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Influence of Infrared Heating Parameters on the Drying Characteristics of Onion Slices

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ABSTRACT

The overall performance of the onion was statistically evaluated based on slice variables such as thickness, infrared power, and air velocity. Drying time, color, shrinkage, water activity, and rehydration ratio are critical parameters in the analysis of material properties. The onion slices were subjected to drying under the ensuing settings: infrared powers of 0.13, 0.22, and 0.34W/cm², air velocities of 0.5, 1.0, and 1.5m/s, and slice thicknesses of 2, 4, and 6 mm. The experimentally acquired dehydrating curves were subjected to a curve-fitting process to align them with the thin-layer drying equations. The findings indicated that the drying time increased with air velocity and slice thickness but decreased with increasing infrared power. The mean activation energy was determined to be 19.02-29.83kJ/mol under various conditions. While the shrinkage ratio increased and declined with air velocity, the rehydration ratio grew and dropped with increasing infrared radiation intensity and air velocity. The increased infrared and reduced air velocity improve water disappearance from the exteriors of the onion. The color change is accompanied by increased airflow and IR.

1. Introduction

Drying is an optimal method for preserving fruits and extending their shelf life. Drying agricultural products is optimal for making fruits more available, as they have an extended shelf life. It is also crucial to progress and increases the marketplace for best, consumer-dried foods with satisfactory color, form, and moral rehydration abilities (El-Mesery and Mwithiga, 2015). The application of infrared technology for drying agricultural products is becoming increasingly prevalent, with traditional methods being supplanted in many instances. The utilization of the infrared drying method in foods has numerous benefits. The direct heating of the material facilitates the rapid drying process. Furthermore, infrared drying requires significantly less energy than hot-air drying. Infrared energy is a form of electromagnetic radiation located just beyond the red end of the visible light spectrum. It is frequently utilized for heating due to its capacity to be absorbed by the substance and transformed into thermal energy (Ye et al., 2021). A heating element engineered to facilitate infrared energy transfer is intended to emit infrared radiation. This can be accomplished using many methods, including carbon or ceramic components, which release infrared radiation upon heating. Rather than warming the surrounding air, these heating components convey heat directly to the material's surface via infrared radiation. This method enhances efficiency by circumventing the necessity to heat air, thereby allowing heat transmission to the substance through convection (Chen et al., 2019). Furthermore, infrared drying requires significantly less energy than hot-air drying. Heat is precisely directed to the required areas, resulting in expedited heating times and less energy use. This heating element is utilized in diverse applications, such as infrared heaters in home and commercial environments, industrial procedures necessitating direct material heating and certain cooktops and ovens.

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The unheated surrounding air enhances safety and comfort in the environment. In a space heated by infrared radiation, the air temperature may be lower than conventional heating; nonetheless, objects and individuals within the room might still experience warmth due to direct heat transfer (Zhang et al., 2022). Despite the extensive research in this area, much is still to be learned about drying food products using infrared energy. For instance, no study examined the impact of sample thickness and drying conditions on the quality of onion slices in an infrared heating system. The objective of this study is to evaluate the Infrared Heating Parameters of air velocity, slice thickness, and infrared power on the drying characteristics of onion slices.

2. Materials and methods

Samples preparation

Red onions (*Beheri*) were acquired from onion farm in Kafr El Sheikh and refrigerated at 4°C. The experiments were conducted at Food Technology Research Institute and Agricultural Engineering Research Institute, Agricultural Research Center, Egypt. After two hours of ambient temperature settling, the samples were detached from the refrigerator. The onions were sliced into thicknesses of 2, 4, and 6mm using a slicing machine, Figure 1 describes the investigational technique.

Experimental drying apparatus

The apparatus incorporates a conveyor belt system, a drying cabinet, and an infrared technique. The drying space comprises chambers with dimensions (0.8 × 0.8 × 0.60m). An aluminium layer with an infrared reflective coating measuring 0.15cm in thickness was applied to the inner surface of the drying chamber. The infrared heater halogen lamps with a wattage of 1000W and a diameter of 35.5cm were installed. The lamps also had a diameter of 0.6 cm. The infrared lamps with tray were located in parallel with a stable 15cm slit. The output power of the infrared radiation can be modified by regulating the voltage with the aid of a power regulator. The convective unit comprises two electrical heaters responsible for generating the requisite drying air velocity. Subsequently, the air flows through a PVC tube and into the drying cabinet via two inlets. A control valve was installed at the PVC pipe's intake to regulate the air flow entering the drying chamber. As the air passed through a pair of electric heaters with a power output of 1.5kW, its temperature increased.

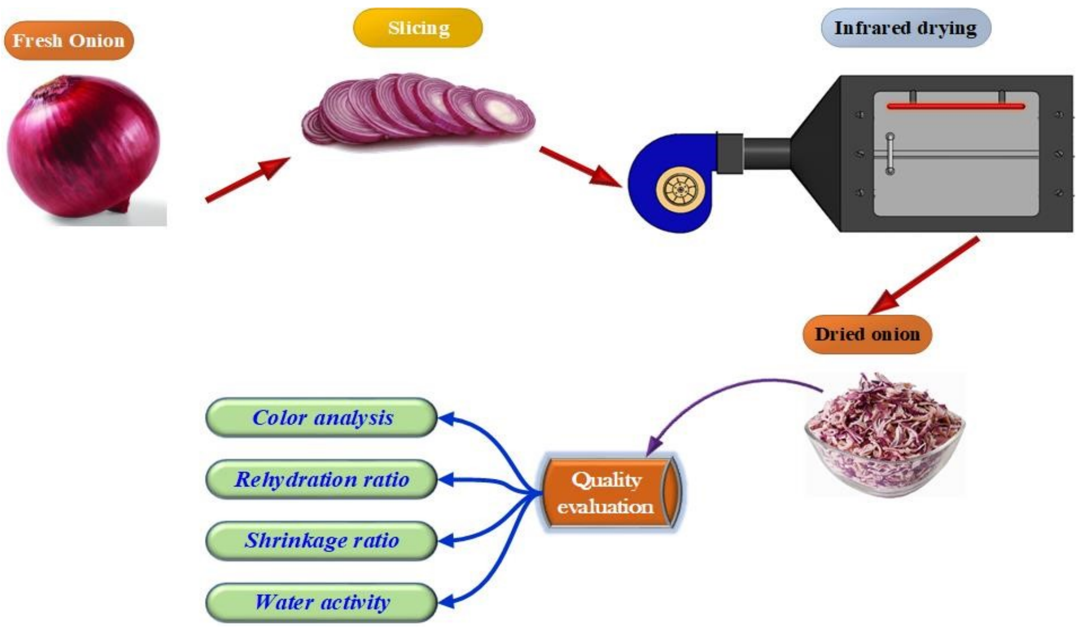

Figure 1. Flowchart of drying onion

Drying operation

The appliance was deactivated for thirty minutes to maintain uniform drying settings. 200 grams of onions were placed in an evenly distributed thin layer on a drier below the wire mesh tray. The onion dehydrating employed the following variables: slice widths of 2, 4, and 6mm; air velocity of 0.5, 1.0, and 1.5m/s; and infrared power of 0.13, 0.23, and 0.35W/cm². The infrared radiation intensity or output power of the lamps could be varied by regulating the voltage through a power regulator. The drying procedure was repeated until the onion slices attained a final water content of approximately 7±0.5% (wb).

Moisture content

Using the method outlined by (Sacilik et al., 2006), a sample of onion slices weighing about 20 grams was dried on a plate in an oven at 105 °C for twenty-four hours. This was done to control the original water content of the onion slices. A more reliable average was obtained by conducting three separate runs to generate the average. The process was repeated three times to provide a more reliable average. The initial moisture content of the samples was determined to be 85.8 ± 0.1% (w.b).

Water activity

The water activity (aw) was measured using an Aqualab water activity meter (Decagon Devices, Model 4 TE, USA) at 25 ± 0.1°C. The apparatus employs a resistive, electrolytic sensor to quantify the moisture content of the surrounding air within a regulated chamber, thereby facilitating an accurate and dependable assessment of the water activity (aw).

Color assessment

The material was subjected to 5 color tests using color measuring devices (CR-400, Minolta). The total color alteration in the new item was calculated utilizing Equation 1. (Zeng et al., 2019)

Where: The value of lightness (L*), redness (a*), and yellowness (b*), the subscript “o” refers to the color reading of fresh samples while “*” refers to the color parameters of dried samples.

$$\delta E = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \qquad (1)$$

Shrinkage ratio

A typical chemical reaction noticed by different dehydration techniques is the shrinkage of nutrition. An accurate evaluation of the water and temperature profiles in hydrated objects is essential, as these variations impact the outcome (Ratti, 2001). The mean principles were subsequently reported (Velic et al., 2007). The shrinkage ratio (Sr) was determined using Equation 2.

$$S_r = 1 - \frac{V_d}{V_o} \qquad (2)$$

where V_o and V_d represent the average volume of a slice before drying and the average volume of the dried slices, respectively.

Rehydration ratio

The present study introduced 150ml of purified water into a 500ml beaker. The glass was subsequently closed and heated for five minutes. After measuring the samples, the rehydration ratio (Rr) was calculated using Equation 3. This approach is outlined by Shewale et al. (2021)

$$Rr = Mr/Md \qquad (3)$$

where Mr is the mass of the rehydrated slices, and Md is the mass of dry slices used for rehydration.

Statistical analysis

The experimental data are presented as means ± standard deviations (SD). Statistical analyses were performed using SPSS statistics software. The effects of various operating settings on the drying properties and quality parameters were assessed using an analysis of variance (ANOVA), which proceeded by a post hoc Duncan's multiple range test at a significance rank of 0.05.

Results and discussion

Drying characteristics

Figure 2 illustrates the impact of various drying parameters on the duration of the infrared dehydrating for 2mm, considering multiple levels of infrared power and air velocity. The drying durations required to reduce the water content to about 7% (w.b) were 240–300 minutes, 160–270 minutes, and 120–180 minutes at infrared power ranging from 0.13-0.35W/cm², respectively. Increased infrared power will result in higher product temperatures and heat absorption, enhanced water transmission pushing force, accelerated dehydrating rate, and reduced drying duration. An increase in air velocity while maintaining constant infrared radiation intensity resulted in extended drying time. The data indicate a significant decrease in the product's drying rate with an increase in air velocity. This pattern was applicable at all levels within the parameters of the current study. The item in question will cool, leading to a decrease in dripping air velocity. The optimal combination of intensity and airflow may lead to a reduction in drying duration. When working with barley, (Afzal and Abe, 2000), (El-Mesery and Elabd, 2021), and (Nowak and Lewicki, 2004) discovered that the dehydrating period rises as air velocity rises.

Figure 3 demonstrates how different slice dimensions affect the length of the drying procedure. The examination is performed under constant air velocity and infrared radiation levels of 0.5m/s and 0.35 W/cm², respectively. The drying frequency increased by 80% and 188%, respectively, as the slice thickness rose from 2 to 6mm. The drying period increased with thickness, as a thicker slice retains more moisture while maintaining an equal outside area exposed to infrared power. Moreover, drying a thicker slice presents more significant challenges due to the extended diffusion pathway for moisture to exit from the interior. A prior study by (Sacilik and Elicin, 2006) revealed propensities similar to those in this report.

Water activity

Table 1 displays the impact of different drying settings on the (a_w) of the samples. According to all drying requirements, the (a_w) slices remain constantly below 0.6, indicating that the samples are not deteriorating due to microbial activity. The average of samples ranged from 0.38 to 0.47. The increased infrared and reduced air velocity improve water disappearance from the exteriors of the onion. The improved water loss from the superficial slice and increased water diffusion within the slices facilitate more rapid attainment of the desired water activity. These results demonstrate that infrared drying techniques can effectively attain the desired water activity (aw) appropriate for prolonged storage durations (Royen et al., 2020).

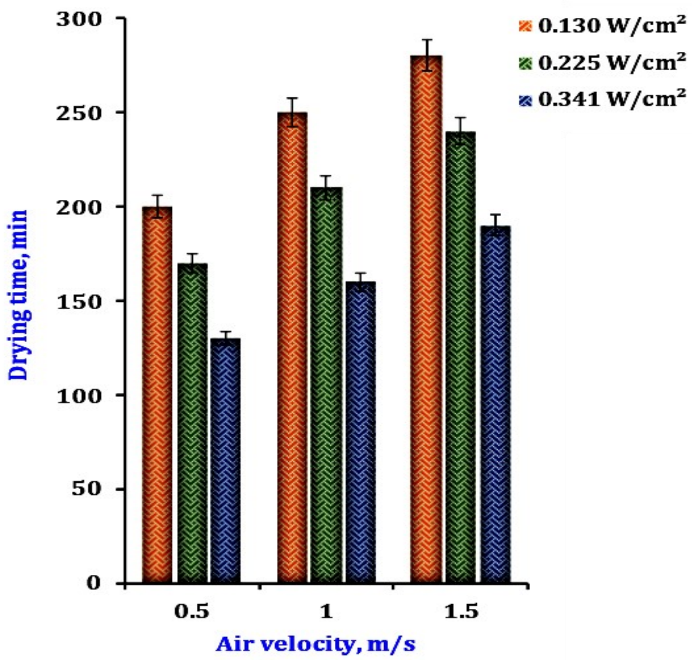

Figure 2. The difference in drying time of onion slices under various drying conditions

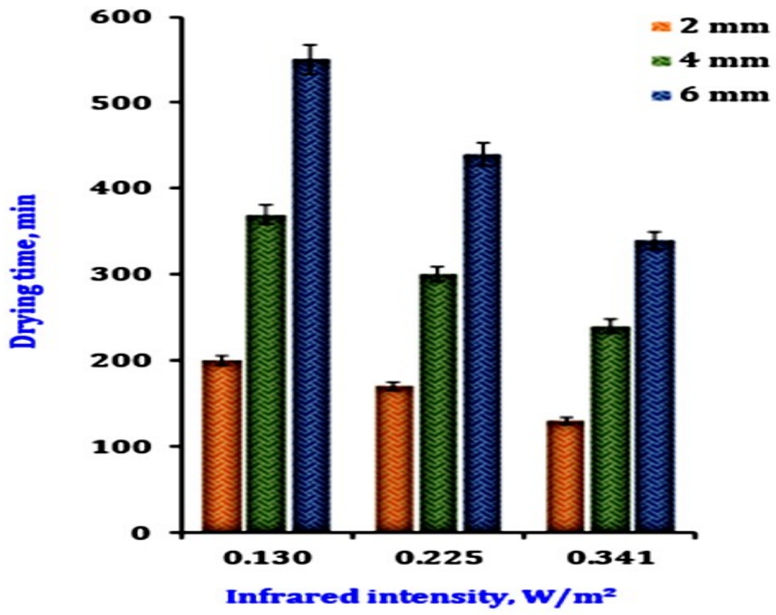

Figure 3. Variation of drying time of different slice thicknesses at various infrared radiation intensities

Table 1. The influence of varying infrared intensities, air velocity and slice thickness on fresh and dried onion slices water activity (a_w)

Run	I, W/cm²	V, m/s	Th, mm	a_w
Fresh				0.953
1	0.130	0.5	2	0.420
2	0.225	0.5	2	0.40
3	0.341	0.5	2	0.382
4	0.130	1.0	2	0.441
5	0.225	1.0	2	0.419
6	0.341	1.0	2	0.390
7	0.130	1.5	2	0.453
8	0.225	1.5	2	0.434
9	0.341	1.5	2	0.392
10	0.341	0.5	2	0.383
11	0.341	0.5	4	0.394
12	0.341	0.5	6	0.419

I: infrared radiation intensity - V: air velocity – Th: Thickness

Color Variation

Figure 4 shows the outcome of drying settings on total color changes. The color variations significantly rose when the air velocity was 0.5m/s, and the IR ranged from 0.13 to 0.35W/cm². The same radiation power range was applied, and a fixed drying air velocity of 1.5m/s increased color variation. The color change is accompanied by increased air velocity and IR. An illustration of the color difference that occurs across dried slices of varying thicknesses may be seen in Figure 5. While 0.5m/s and the power were attuned to 0.35W/cm², the color changes of dried samples with slices 2, 4, or 6mm thick were 8.98, 13.88 and 20.01. With increasing slice thickness, the huge difference became more pronounced. The rise in δE that occurs with growing slice thickness may be due to a prolonged drying time. They also observed that the colour difference became more pronounced as the thickness of the onion slices grew (Rajoriya et al., 2020).

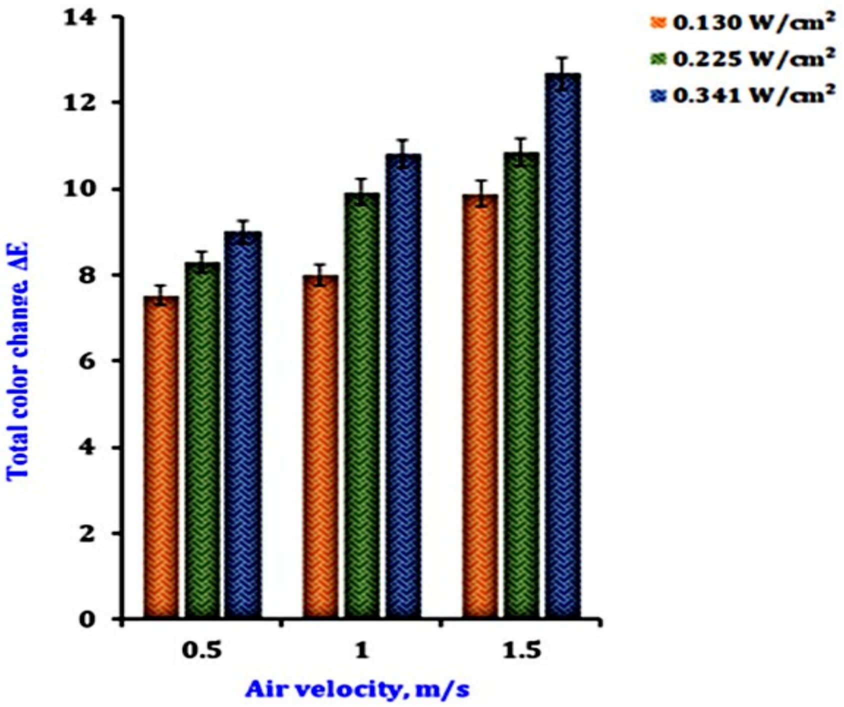

Figure 4. Total color change of dried slices under various drying conditions

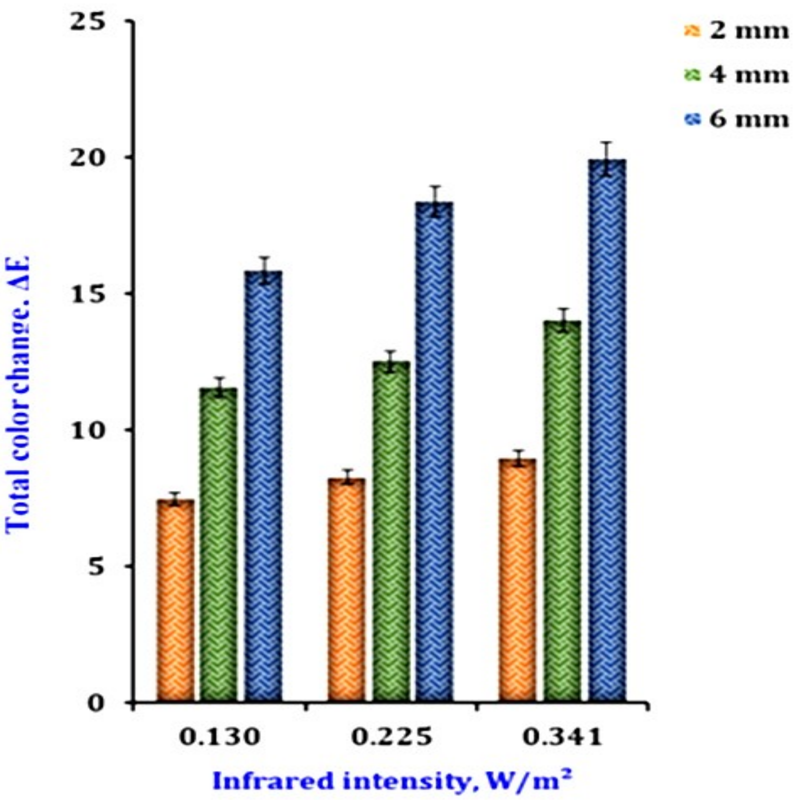

Figure 5. Color difference change of dried onion at slice thickness during infrared drying

Shrinkage ratio

The (Sr) samples dehydrated through infrared are shown in Figure 6. With the power increased from 0.13 to 0.35W/cm², the (Sr) released decreased from 0.20 to 0.18, and the air velocity was maintained at 0.3m/s. The Sr decreased from 0.25 to 0.21 while maintaining the same IR power and air velocity of 1.0m/s. Therefore, the lowest values of the shrinkage ratio were obtained by operating at a low air velocity and a considerable infrared radiation intensity of 0.34W/cm². Under increasing intensity and low air velocity conditions, a small amount of shrinkage occurs on both sides of the onion's outer surfaces. This is because the product temperatures are more significant, and the moisture content is lower (Mayor and Sereno, 2004). The slice thickness of the dried onion's shrinkage ratio was significantly affected by the slice thicknesses, as shown in Figure 7. Shrinkage ratios were 0.19, 0.16, and 0.13 for slice thicknesses of 2, 4, and 6 mm, respectively (El-Mesery et al., 2024) observed reduced Sr by rising thickness despite employing convective hot air dryers.

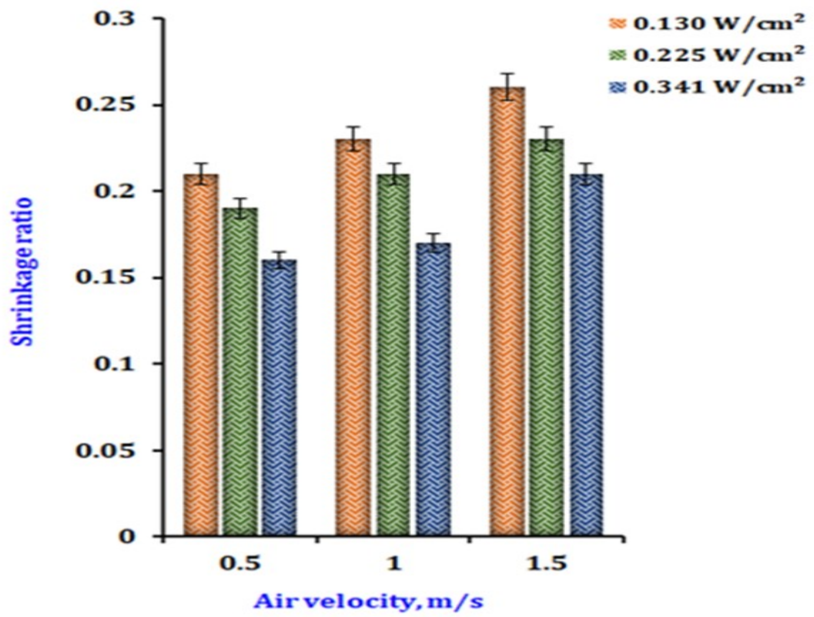

Figure 6. The effect of drying conditions on the shrinkage ratio of dried onion slices

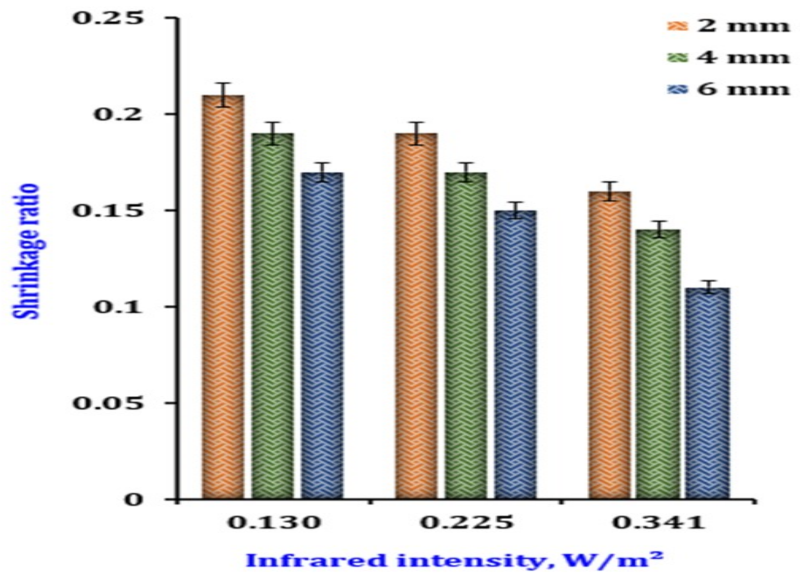

Figure 7. The effect of slice thickness on the shrinkage ratio of dried onion

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Rehydration ratio

Onion slices that have been dry in the past are shown in Figure 8. The rehydration ratio is shown after the slices have been dried using various drying air velocities and infrared radiation intensities. The dryer reaches its lowest value of 3.5 when operating at the lightest air velocity and the greatest IR, and it reaches its highest value of 5.1 when operating at the shallowest air velocity and the highest IR. With an increase in the IR, it is evident that the rehydration ratio drops as the air velocity increases. Regarding changes in the rehydration ratio, increasing or decreasing the air velocity has a higher influence than changing the radiation intensity. It is possible to argue that the objects heated up more rapidly when exposed to greater infrared intensities, accelerating the generation of vapor inside the object and increasing its porosity (Kocabiyik and Tezer, 2009). The slice thickness affects the dried onion's rehydration ratio, as shown in Figure 9. The thickness was determined to be between 2 and 6mm, and the power was 0.34W/cm². The air velocity was 0.3m/s. In contrast to the onion with a thickness of 4mm, the (Rr) with thicknesses of 4 and 6mm was found to be 53 and 35% more significant, individually. It may be deduced from this that the (Rr) was directly proportional to the thickness of the slice and that it grew concerning thickness (Elicin and Sacilik, 2005).

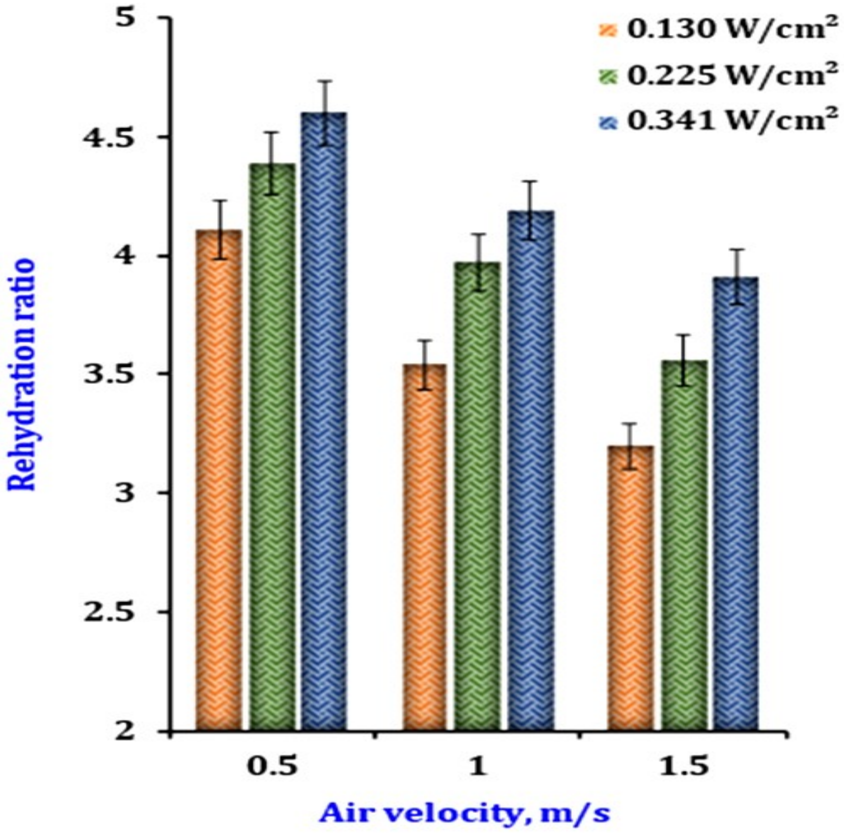

Figure 8. Rehydration ratio as related to different drying conditions

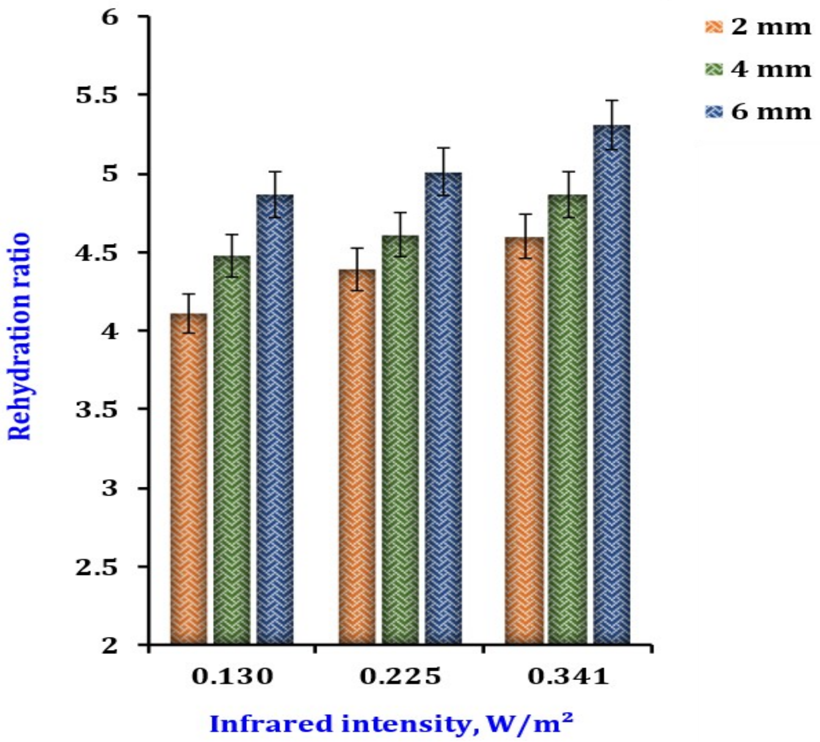

Figure 9. The rehydration ratio as a function of thickness

4. Conclusions

This study investigated the influence of slice thickness, air velocity and infrared power drying behavior, and onions' physio-quality parameters. The drying period rises with rising air velocity, independent of IR. The findings demonstrate that water activity achieved through IR drying ensures adequate storage stability. With increasing slice thickness and infrared light intensity, moisture diffusivity decreased as air velocity rose. With a decrease in air velocity and increased rehydration ratio, there was a corresponding rise in thickness and infrared power. Use of "Sr" without explanation may confuse readers. With an increase in airflow, the shrinkage ratio exhibited an upward trend; conversely, increased slice thickness and infrared intensity resulted in a decline. The color difference increased with the onion slice's thickness and the infrared light's intensity.

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