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Research Article

Profile drying: A novel multistage convection drying method for indian dark red onion slices

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ABSTRACT

Drying increase shelf life and preserve nutritional value. Convection drying experiments are conducted at different novel multistage drying profiles and at constant 60°C temperature. Velocity varied in the range of 2, 3.6, 5.7, and 7.7 m/s for the dark Indian dark red onion. The objective is to analyse the multistage novel convection profile drying method for onion slices at high velocity. The constant 60°C air-drying process consumes 18.88% to 34.98% more energy than multistage drying profiles for the 360 minutes of convection drying. The arithmetic mean of effective moisture diffusivity lies between 1.002396×10^{-12} to 7.898936×10^{-11}. A better drying rate is found for constant 60°C constant temperature, but higher activation energy (1.23710647 to 1.8186585 kJ/mol) is required than drying profiles. The rehydration ratio of the profile is observed to be higher and rises uniformly with time compared to a constant 60°C. In the proximate analysis, it was observed that crude FAT, Carbohydrate, total energy, Potassium, and Calcium contents are increased on the onion's drying. Total ash content and total mineral content were detected to be decreased with drying.

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INTRODUCTION

Drying is the moisture elimination process from agriculture produce or food. Drying is used to escalate shelf life and conserve nutritional value. The type of produce and process differentiates the drying methods. Onion is agricultural produce, very commonly used in culinary preparations and for several medicinal purposes. Convection drying of onion is one of the conventional and most straightforward methods adopted universally.

Numerous literature shed light on drying of onion and reports that the available constant air temperature range investigated was 40 to 90°C, and the air velocity range was 0.2 to 2 m/s [1-8].

Cabrera-Rabi et al. proposed that in the onion drying process, it was favoured to drop the drying temperature after a definite time to ameliorate the dehydration process [9]. Soponronnarit et al. reported that the three-step drying

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method is proficient for shorter drying time and lower energy consumption [10]. In the three-step drying method drying air temperature used was 80, 80, and 67°C, and the drying time provided was 30, 30, 102 minutes, whereas the volume flow rate was 33.9, 13.5, and 6.8 m^3/min.

Munde and Agrawal reported that the time required for drying reduces by 25% with the four-step drying method compared to the two-step drying method [11].

Similar observations are also reported with the three-step drying method with 65, 55, and 45°C for 2, 5, and 7 hours respectively. It was perceived that the three-step drying method saves energy 12.70 % than constant temperature drying with an extension of 30 minutes of drying time [12].

The objective of the present work is to propose a novel multistage convection profile drying method. The proposed method varies from the literature in providing profile drying with temperature and drying time steps. Researchers have provided steps in terms of velocity, moisture, time, and temperature variation in the literature. Most of the convection drying methods available in the literature have used drying with constant air temperature. However, the proposed multistage convection drying method implemented novel profile drying of time and temperature steps with the constant velocity at inlet.

MATERIALS AND METHODS

Convective drying finds significant applications in the drying of agricultural produce. In the present study, thin onion slices are positioned in the hot air stream for convective drying. The raw material preparation and drying is as discussed.

Raw Material Preparation

Fresh Indian dark red onions of medium size (around 50 to 60 mm diameter) were purchased from the local market in Pune, India. Randomly selected onion samples were cleaned and peeled. Onion slices of 4 to 5 mm thickness were cut perpendicular to the axis with a sharp onion slicer. Approximately 100 grams of onion slices were placed in a single layer for each test.

Experimental Setup

The convection drying experiments were conducted in a laboratory air-dryer (Figure 1). It consists of an airflow rate control segment, heating control segment, and drying test compartment, as shown in Figure 2.

Air blower of 1200 CFM capacity with variable frequency drive (VFD) is used to deliver high air velocity and volume.

Thermistor controlled electric resistance heater is used for heating air, delivered by a blower. The digital temperature controller is used to create the profile pattern in the heating section. It consists of a PID controller (Nippon, NC2438) and a Solid-state relay (FOTEK, SSR - 40DA). By altering the input program to PID, variable profile temperature input is generated for variable time steps.

Heated air is allowed to enter the drying chamber. The drying chamber consists of the inlet, an air outlet, and a produce loading door. It was made with 18 mm regular waterproof plywood coated internally and externally with

Figure 1. Air dryer experimental setup.

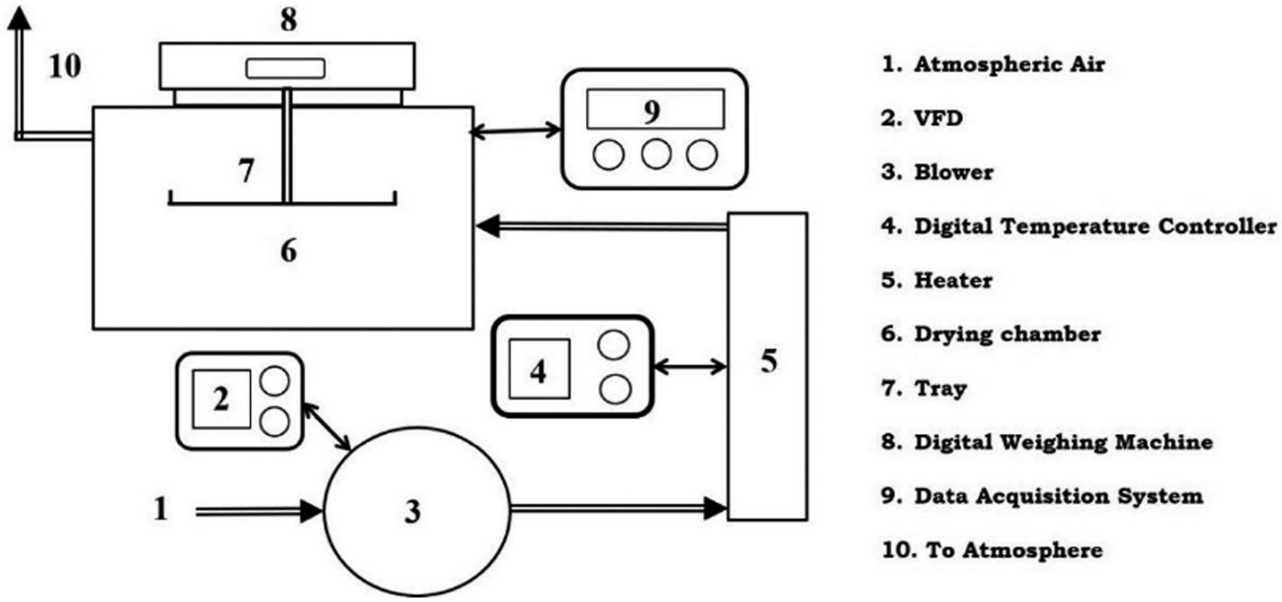


Figure 2. Schematic diagram of the experimental setup.

laminates of 1 mm. It was lined inside with aluminium foil to provide reflective insulation.

The wire mesh tray was suspended vertically in the drying chamber. The wire mesh tray with onion slices creates the blockage effect. This arrangement leads to increase the turbulence and heat transfer in the stream of flowing air [13]. Moisture loss during dehydration was measured by periodic weighing with an electronic analytical balance (HMT, accuracy: 0.01 gram). The arrangement was made in such a manner, that the onion slices remain isolated from ambient.

Dry bulb temperatures were measured with PT-100 temperature sensors and recorded periodically with a data acquisition system. The air velocity was measured using a hot-wire anemometer (Lutron - AM 4204, accuracy: ±5%). The velocity of air was measured at the inlet and outlet of the drying chamber.

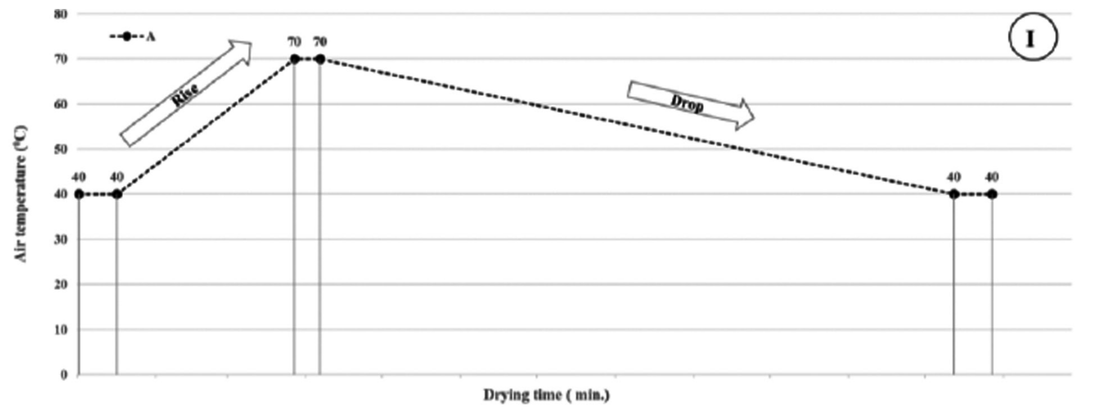
Convection drying tests were performed at different drying profiles designated as 'A', 'B', 'C', and at constant 60°C temperature from November 2017 to January 2019. Ambient temperature range 21.6 to 34.4°C was observed due to the fact of Indian climatic conditions. The PID was programmed to achieve a certain temperature as per requirement and as per time interval. The temperature range for all the visibility is 40 to 70°C. The total duration of the drying test was 390 minutes, including 30 minutes for preheating at 40°C. Profile drying is the novel six-step drying method, consisting of gradually increasing (rise) and decreasing temperature (drop) with different time steps. The digital temperature controller was set to maintain the input air temperature as indicated in Figure 3 for each profile drying.

In the 'A' profile, after preheating air for 30 minutes, 70 minutes time duration is provided for air to reach 70°C temperature. The attained temperature is maintained for 10 minutes.In the next step, 250 minutes, time duration is provided for a gradual drop in temperature. In the end, 40°C temperature was maintained for 15 minutes duration (Figure 3.a).

Similarly, all the six steps were repeated for the 'B' profile (Figure 3.b) and 'C' (Figure 3.c) profile with a change in time steps for the gradual rise and drop in temperature, respectively. Profile average air temperature distribution with drying time is as shown in Figure 4.

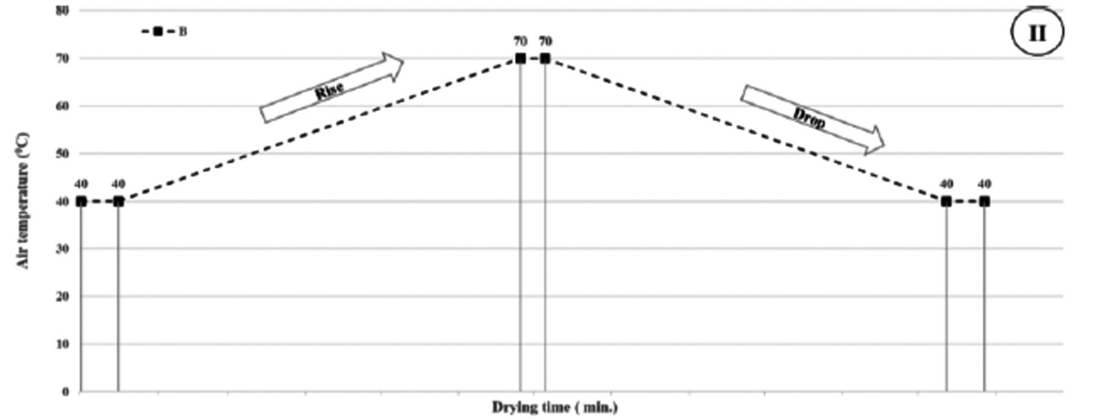
An air velocity of 2, 3.6, 5.7, and 7.7 m/s were maintained at the inlet section during the preheating period for each temperature profile drying. The weight of onion slices was measured after an interval of 30 minutes. Bias errors are taken care of by calibration of measuring instrument. Each experiment set was repeated three times with fresh Indian dark red onion slices for taking care of random errors. Uncertainty of measured and calculated parameters are observed to be within range.

The rehydration process for dried onion slices was carried out at 26±1°C. Randomly selected three dried onion slice samples from the same temperature profile group used for the experiment. The initial weight of each onion slice was measured separately. Three onion slices were immersed in three separate 50 ml beakers, filled with distilled water. The rehydration process is allowed to be continued for 60 minutes. After 10 min gap, rehydrated onion slices were removed for measuring weight. Before measurement, surface moisture was removed with tissue paper.



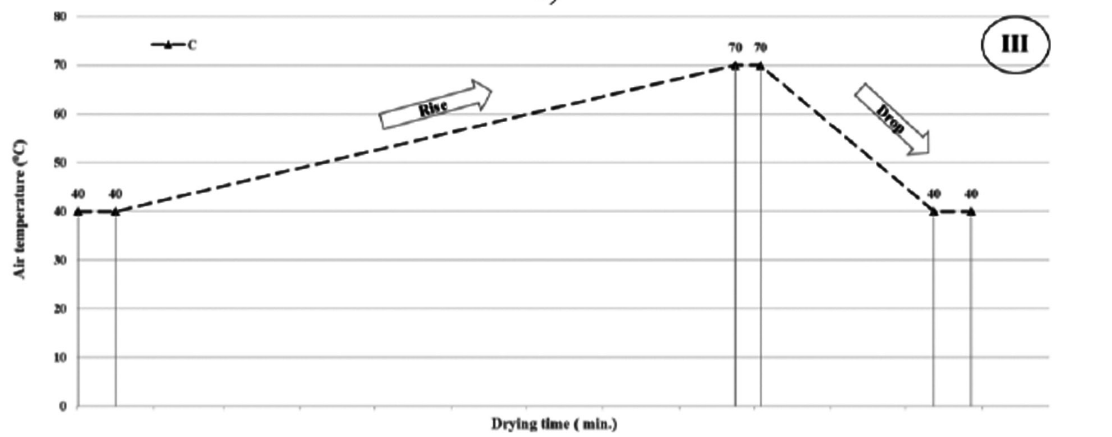
Drying time (min.)	15	30	100	110	360	375
Air temperature (°C)	40	40	70	70	40	40

a)



Drying time (min.)	15	30	190	200	360	375
Air temperature (°C)	40	40	70	70	40	40

b)



Drying time (min.)	15	30	280	290	360	375
Air temperature (°C)	40	40	70	70	40	40

c)

Figure 3. Time stepwise temperature details of multistage drying profiles a) 'A', b) 'B' and c) 'C'.

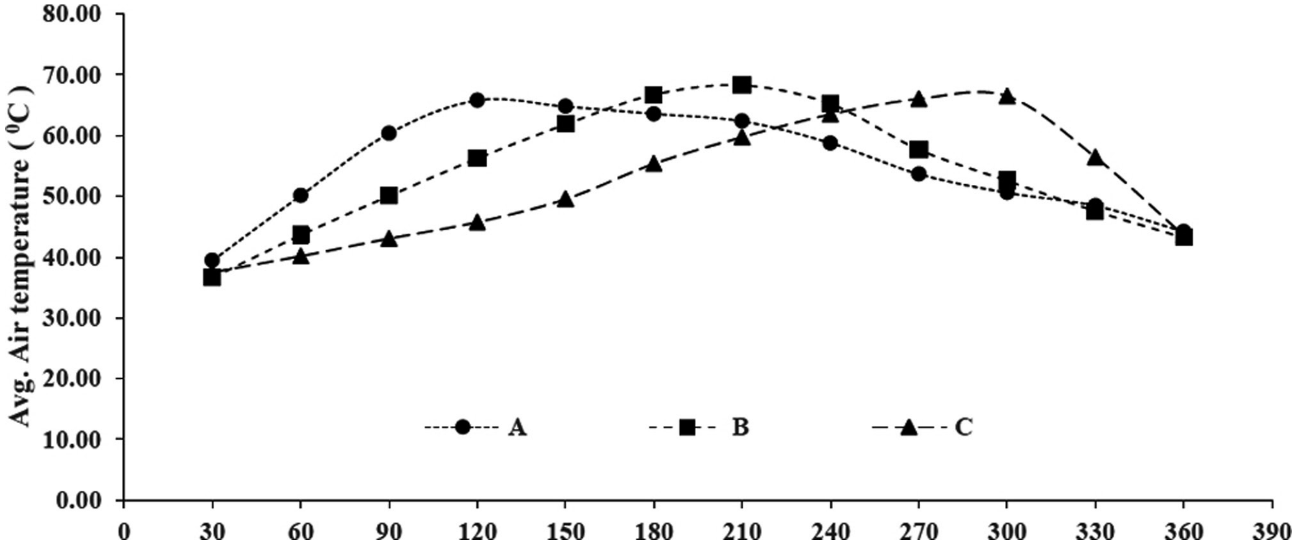


Figure 4. Variation of air temperature with drying time for novel profile convective drying of onion slices.

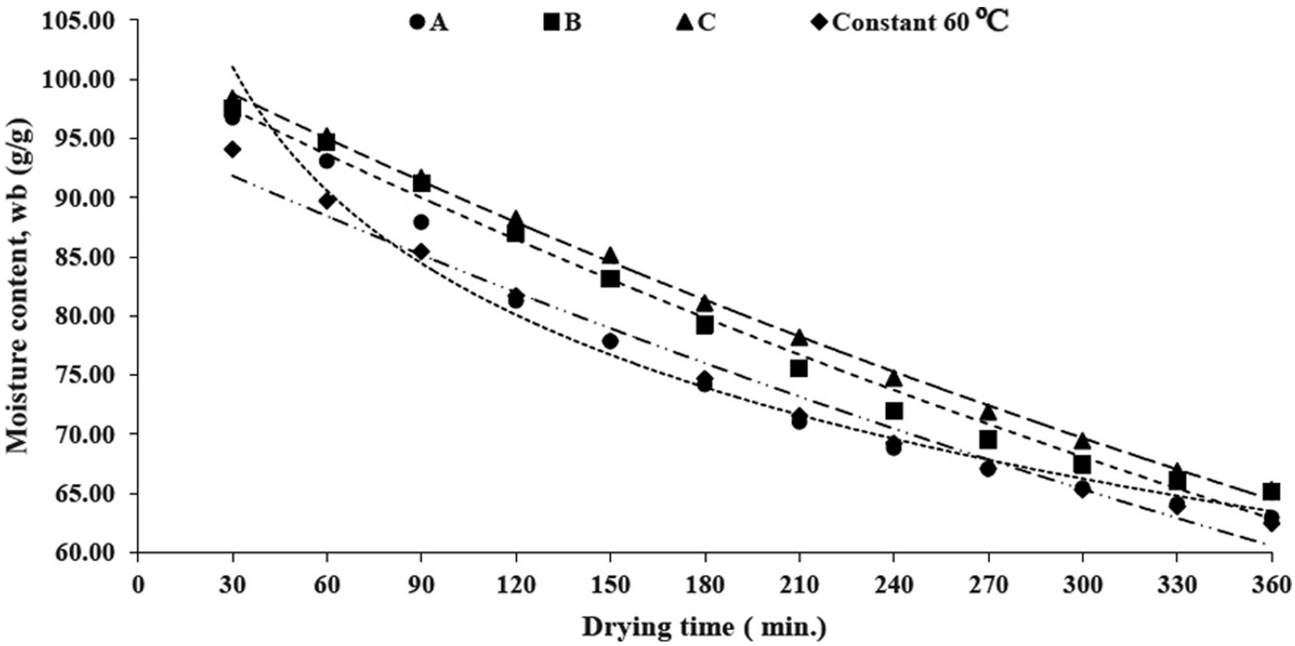


Figure 5. Variation in wet basis moisture content with drying time for temperature profile 'A,' 'B,' 'C' and constant 60°C.

The rehydration ratio was calculated from the ratio of the weight of the rehydrated sample to the weight of the dried sample.

RESULTS AND DISCUSSION

The results were obtained by investigating the effect of profile and constant temperature drying on moisture removal, drying rate, and moisture removed per mass flow rate are discussed below. Effective moisture diffusivity and activation energy were calculated and compared.

Effect of Profile and Constant Temperature Drying on the Moisture Removal Process

The drying air temperature profile has a substantial effect on the drying of Indian dark red onion slices. The moisture content variation at temperatures profile of 'A', 'B', 'C', and constant 60°C with drying time is shown in Figure 5.

'A' profile and constant 60°C show the best wet basis moisture removal at 360 minutes of drying duration.

In 180 minutes out of total moisture removed, 66.71 % moisture removed with 'A' profile and 61.31% moisture removed with constant 60°C, whereas for 'B' profile, it is 56.31% and least is observed with temperature 'C' profile, 52.27%. Out of total moisture removed, 75 % moisture was removed at 202 minutes with 'A' profile, 220 minutes with constant 60°C, 239 minutes with 'B' profile, and 258 minutes with 'C' profile.

'A' profile drying occurred in two stages. In the first stage (rise), the temperature rises from 40 to 70°C in one-third duration out of the total drying duration. In the second stage (drop), the temperature gradually decreases to 40°C in the remaining drying duration. In the rise stage, along with the evaporation of surface moisture, the tendency of moisture migration to the surface may be getting accelerated to provide rapid drying due to a sudden rise in temperature as compared to 'B' and 'C' profile. In the drop stage, the moisture removal from a limited upper layer may be sluggish because of air's tendency to hold less moisture at a lower temperature. In the 'B' and 'C' profile, the rise stage is elongated to one-half and two-third duration, respectively. Prolonged contact of high-temperature air hardens cells of top layers, making the migration of moisture slower.

In total, the moisture content versus drying time trend is comparatively smoother. Kemp et al. noted a similar observation for drying kinetics [14] and Bhong and Kale [15].

The moisture removal process from dark red onion accelerates as temperature increases. Similar trends were observed by Kiranoudis et al. [16], Olalusi [17], and Demiray et al. [18] for the nearly same range of constant temperature drying.

During all drying curves (Constant temperature and profile drying), the initial constant drying period is concise and escapes unnoticed. Onion, being hygroscopic, it rapidly enters and exhibits a more extended falling rate period. A similar observation has also been stated by Olalusi [17], Demiray et al. [18], and Kalbasi [19].

In total, it can be clinched that all the curves except the 'A' profile exhibit the exponential nature, which indicates that the moisture content removal process shrinks more slowly as moisture content reduces. 'A' profile illustrates the logarithmic curve, which specifies that moisture content removal initially rises rapidly, then progressively slows down.

Effect of Profile and Constant Temperature Drying on Moisture Removal per Unit Mass Flow Rate (Moisture - Air Ratio)

Airflow is a vital functional constraint in analyzing the moisture removal process. The moisture removal process with temperature profile drying can help understand if the comparison is made with a mass of air utilized per unit time. Moisture – air ratio variation of air for 'A', 'B', 'C' profile, and constant 60°C constant temperature with drying time is shown in Figure 6.

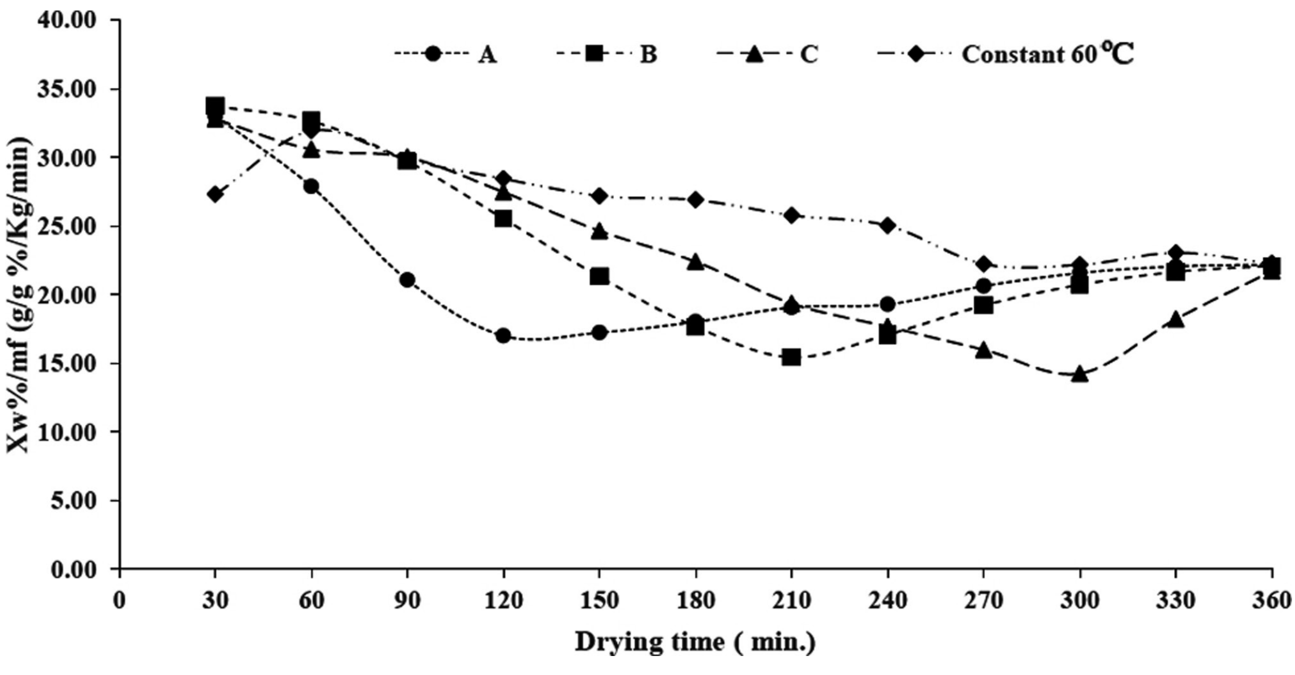


Figure 6. Variation in the ratio of moisture content removed and mass flow rate with drying time for temperature profile 'A,' 'B,' 'C' and constant 60°C.

In profile drying, the inlet velocity and mass flow rate of dry air gradually increases and decreases as temperature varies. The curves of moisture – air ratio is the replica of average temperature curves for temperature profile.

The minimum moisture – air ratio for the drying profile is observed when the temperature is maximum. At peak temperature, velocity is high and at high velocity, and this the stay time is lower, leading to making moisture – air ratio smaller.

In temperature 'A' profile drying, the ratio is decreased gradually, which may be due to the vanishing of moisture from a few upper layers. In the meantime, moisture gets migrated from the lower level to the upper layer. After 120 minutes, migrated moisture is again available for removal; hence moisture – air ratio increases gradually. It also indicates that a high moisture – air ratio specifies that more moisture is removed per mass flow rate.

In temperature 'B' profile drying, it is observed that the moisture – air ratio is gradually decreased at a slower pace till 210 minutes. Similar phenomena have occurred in the 'C' profile. The moisture – air ratio for a constant 60°C displays a downward trend.

In drying during the rise stage, heat available is utilized in two phases. In the first phase, heat removes moisture, and in the second phase, it assists moisture migration. Slowly the moisture available in top layers reduces, and in the same manner, the ratio of moisture content and mass flow rate reduces. After peak temperature, a slight increase in moisture – air ratio is observed. The drop in moisture – air ratio during the rising stage and a slight increase during the drop stage is attributed to mass flow rate changes on account of temperature variation and corresponding volume changes.

In general, it is observed that, as velocity increases, the mass flow rate of air increases, and it leads to reduce the moisture – air ratio. This behaviour is in line with Bhong and Kale [20].

Effect of Profile and Constant Temperature Drying on Drying Rate

The drying rate postulates the rate of moisture removal concerning the previous state at a specific time. The drying rate of Indian dark red onion slices for profile 'A', 'B', 'C', and constant 60°C with drying time is shown in Figure 7. All the curves for different velocities indicate falling rate behaviour.

The drying rate curves indicate that the moisture removal process from Indian dark red onion slices is stable and smooth.

For the 'A' profile, the drying rate witnessed to rise till 120 minutes. After 120 minutes, a sudden fall is detected, and after that almost gradual decrease in drying rate is observed. In the 'A' profile, the temperature is raised till 70°C, the free moisture is available on the slice surface, and moisture available in upper layers can readily

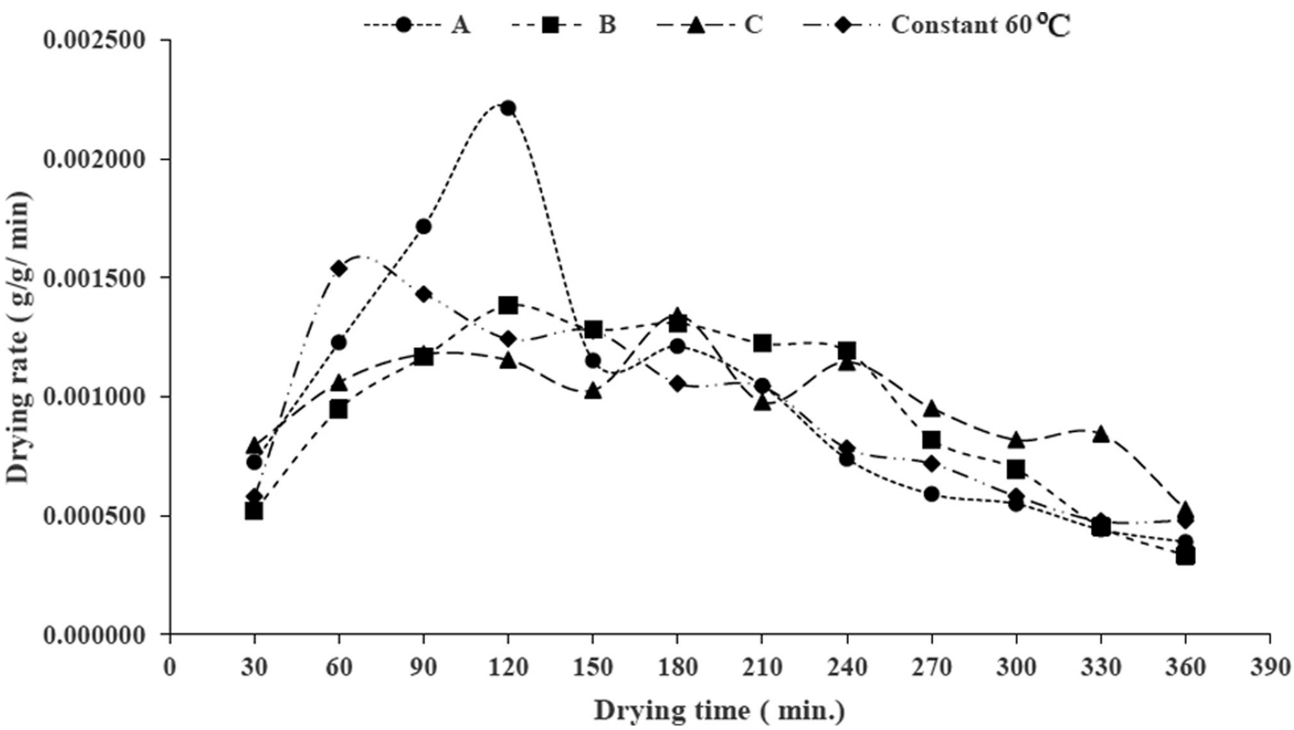


Figure 7. Variation in drying rate with drying time for temperature profile 'A,' 'B,' 'C' and constant 60°C.

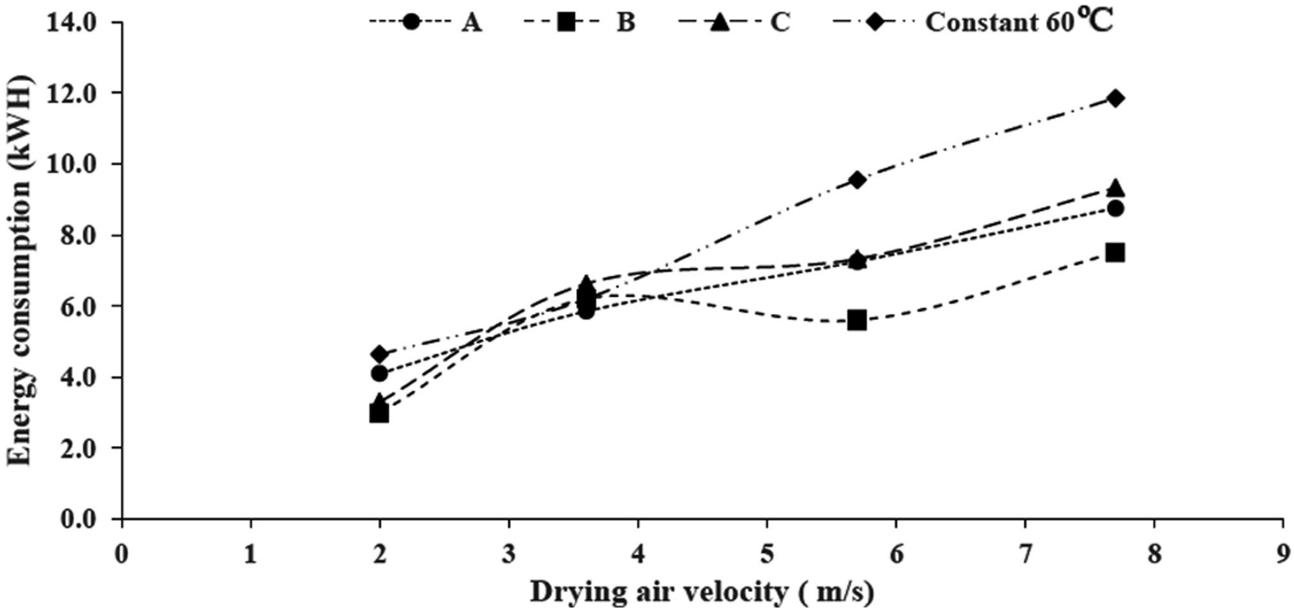


Figure 8. Variation of energy consumption with initial drying air velocity for temperature profile 'A,' 'B,' 'C' and constant 60°C.

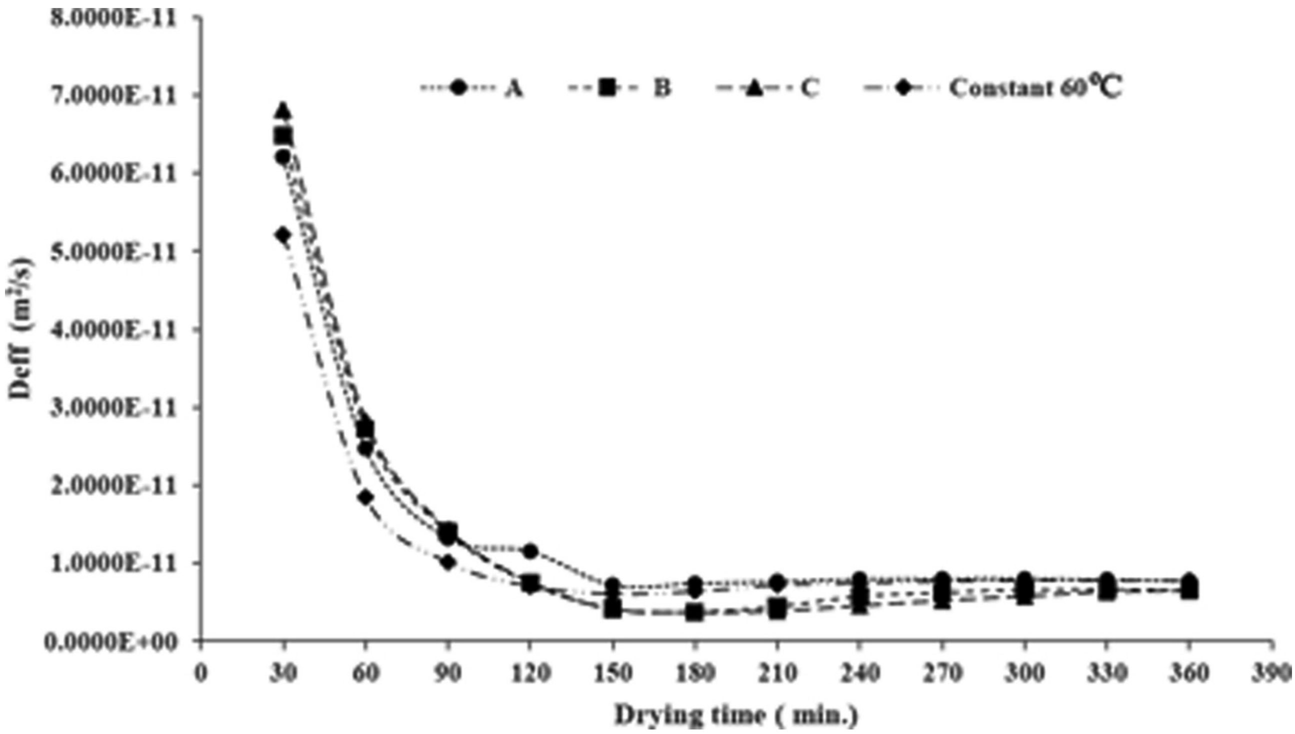


Figure 9. Variation of effective moisture diffusivity with drying time for temperature profile 'A', 'B,' 'C' and constant 60°C.

accessible for removal. Hence it causes to increases the moisture removal rate to 120 minutes. All the moisture available in the upper layers gets evaporated. The heat supplied is also gradually decreasing, which leads to a delay of the process to bring moisture trapped in lower layers to the upper layer. In this time gap, the sudden crunch of moisture, availability is observed, leading to a sudden fall in the drying rate.

For the 'B' profile, the drying rate witnessed a gradual rise till 120 minutes, similar to the 'A' profile curve. In contrast to the 'A' profile, the temperature rise is set to 210 minutes; hence small gradual reduction is observed in the drying rate. After 240 minutes, as per the gradual decrease in temperature, the drying rate reduces.

Similar to the 'A' and 'B' profile, in the 'C' profile drying rate detected to be rise till free moisture of the surface and the moisture available in upper layers get evaporated. The peak temperature is achieved at about 300 minutes. The drying rate dropped at 150 and 210 minutes; this is due to a delay in the migration of moisture from the lower layer to the upper surface, which leads to making the process shingly.

At a constant 60°C, the falling drying rate is observed after 60 minutes. A minor drop in drying rate is observed in some places. The smooth process of migration of moisture from the bottom layer to the surface is taking place.

Overall, it is observed that the moisture content curve is smoother than the drying rate curve. In the present study, the drying rate plot typically has a substantial amount of random noise. As moisture content reduction takes place with extended drying time, noise becomes more turbulent towards the end. This behaviour is in line with Kemp et al.'s observations [14].

It can be quantified that drying air temperature creates a significant impact on the drying rate. This observation is in line with Stegou – Sagia and Fragkou [21]. All the profile exhibits a better drying rate whenever a high temperature of drying air is provided. Also, it is observed that, though initially, air velocity is constant, it rise with drying air temperature. High temperature and high air velocity overcome moisture migration resistance, and a high drying rate is observed. Inclusively, in Indian dark red onion, internal mass transfer resistance controls the moisture transfer process at higher temperatures and velocity than external resistance. This result is in line with McMinn and Magee [22].

Effect of Profile and Constant Temperature Drying on Energy Consumption

Energy consumption is one of the prominent parameters from an efficiency point of view in the drying process. In convection drying, efficient use of energy to dry produce is anticipated. In the present work, energy consumption is measured for heating air at different air velocity inputs, as input for blower remains constants for all drying conditions at stated air velocity (Figure 8).

Profile 'B' and 'C' requires the lowest energy for drying at For 2 m/s air velocity. For air velocity 3.6 m/s, 'B' profile and constant air temperature constant 60°C consumes 6.2 kWh, whereas 'A' profile consumes 5.9, and 'C' profile consumes 6.6 kWh. The minimum energy consumption was observed for drying with a 'B' profile for 5.7 and 7.7 m/s air velocity. At air velocity, 5.7 m/s, 'A' profile and 'C' profile consumes almost the same energy.

The maximum energy consumption witnessed with constant 60°C at all air velocity, except 3.6 m/s. This may be due to the time step variations set for the rise and drop stage, as comparative sudden rise and drop consumes more power than the gradual rise and gradual drop.

Constant 60°C air-drying process consumes 18.88 % more energy than drying with 'A' profile, 34.98 % more energy than with 'B' profile, and 22.62% more energy than with 'C' profile.

Effect of Profile and Constant Temperature Drying on Effective Moisture Diffusivity and Activation Energy

The effective moisture diffusivity (D_{eff}) illuminates the drying characteristics. Irrespective of diffusion's mechanism, an effective diffusivity value (D_{eff}) describes the rate of moisture movement [21]. Effective moisture diffusivity is calculated using the equation proposed by Crank [23] [24].

Variation of effective moisture diffusivity for profile 'A', 'B', 'C', and constant 60°C with drying time is shown in Figure 9. The maximum effective diffusivity is observed for the 'C' profile, and the minimum is found for a constant 60°C at 30 minute drying time.

The sudden drop in effective moisture diffusivity is observed 60 minute drying time for all profiles and constant temperature, due to vanishing of surface moisture.

After 150 minutes of drying time, nearly constant moisture diffusivity is observed for all profiles and constant temperature. After 360 minutes of drying, all the temperature profile and constant temperature drying indicate almost the same moisture diffusivity. The 'A' profile reveals comparatively higher moisture diffusivity, and the 'C' profile exhibits lower moisture diffusivity, after 90 minutes of drying time. Effective diffusivity reduced with the reduction of moisture content in onion slices. Similar findings are observed by Rahman S and Jack Lamb [25] with pineapple.

It is found that, for all profiles and constant temperature drying, the values of effective moisture diffusivity lies between 1.002396×10^{-12} to 7.898936×10^{-11}. These values are within the general range of 10^{-8} to 10^{-12} m^2/s for drying food materials [22].

Features affecting diffusion energy are substantial to explain drying kinetics. Temperature is one of the robust

Table 1. Average activation energy for different drying profile and constant temperature of onion slices

Profile/Constant temperature	Average activation energy (kJ mol^{-1})
A	70.5469604
B	70.78509547
C	70.20354344
60°C	72.02220194

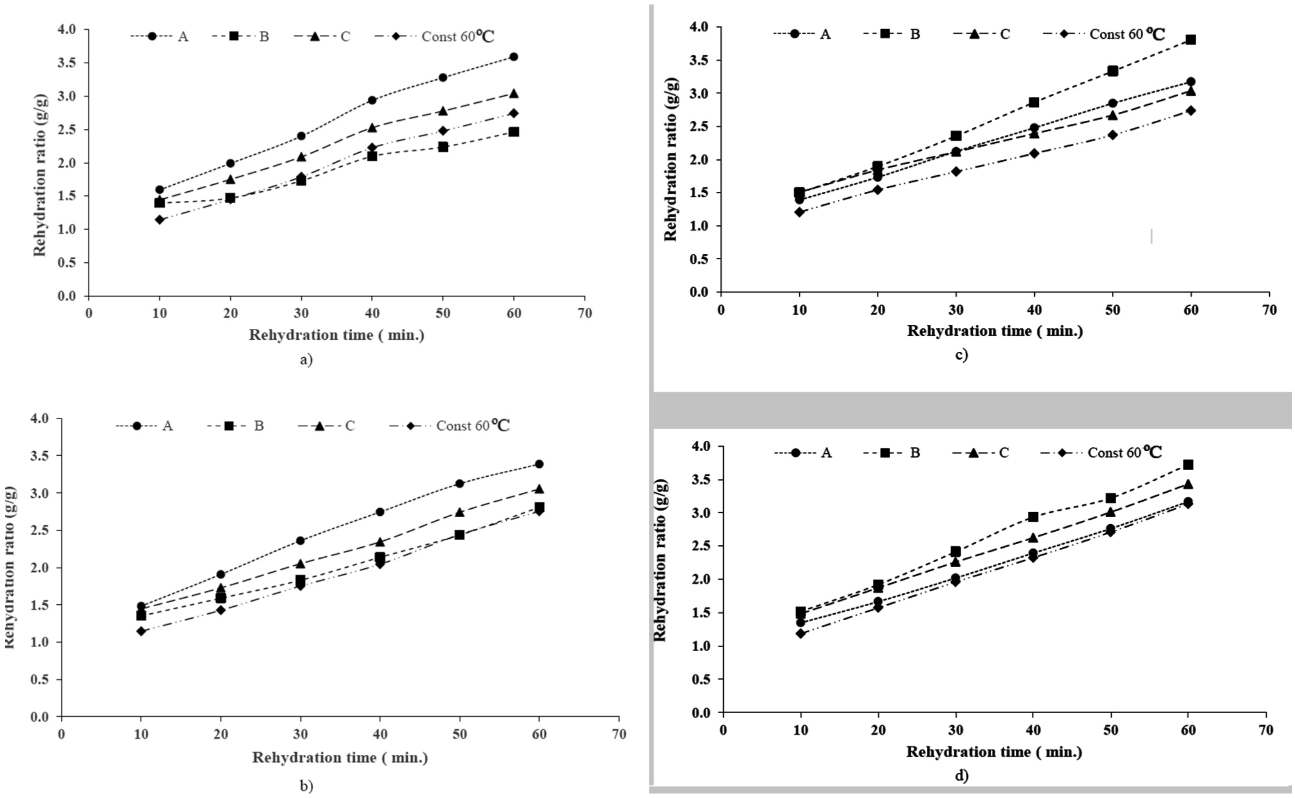


Figure 10. Variation of rehydration ratio with rehydration time for a) 2 m/s, b) 3.6 m/s, c) 5.7 m/s and d) 7.7 m/s air velocity.

Table 2. Proximate composition of profile mode, constant mode dried onion and fresh onion (per 100 g of the onion)

	'A' Profile	'B' Profile	'C' Profile	60°C	Fresh
Crude Fat (gram)	0.9	0.7	1.4	1.2	0.2
Crude Protein (gram)	1.895	6.91	8.625	7.425	2.36
Crude Fibre (gram)	4.5	4	3.5	3.8	3.75
Ash content (gram)	10.12	2.07	2.1	3.2	15.15
Carbohydrates (gram)	44.6	66.8	60.8	60.2	24.2
Energy (Kcal)	191	304	299	280.4	107
Mineral (gram)	1.6	2.7	3.2	2.8	3.3
Sodium (gram)	0.4	0.032	0.12	0.02	0.24
Potassium (gram)	0.079	0.039	0.04	0.063	0.022
Calcium (gram)	0.23	0.42	0.65	0.85	0.2
Phosphorus (gram)	0.13	0.6	0.6	0.56	0.15

parameters affecting diffusion energy. The activation energy (E_a) is the kinetic energy driven by the temperature required for the produce drying process. The activation energy was calculated using the slope of $\ln D_{eff,avg}$ versus the reciprocal of the absolute drying air temperature ($1/T_{abs}$) [23], [24]. It is observed that minimum activation energy is required for 'C' profile (Table 1). Whereas for constant 60°C, maximum activation energy is needed. Optimum use of energy for temperature profile and air velocity variation observed for 'A' profile. A better drying rate is found for constant 60°C constant temperature, but high activation energy is required.

The average activation energy for all profiles and constant temperature drying has been observed in the range of 70.20354344 to 72.02220194 kJ mol^{-1}.

Effect of Profile and Constant Temperature Drying on Rehydration Ratio

The rehydration ratio is an important quality characteristic for the dried onion slices in the present study. The rehydration ratio observed to rise proportionally with a rise in the rehydration duration (Figure 10). The maximum rehydration ratio was found for profile 'A' at air velocity 2 and 3.6 m/s (Figure 10.a and 10.b). Similarly, the maximum rehydration ratio was detected for profile 'B' at air velocity 5.7 and 7.7 m/s (Figure 10.c and 10.d). Cumulatively, it can be stated that for constant 60°C, rehydration ratio is found to be minimum at all air velocities except 2 m/s. With 2 m/s air velocity, it is observed that profile 'B' exhibits the lowest rehydration ratio after 30 minutes.

The rehydration ratio for profile 'A' typically decreases as velocity increases. Whereas, for profile 'B' rehydration ratio increases as velocity increases. Profile 'C' and constant 60°C exhibit uniform rise in rehydration ratio with air velocity. Similar finding related to air velocity is observed by EL-Mesery and Mwithiga [8]

The degree of the structural impairment to layers in the onion slices directly affects the rehydration process [26]. Rehydration ratio is influenced by the drying profile and eventually drying temperature [27]. The rehydration ratio of profile 'A,' 'B,' 'C' is observed to be higher and rises uniformly with time compared to a constant 60°C. It undoubtedly specifies that in profile drying, less structural damage to the inside layers of the onion slices has occurred than constant 60°C temperature.

Effect of Profile and Constant Temperature Drying on Nutritional Content

Raw onions are low in calories (110 kcal/100 g) yet increase great essence to a wide diversity of foods. It has judicious quantities of Protein, Fat, Fiber, and virtuous quantities of Calcium, Phosphorous, and Potassium.

The onion was dried at profile temperature mode ('A', 'B', 'C') and at constant temperature mode (60°C) for 390 minutes of drying time (including 30 minutes of preheating). Three samples for each temperature mode and three fresh onion samples were analyzed for the proximate composition to study the effect of drying.

Nutritional contents of the samples were determined by standard methods (AOAC 2000) [28]. The average of three proximate compositions fresh and dried onion is shown in Table 2.

Crude FAT content was detected to be increased on the drying of the onion sample. The highest crude protein content (365%) was observed with profile 'C' drying, and the lowest (80%) was observed with profile 'A' drying. There is no significant rise in crude Fiber content observed with drying.

Total ash content was observed to be decreased with drying. In Profile 'A', drying 10.12 gram of total ash content was found compared to the 15.15-gram ash content of fresh onion. Total mineral content was examined to be decreased with drying. Profile 'C' drying exhibit nearly the same mineral content as a fresh onion sample.

In mineral composition, a 67% rise in Sodium is observed with profile 'A' drying. Uppermost Potassium rise (around 259%) observed with profile 'A' drying. More than threefold Calcium rise revealed with constant 60°C. Profile 'B', 'C' drying exhibit more than a 300% rise in Phosphorus. A decrease in Phosphorus content was observed with profile 'A' drying.

Growth of around 1.5-fold in Carbohydrate and total energy content were examined with onion drying, except profile 'A' drying. The upsurge of half fold in Carbohydrate and total energy content were found with profile 'A' drying.

Inclusively, it can be stated as, profile 'C', 'B' drying produce provides less nutritional loss during drying.

CONCLUSIONS

The following findings are derived from experimental data analysis for novel multistage profile drying of Indian dark red onion slices.

Moisture removal process from Indian dark red onion accelerates as temperature increases. Temperature 'A' profile and constant 60°C show the best wet basis moisture removal at 360 minutes. Drying curves for the 'B' and 'C' profile exhibit the exponential nature, while the 'A' profile illustrates logarithmic nature.

In profile drying, the inlet velocity and mass flow rate of dry air gradually increase and decrease as temperature varies. In Indian dark red onion, internal mass transfer resistance controls the moisture transfer process at higher temperature and velocity than external resistance.

Constant 60°C air-drying process consumes 18.88 % more energy than drying with 'A' profile, 34.98 % more energy than with 'B' profile, and 22.62% more energy than with 'C' profile.

It is found that, for all profiles and constant temperature drying, the values of effective moisture diffusivity lies between 1.002396×10^{-12} to 7.898936×10^{-11} and the average activation energy for all profiles and constant temperature drying has been observed in the range of 70.20354344 to 72.02220194 kJ mol^{-1}.

The rehydration ratio for profile 'A' typically decreases as velocity increases, whereas for profile 'B' rehydration ratio increases as velocity increases. Profile 'C' and constant 60°C exhibit uniform rise in rehydration ratio with air velocity. Overall, it is detected that in profile drying, less structural damage to the inside layers of the onion slices has occurred than constant 60°C temperature.

In the proximate analysis, it was detected crude FAT, Carbohydrate, total energy, Potassium, and Calcium contents are increased on drying of onion. There is no significant rise in crude Fiber content observed with drying. Total ash content and total mineral content were detected to be decreased with drying. Maximum crude protein content was observed with profile 'C' drying. Maximum 50% of Sodium observed on drying with profile 'C' drying compared to a fresh onion. Except for profile 'A', the rest of the drying modes revealed a decrease in Phosphorus content with drying. Inclusively, it can be stated as, profile 'C', 'B' drying generate less nutritional loss during drying.

The present study can be extended in the analysis of prolonged drying duration for multistage profile drying.

NOMENCLATURE

D_{eff}	Effective moisture diffusivity	$m.s^{-1}$
D_r	Drying rate	$g.g^{-1}.min$
E_a	Activation energy for diffusion	$KJ.mol^{-1}$
E_c	Energy consumption	kWH
$\dot{m}$	Mass flow rate	$kg.\ s^{-1}$
X_w	Wet basis moisture content	g water. g^{-1} dry matter or % wet basis
R_c	Rehydration ratio	g. g^{-1} or %
t	Drying time	s
T	Input hot air temperature	°C
V	Air velocity	$m.s^{-1}$
Δt	Drying time interval	s

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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