1.27 |
| Radish | 16.63±0.83 | 22.14±1.10 | 26.17±1.31 |

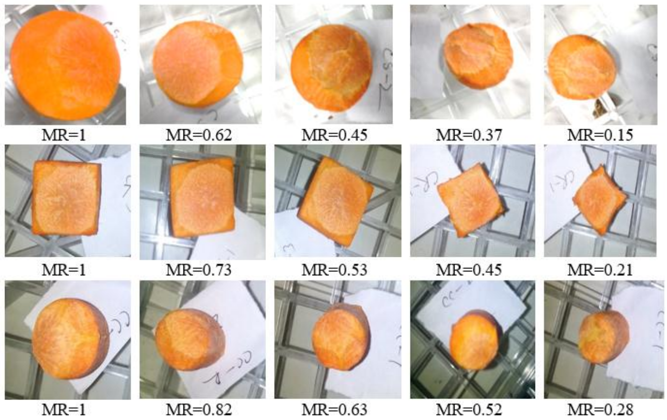
3.3 Deformation

The deformation of the Brinjal is shown in Fig.4(a). For maintaining time of drying (4 hours for each sample) and the softness of Brinjal, the deformation of the Brinjal appeared clearly compared to the Carrot and Radish. If the drying time of Carrot and Radish sample is more, than the deformation of the samples would appear clearly. The deformation of the Carrot and Radish are shown in Fig.4(b) and Fig.4(c). The appearance of the samples are given according to their moisture content and drying time. All the readings are shown here maintained one hour time interval. The deformation kinetics depends on size and shape of the sample during drying. For slice sample throughout moisture transfer the change of shape, strain, roughness is smaller than the rectangular and cylindrical sample that’s why the shrinkage produced for the slice sample is comparatively lower than the other two samples used in this study.

Due to higher deformation and roughness of the rectangular and cylindrical sample than the slice sample, the appearance of the rectangular and cylindrical sample are not so good. The appearance of the dried food is a crucial factor. If the dried sample appear very ugly, it is not so attractive to eat which is another phenomenon established here. For slice sample, the appearance of the plant-based food material during drying is brighter than the rectangular and cylindrical sample.




(a)

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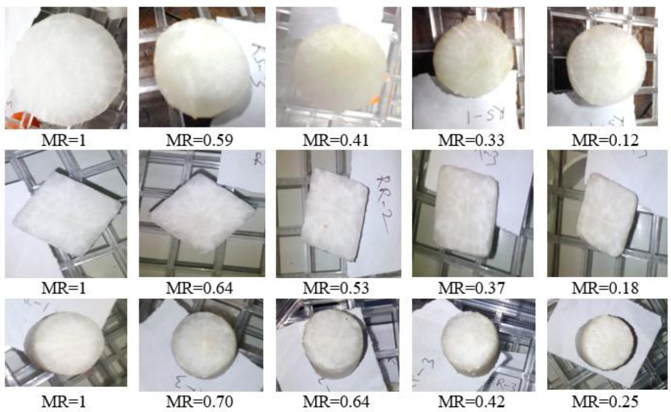


(c)

**Fig.4** View at different stages of the slice, rectangular and cylindrical samples during drying of (a) Brinjal; (b) Carrot; and (c) Radish

## 4. Conclusion

The drying characteristics like energy consumption and drying kinetics of different plant-based food materials are studied in this experiment. Three different sample shapes are analyzed here. There are many factors on which the drying parameters depends on like temperature, humidity, drying time, sample shapes and size etc. In this study, the sample shapes are represented more significantly with practical implementation. Only by changing the shape of the sample instead of changing another parameter can be saved a large amount of energy during drying of plant-based food material. Consequently, the amount of GHG production as like as environmental pollution during food drying is also reduced.

## 5. Acknowledgment

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