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FigureArticle

Effect of moisture contents on drying rate at varying regulated temperatures and fan speeds of some leafy vegetables

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Abstract: This research investigates the effects of drying on some selected vegetables, which are Telfaria occidentalis, Amaranthu scruentus, Talinum triangulare, and Crussocephalum biafrae. These vegetables were collected fresh, sliced into smaller sizes of 0.5 cm, and dried in a convective dryer at varying temperatures of 60.0 °C, 70.0 °C and 80.0 °C respectively, for a regulated fan speed of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}, and for a drying period of 6 h. It was discovered that the drying rate for fresh samples was 4.560 $gmin^{-1}$ for Talinum triangulare, 4.390 $gmin^{-1}$ for Amaranthu scruentus, 4.580 $gmin^{-1}$ for Talinum triangulare, and 4.640 $gmin^{-1}$ for Crussocephalum biafrae at different controlled fan speeds and regulated temperatures when the mass of the vegetable samples at each drying time was compared to the mass of the final samples dried for 6 h. The samples are considered completely dried when the drying time reaches a certain point, as indicated by the drying rate and moisture contents tending to zero. According to drying kinetics, the rate of moisture loss was extremely high during the first two hours of drying and then steadily decreased during the remaining drying duration. The rate at which moisture was removed from the vegetable samples after the drying process at varying regulated temperatures was noted to be in this trend: 80.0 °C > 70.0 °C > 60.0 °C and 6.0 ms^{-1} > 3.0 ms^{-1} > 1.5 ms^{-1} for regulated fan speed. It can be stated here that the moisture contents has significant effects on the drying rate of the samples of vegetables investigated because the drying rate decreases as the regulated temperatures increase and the moisture contents decrease. The present investigation is useful in the agricultural engineering and food engineering industries.

Keywords: drying rate; moisture content; vegetables; fan speed; drying

1. Introduction

Drying could be described as a process of transfer of heat and mass that take place at the surface of a drying material and also inside of it. It helps in the reduction of moisture of the internal components of the vegetable samples, inhibits the growth of microbial within the sample of vegetable, and also the chemical changes during storage, which prolong the shelf life of dried samples, and improve its quality [1,2]. The transfer of water during the drying process can be described in two ways, the first one is the transfer of water from the internal part of the vegetable samples to its surface and the other one is the diffusion of water from the surface of the vegetables to its surrounding through the process of evaporation [3–5].

Drying of the produce of agriculture such as grains, fruits, and vegetables with the sun is a very common method because sun is available everywhere. Some of the factors affecting the drying rate are the velocity of wind, relative humidity, type of crops, solar radiation, and the mass per unit area of the products [6,7].

Moisture dehydration is one of the ancient systems of preserving agricultural products like vegetables that enhances a better storage life, loss reduction during storage, and cost reduction during transportation of the vegetable samples. Drying of vegetable samples gives room to improve the digestibility and palatability of the samples of vegetables, which also affect the color, flavor, and appearance of the vegetables [8,2,9].

Through the process of drying, the storage life of vegetables is enhanced and also minimizes their moisture content by deactivating the microbes that causes the destruction or deterioration of such vegetable. Drying is a thermal process by which heat is applied to the sample of vegetables to be dried and the water in those vegetables is removed [8,10]. In general, dried samples of vegetables are useful medicine and for industrial purposes [11,12].

Percentage nutritional values in the samples of the vegetables decreased as drying took place, therefore to have maximum nutritional values from vegetables, fresh consumption remains the best. However, for storage purposes, irrespective of the species and quantity of vegetables prepared, for this convective dryer, regulated temperatures of 60.0 °C to 80.0 °C and regulated fan speed of 1.5 ms^{-1} to 3.0 ms^{-1} can be used [1,13].

Various researches have been carried out on the drying of agricultural products and many of it published in the literature. Despite all these, information relating to the drying of agricultural products that specifies varying regulated drying temperatures is yet to be detailed. Therefore, in this work, the effects of moisture contents on drying rate under different regulated drying temperatures and fan speed of four different vegetable specimens are spotlighted. The present work is useful in the agriculture and food industries.

2. Methodology

2.1. Materials

The leafy vegetables used for the experimental investigation are itemized in **Table 1**.

Table 1. variety of vegetables.

English names	African spinach	Waterleaf	Lettuce	Fluted pumpkin
Botanical Names	*Amaranthu scruentus*	*Talinum triangulare*	*Crussocephalu m biafrae*	*Telfaria occidentalis*

Vegetable samples were obtained from the Adehun street market in Ado-Ekiti, Nigeria, washed with tap water, and allowed to dehydrate.

2.2. Basic theoretical equations

Percentage moisture contents

The equation to calculate both the moisture contents (%) and the drying rate ($gmin^{-1}$) were stated in Equations (1) and (2) as detailed by Oluwaleye et al. (2017) [7]

Moisture Contents (%);

$$MC_{wb} = \frac{M_I - M_D}{M_I} \times 100\% \tag{1}$$

for which;
MC_{wb} = moisture content (%)
M_I = mass of sample before drying (g)
M_D = mass of samples after drying (g)
Percentage drying rate
Drying rate (DR) of the dried vegetable samples was estimated using:

$$D_R = \frac{M_I - M_D}{T_\Delta} \times 100\% \tag{2}$$

for which;
D_R = Drying rate ($gmin^{-1}$)
M_I = mass of sample before drying (g)
M_D = mass of samples after drying (g)
T_Δ = difference in drying time (min)

2.3. Experimental set-up

A rectangular convective dryer shown in **Figure 1** below was used for the drying process. The dryer is comprised of five major parts which are: the base frame that gives support to other parts of the dryer; the fan housing to force the ambient air into the chamber across the heating elements; the chamber that holds the drying cage and the heating elements; cage that hold the samples of vegetables inside the chamber and the three heating elements of 3 kW each connected in parallel to heat the inlet air and the connection is done in a way that each of the heaters can be switched on separately.

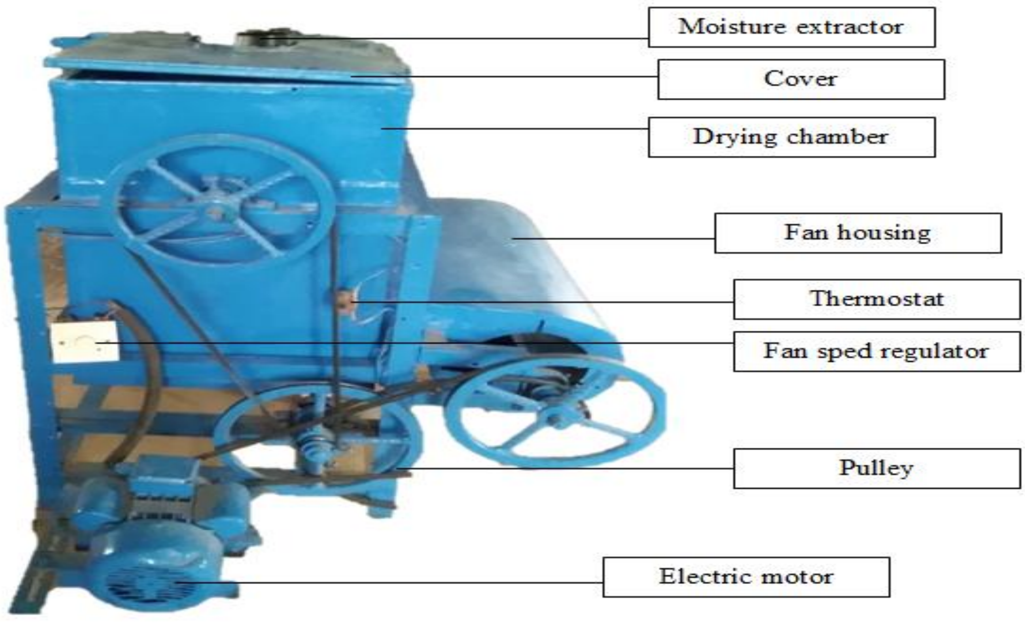

Figure 1. side view of the dryer (source: Adeleye et al., 2021 [1]).

2.4. Drying procedure

In the process of drying, the collection of the vegetable samples is the very first step to be taken. The vegetable samples collected were sliced into smaller sizes and loaded into the cage of the drying chamber. Then, simultaneous switching on both the electric motor and the heating elements followed. The inlet air blown into the chamber by the fan got heated through the heating elements; the heated air rose within the chamber while the moist air got expelled through the extractor mounted on the door of the dryer in the process. Vegetable samples dried at different regulated temperatures and fan speeds were taken from the chamber and measured two times at an interval of 10 min and the average values of the samples were calculated and used in the plotting

3. Result and discussion

3.1. Drying rate

Using different regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, and regulated fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1}, and 6.00 ms^{-1}, the drying rate of the vegetable samples were calculated using, $D_R = \frac{M_I - M_D}{T_\Delta} \times 100\%$, and depicted in **Figure 2** to **Figure 13**.

For *Telfaria occidentalis* (**Figure 2**), initially, when the moisture content was 82%, the drying rate was 4.560 $gmin^{-1}$ at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Telfaria occidentalis* reduced to 63%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate decreased to 4.300 $gmin^{-1}$, 4.200 $gmin^{-1}$, and 4.200 $gmin^{-1}$, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, when the moisture content was 45%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.830 $gmin^{-1}$, 3.750 $gmin^{-1}$, and 3.710 $gmin^{-1}$, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But when the moisture content reduced to 29%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.440 $gmin^{-1}$, 3.280 $gmin^{-1}$, and 3.220 $gmin^{-1}$, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Furthermore, as the moisture content reduced to 5%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate were 1.330 $gmin^{-1}$, 1.220 $gmin^{-1}$, and 1.110 $gmin^{-1}$, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 1%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 1.000 $gmin^{-1}$, 1.000 $gmin^{-1}$, and 0.200 $gmin^{-1}$, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Telfaria occidentalis* had retained 0% of water.

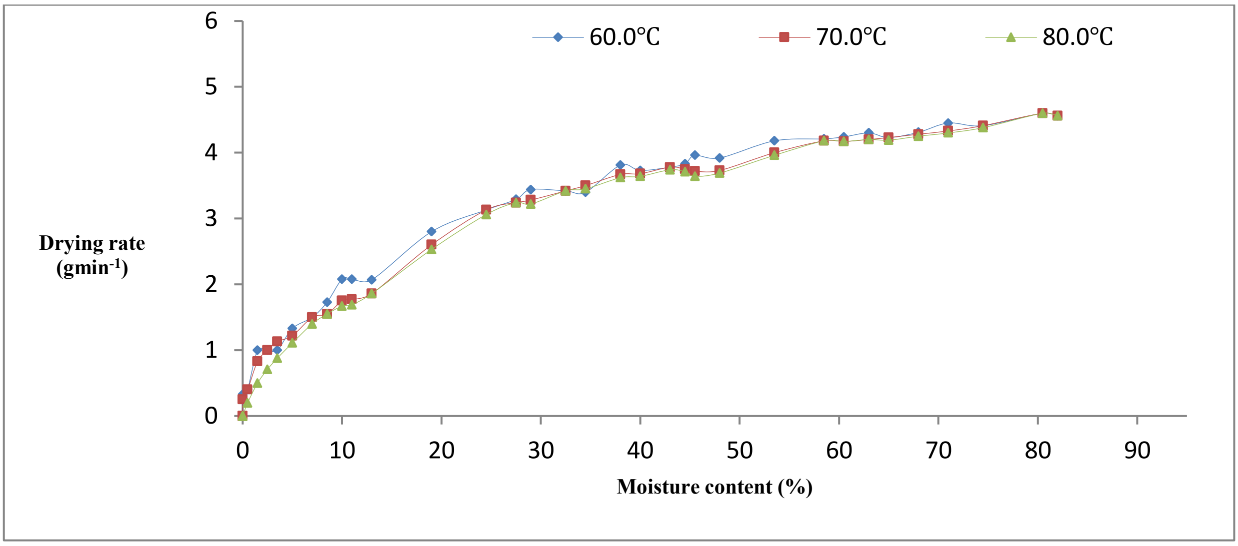

Figure 2. Drying rate (gmin^{-1}) against moisture content (%) of Telfaria occidentalis at the fan speed of 1.50 ms^{-1}.

For *Telfaria occidentalis* (**Figure 3**), initially, when the moisture content was 82%, the drying rate was 4.560 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Telfaria occidentalis* reduced to 63%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate decreased to 4.230 gmin^{-1}, 4.170 gmin^{-1}, and 4.200 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, when the moisture content was 44%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.750 gmin^{-1}, 3.710 gmin^{-1}, and 3.710 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. However when the moisture content reduced to 29%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.280 gmin^{-1}, 3.220 gmin^{-1}, and 3.220 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Additionally, as the moisture content reduced to 5%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 1.220 gmin^{-1}, 1.110 gmin^{-1}, and 1.110 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. Nonetheless, at the moisture content of 0.5%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 0.200 gmin^{-1}, 0.200 gmin^{-1}, and 0.200 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, this indicates that *Telfaria occidentalis* had retained 0% of water.

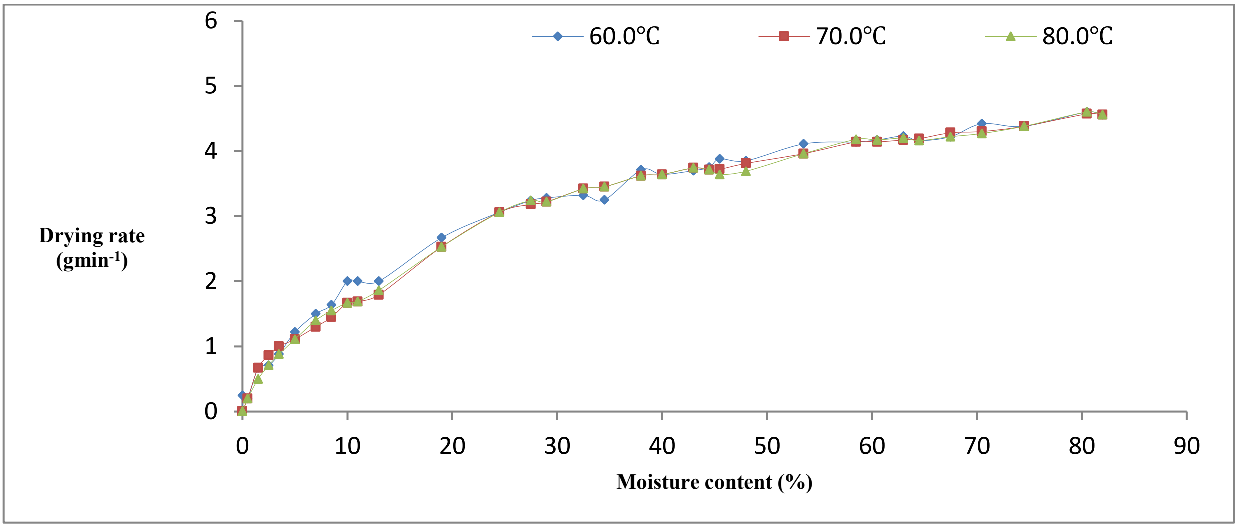

Figure 3. Drying rate (gmin^{-1}) against moisture content (%) of Telfaria occidentalis at the fan speed of 3.00 ms^{-1}.

For *Telfaria occidentalis* (**Figure 4**), initially, when the moisture content was 82%, the drying rate was 4.560 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Telfaria occidentalis* reduced to 62%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate decreased to 4.200 gmin^{-1}, 4.130 gmin^{-1}, and 4.170 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

When the moisture content was 44%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.710 gmin^{-1}, 3.670 gmin^{-1}, and 3.670 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. However, when the moisture content reduced to 28%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.220 gmin^{-1}, 3.220 gmin^{-1}, and 3.170 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, as the moisture content reduced to 6%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 1.600 gmin^{-1}, 1.000 gmin^{-1}, and 1.200 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 0.5%, at a regulated fan speed of 6 ms^{-1}, the drying rate was 0.200 gmin^{-1}, 0.000 gmin^{-1}, and 0.200 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, this indicates that *Telfaria occidentalis* had retained 0% of water.

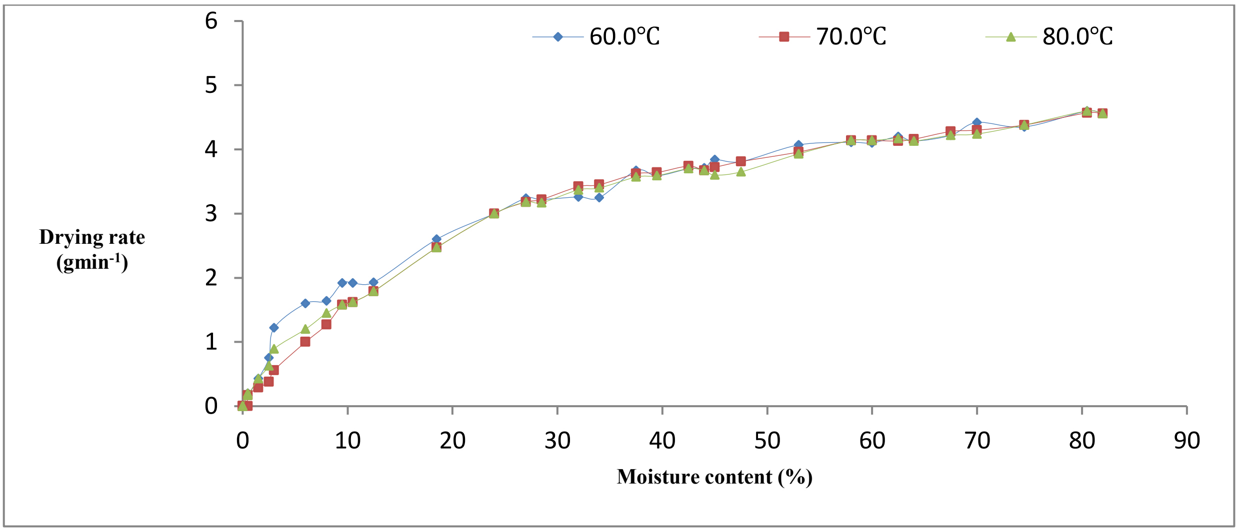

Figure 4. Drying rate (gmin^{-1}) against moisture content (%) of Telfaria occidentalis at the fan speed of 6.00 ms^{-1}.

For *Amaranthu scruentus* (**Figure 5**), initially, when the moisture content was 79%, the drying rate was 4.390 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Amaranthu scruentus* reduced to 61%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate decreased to 4.200 gmin^{-1}, 4.130 gmin^{-1}, and 4.100 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, when the moisture content was 42%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate were 3.580 gmin^{-1}, 3.540 gmin^{-1}, and 3.500 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content reduced to 27%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.170 gmin^{-1}, 3.060 gmin^{-1}, and 3.000 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Additionally, as the moisture content reduced to 5%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 1.090 gmin^{-1}, 1.090 gmin^{-1}, and 0.910 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 0.5%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 0.250 gmin^{-1}, 0.500 gmin^{-1}, and 0.250 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Amaranthu scruentus* had retained 0% of water.

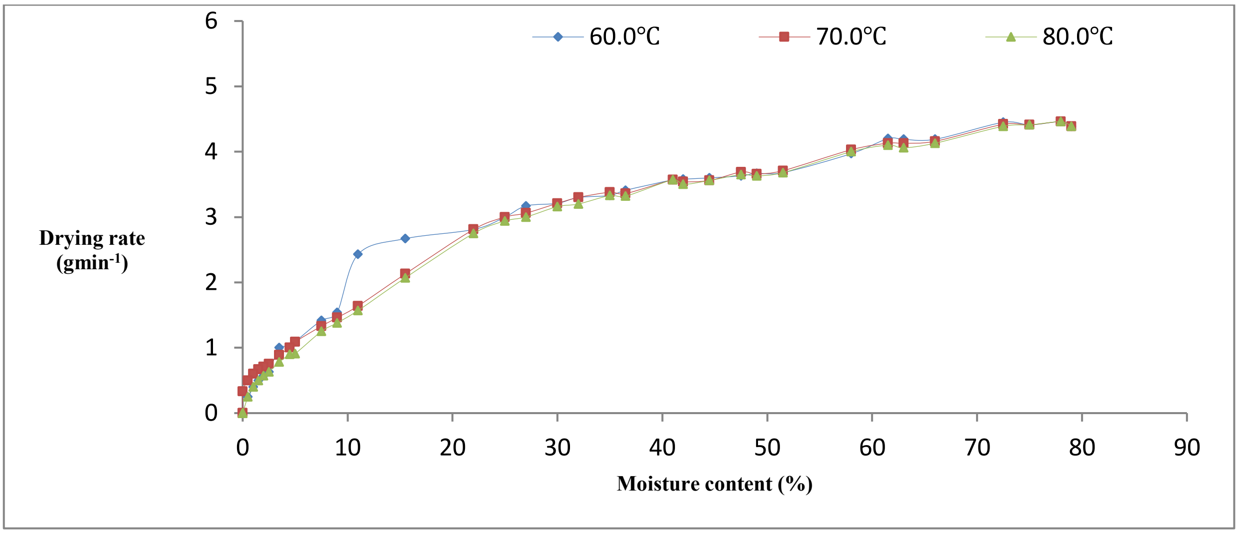

Figure 5. Drying rate (gmin^{-1}) against moisture content (%) of Amaranthu scruentus at the fan speed of 1.50 ms^{-1}.

For *Amaranthu scruentus* (**Figure 6**), initially, when the moisture content was 79%, the drying rate was 4.390 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Amaranthu scruentus* reduced to 61%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate decreased to 4.130 gmin^{-1}, 4.070 gmin^{-1}, and 4.100 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, when the moisture content was 42%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.540 gmin^{-1}, 3.500 gmin^{-1}, and 3.500 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But when the moisture content reduced to 27%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.110 gmin^{-1}, 3.000 gmin^{-1}, and 3.000 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Furthermore, as the moisture content reduced to 5%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 1.000 gmin^{-1}, 1.000 gmin^{-1}, and 0.910 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 1%, at a regulated fan speed of 3 ms^{-1}, the drying rate was 0.250 gmin^{-1}, 0.250 gmin^{-1}, and 0.250 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Amaranthu scruentus* had retained 0% of water.

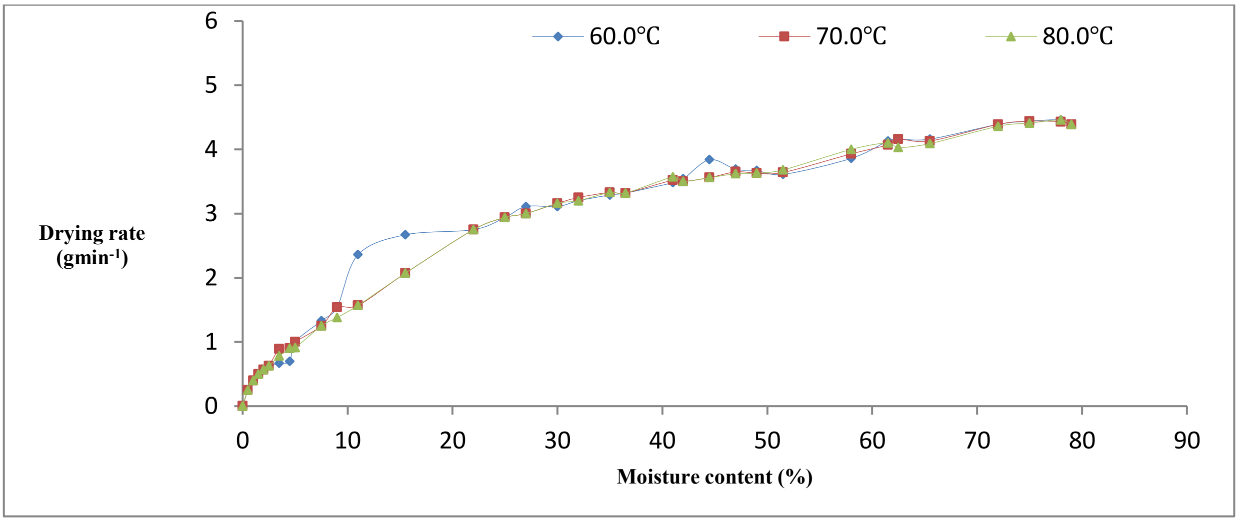

Figure 6. Drying rate (gmin^{-1}) against moisture content (%) of Amaranthu scruentus at the fan speed of 3.00 ms^{-1}.

For *Amaranthu scruentus* (**Figure 7**), initially, when the moisture content was 79%, the drying rate was 4.390 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Amaranthu scruentus* reduced to 61%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate decreased to 4.100 gmin^{-1}, 4.070 gmin^{-1}, and 4.070 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Furthermore, when the moisture content was 42%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.500 gmin^{-1}, 3.460 gmin^{-1}, and 3.460 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But when the moisture content reduced to 26%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.060 gmin^{-1}, 3.000 gmin^{-1}, and 2.940 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, as the moisture content reduced to 5%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 0.910 gmin^{-1}, 0.910 gmin^{-1}, and 0.910 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. Nonetheless, at the moisture content of 1%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 0.200 gmin^{-1}, 0.200 gmin^{-1}, and 0.200 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Amaranthu scruentus* had retained 0% of water.

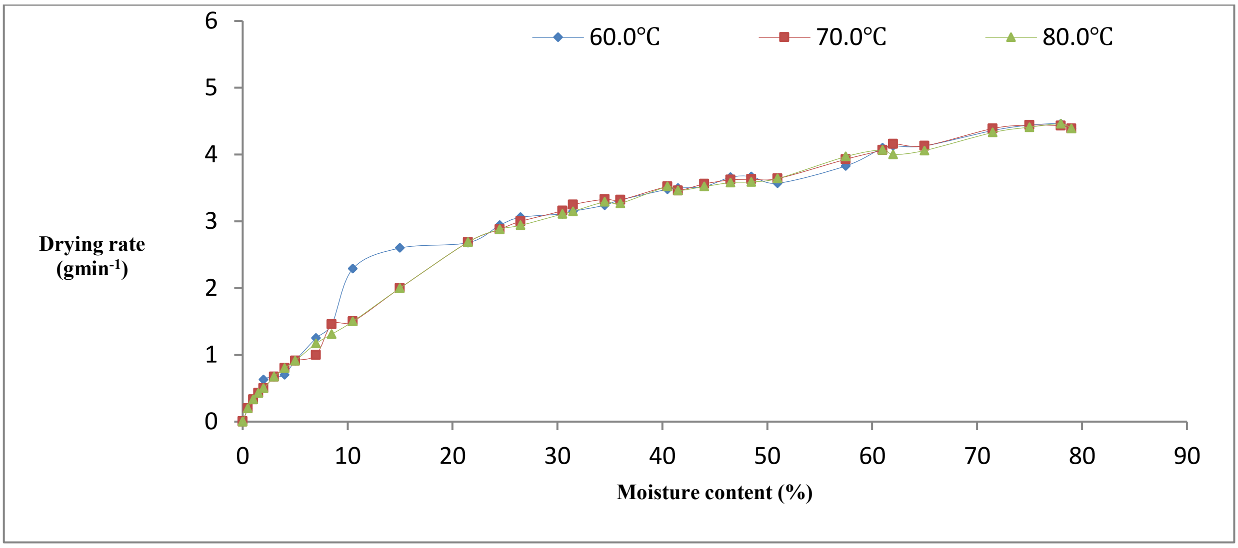

Figure 7. Drying rate (gmin^{-1}) against moisture content (%) of Amaranthu scruentus at the fan speed of 6.00 ms^{-1}.

For *Talinum triangulare* (**Figure 8**), initially, when the moisture content was 82%, the drying rate was 4.580 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Talinum triangulare* reduced to 64%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate decreased to 4.400 gmin^{-1}, 4.330 gmin^{-1}, and 4.300 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

When the moisture content was 46%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.830 gmin^{-1}, 3.710 gmin^{-1}, and 3.670 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. However, when the moisture content reduced to 30%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.500 gmin^{-1}, 3.390 gmin^{-1}, and 3.330 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, as the moisture content reduced to 9%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 1.830 gmin^{-1}, 1.670 gmin^{-1}, and 1.580 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. However, at the moisture content of 1%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 1.000 gmin^{-1}, 1.000 gmin^{-1}, and 0.330 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, this shows that *Telfaria occidentalis* had retained 0% of water.

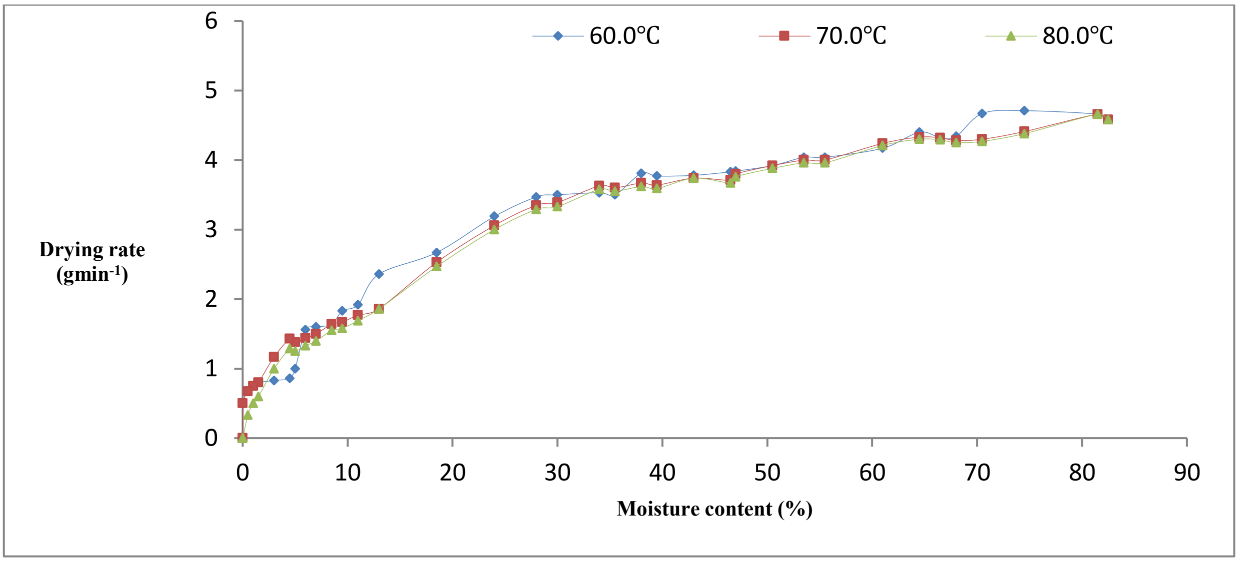

Figure 8. Drying rate (gmin^{-1}) against moisture content (%) of Talinum triangulare at the fan speed of 1.5 ms^{-1}.

For *Talinum triangulare* (**Figure 9**), initially, when the moisture content was 82%, the drying rate was 4.580 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Talinum triangulare* reduced to 64%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate decreased to 4.330 gmin^{-1}, 4.300 gmin^{-1}, and 4.300 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Moreover, when the moisture content was 44%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.750 gmin^{-1}, 3.670 gmin^{-1}, and 3.670 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But when the moisture content reduced to 30%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.390 gmin^{-1}, 3.330 gmin^{-1}, and 3.330 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, as the moisture content reduced to 5%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 0.880 gmin^{-1}, 1.250 gmin^{-1}, and 1.250 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 1%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 0.330 gmin^{-1}, 0.330 gmin^{-1}, and 0.330 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, this shows that *Talinum triangulare* had retained 0% of water.

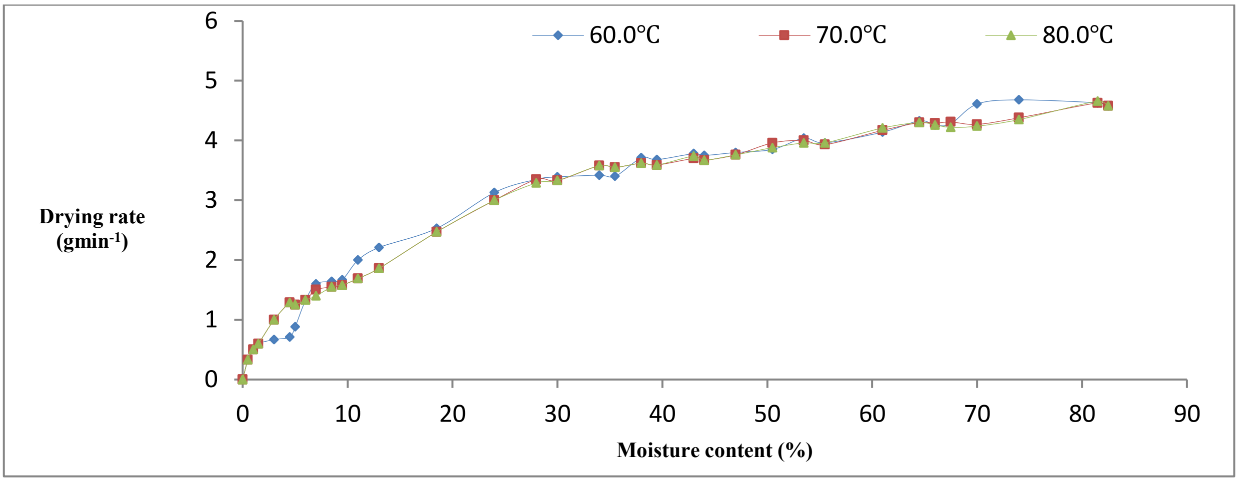

Figure 9. Drying rate (gmin^{-1}) against moisture content (%) of Talinum triangulare at the fan speed of 3.00 ms^{-1}.

For *Talinum triangulare* (**Figure 10**), initially, when the moisture content was 82%, the drying rate was 4.580 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Talinum triangulare* reduced to 64%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate decreased to 4.300 gmin^{-1}, 4.270 gmin^{-1}, and 4.270 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, when the moisture content was 44%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.710 gmin^{-1}, 3.630 gmin^{-1}, and 3.630 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. However, when the moisture content reduced to 31%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.330 gmin^{-1}, 3.280 gmin^{-1}, and 2.390 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Moreover, as the moisture content reduced to 9%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 1.580 gmin^{-1}, 1.580 gmin^{-1}, and 1.500 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 1%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 0.250 gmin^{-1}, 0.250 gmin^{-1}, and 0.250 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Talinum triangulare* had retained 0% of water.

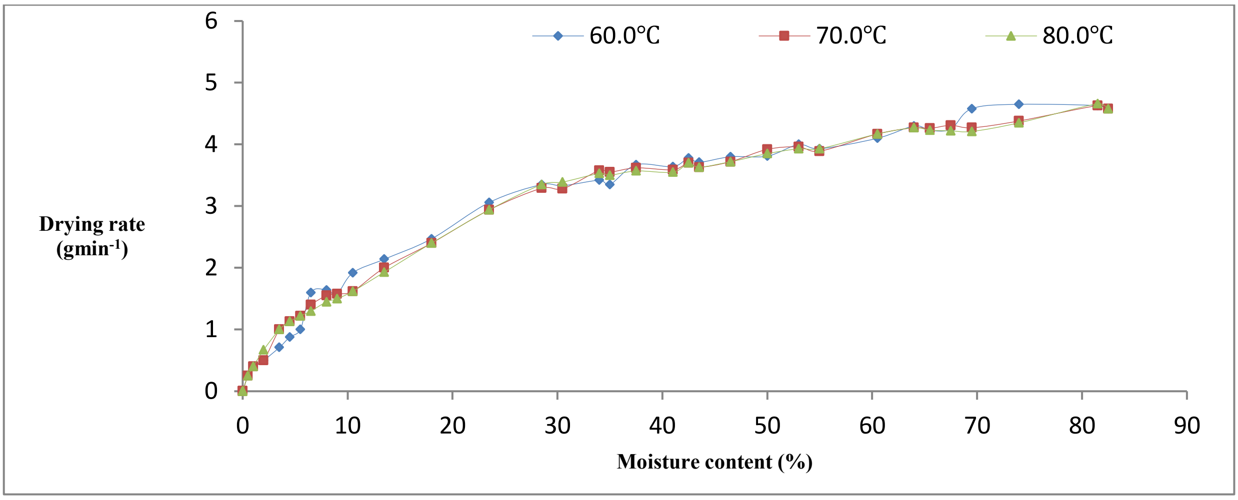

Figure 10. Drying rate (gmin^{-1}) against moisture content (%) of Talinum triangulare at the fan speed of 6.00 ms^{-1}.

For *Crussocephalum biafrae* (**Figure 11**), initially, when the moisture content was 83%, the drying rate was 4.640 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Crussocephalum biafrae* reduced to 65%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate decreased to 4.400 gmin^{-1}, 4.330 gmin^{-1}, and 4.300 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Moreover, when the moisture content was 44%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.750 gmin^{-1}, 3.710 gmin^{-1}, and 3.670 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But when the moisture content reduced to 29%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 3.390 gmin^{-1}, 3.220 gmin^{-1}, and 3.220 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

When the moisture content reduced to 6%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 1.670 gmin^{-1}, 1.330 gmin^{-1}, and 1.220 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 1%, at a regulated fan speed of 1.50 ms^{-1}, the drying rate was 0.500 gmin^{-1}, 0.500 gmin^{-1}, and 0.250 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Crussocephalum biafrae* had retained 0% of water.

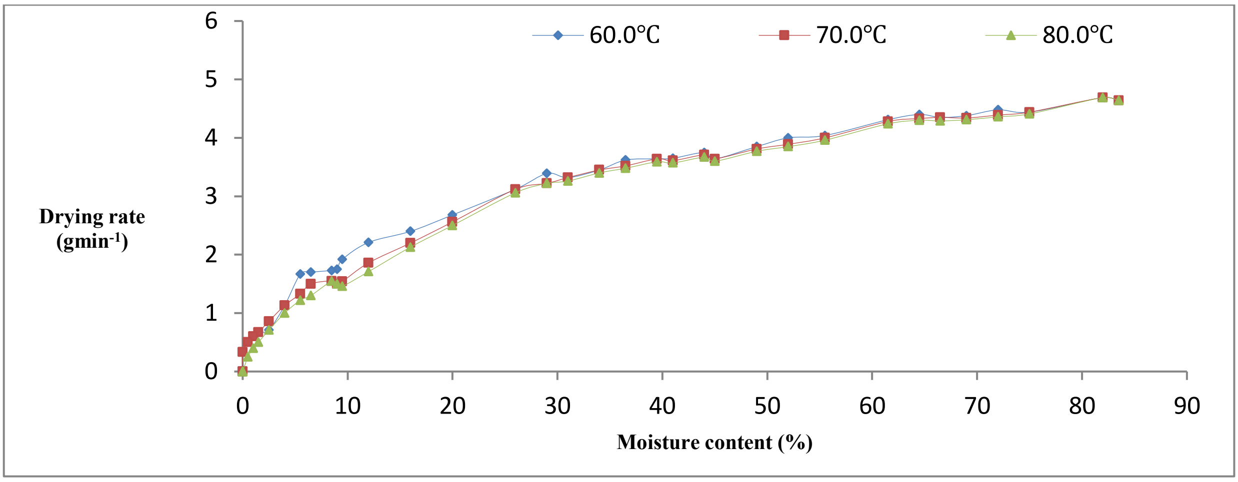

Figure 11. Drying rate (gmin^{-1}) against moisture content (%) of Crussocephalum biafrae at the fan speed of 1.50 ms^{-1}.

For *Crussocephalum biafrae* (**Figure 12**), initially, when the moisture content was 84%, the drying rate was 4.640 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Crussocephalum biafrae* reduced to 65%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate decreased to 4.300 gmin^{-1}, 4.300 gmin^{-1}, and 4.300 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Moreover, when the moisture content was 44%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.670 gmin^{-1}, 3.670 gmin^{-1}, and 3.670 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. However, when the moisture content reduced to 29%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 3.280 gmin^{-1}, 3.220 gmin^{-1}, and 3.220 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Additionally, as the moisture content reduced to 6%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 1.330 gmin^{-1}, 1.110 gmin^{-1}, and 1.220 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 1%, at a regulated fan speed of 3.00 ms^{-1}, the drying rate was 0.250 gmin^{-1}, 0.250 gmin^{-1}, and 0.250 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Crussocephalum biafrae* had retained 0% of water.

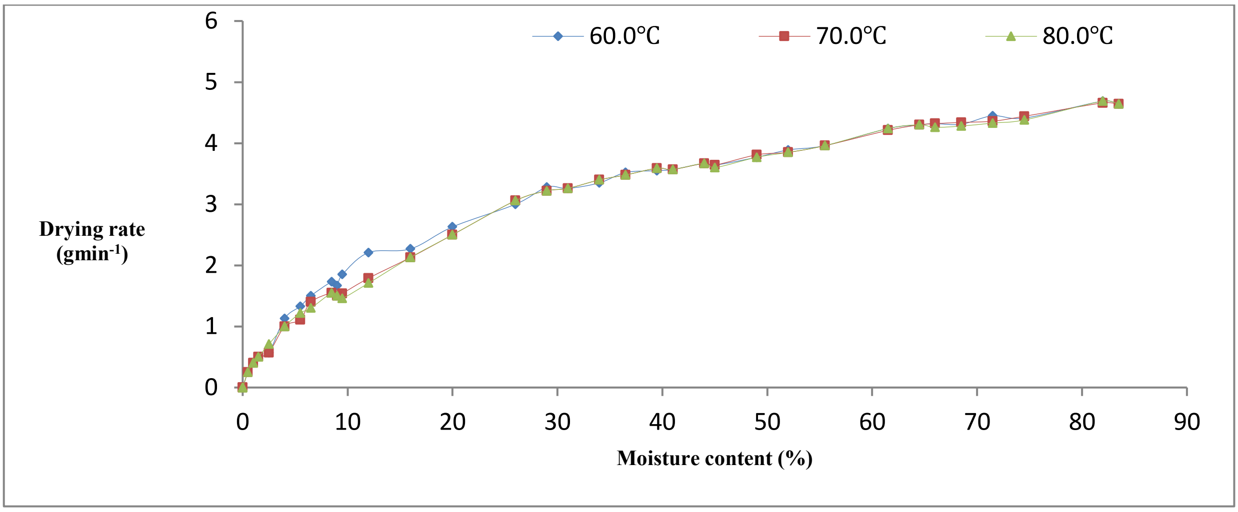

Figure 12. Drying rate (gmin^{-1}) against moisture content (%) of Crussocephalum biafrae at the fan speed of 3.00 ms^{-1}.

For *Crussocephalum biafrae* (**Figure 13**), initially, when the moisture content was 84%, the drying rate was 4.640 gmin^{-1} at the varying fan speeds of 1.50 ms^{-1}, 3.00 ms^{-1} and 6.00 ms^{-1}; and regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. When the moisture content of *Crussocephalum biafrae* reduced to 64%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate decreased to 4.270 gmin^{-1}, 4.270 gmin^{-1}, and 4.270 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Moreover, when the moisture content was 43%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.540 gmin^{-1}, 3.580 gmin^{-1}, and 3.580 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. Nonetheless, when the moisture content reduced to 29%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 3.220 gmin^{-1}, 3.170 gmin^{-1}, and 3.170 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively.

Also, as the moisture content reduced to 9%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 1.580 gmin^{-1}, 1.500 gmin^{-1}, and 1.500 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively. But, at the moisture content of 2%, at a regulated fan speed of 6.00 ms^{-1}, the drying rate was 0.330 gmin^{-1}, 0.330 gmin^{-1}, and 0.170 gmin^{-1}, at the regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, respectively, meaning that *Crussocephalum biafrae* had retained 0% of water.

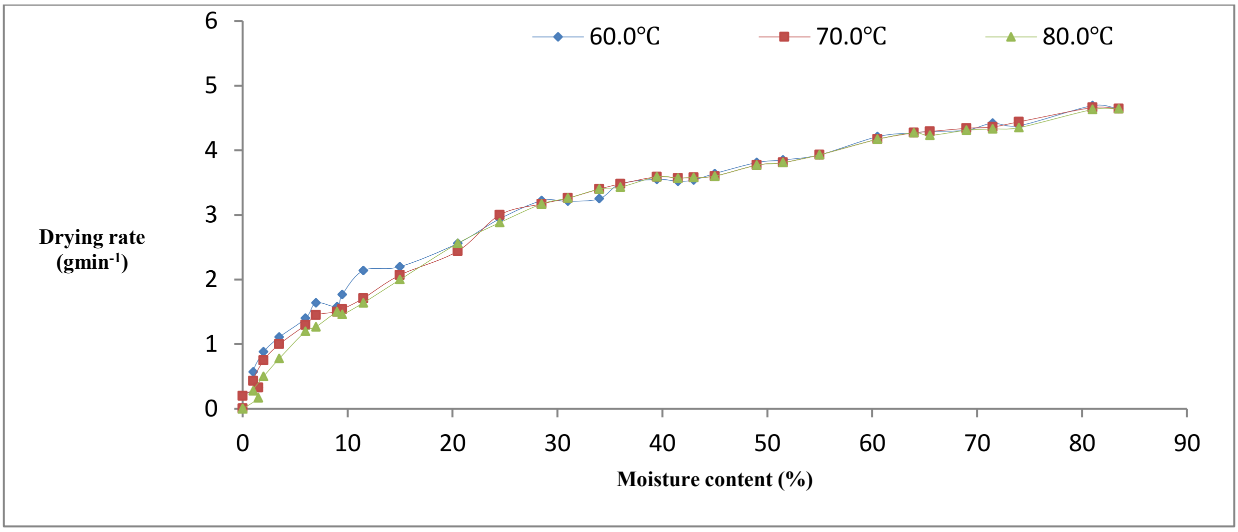

Figure 13. Drying rate (gmin^{-1}) against moisture content (%) of Crussocephalum biafrae at the fan speed of 6.00 ms^{-1}.

4. Conclusion

A study was experimentally carried out on the effects of drying rate on four different specimens of vegetables, namely *Telfaria occidentalis*, *Amaranthu scruentus*, *Talinum triangulare*, and *Crussocephalum biafrae*. A thermostat was used to regulate the drying temperature of the convective dryer used for drying the vegetable samples. The vegetable specimens were dried at regulated drying temperatures of 60.0 °C, 70.0 °C and 80.0 °C, and the effects of the drying rate on the moisture contents of the vegetables were investigated. The effect of drying rate on the moisture contents of the four samples of vegetable has been presented in this research. It showed that the sample dried at 80.0 °C had the highest drying rate, followed by samples dried at 70.0 °C and samples dried at 60.0 °C in that sequence. This work spotlights the effects of moisture contents on the drying rate under different varying regulated drying temperatures and fan speeds on four different vegetable specimens The output of the present work can be applied in food industries, and engineering in agriculture.

Author contributions: Conceptualization, SAA and IOO; methodology, SAA, IOO and TSA; software, SAA and TSA; validation, SAA; formal analysis, SAA, IOO and TSA; investigation, SAA, IOO and TSA; resources, SAA, IOO and TSA; data curation, SAA; writing—original draft preparation, SAA; writing—review and editing, SAA, IOO and TSA; visualization, SAA, IOO and TSA; supervision, IOO; project administration, SAA, IOO and TSA. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

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