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EFFECT OF MICROWAVE AND INFRARED RADIATION ON DRYING OF ONION SLICES

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ABSTRACT

Onion slices (*Allium cepa* L.) weighing 100 g with a moisture content of 7.3 g water/g dry matter were dried using microwave and infrared radiation methods to a moisture content of 7% (wet basis). Three different output power levels of 200, 300 and 400 W were used for microwave drying, whereas the infrared drying treatment involved three intensity levels that were 3000, 4000 and 5000 W/m^2, a drying air temperature of 35 ^oC and air velocity of 0.5 m/s. A comparison of the drying kinetics, data revealed that microwave drying was more effective in shortening drying time when compared with infrared drying. Results also revealed that microwave dried onion slices were lighter in color and had higher rehydration ratios meanwhile, onion slices were darker in color and had lower rehydration ratios when infrared drying method was employed. To evaluate the drying kinetics of onion slices, experimental data obtained in this study were fitted with four models i.e. Newton, Henderson & Pabis, Page and modified Page models. The goodness of fit for each model was evaluated using coefficient of determination (R^2) and chi-square (χ^2) of these drying models, with the Page model yielding the best fit (R^2 = 0.998, χ^2 = 0.00016).

KEYWORDS: Microwave, Infrared Radiation, Onion Slices, Drying, Modeling, Color, Rehydration

INTRODUCTION

Onion (*Allium cepa L.*) is considered one of the second most important horticultural crops worldwide and has always been most widely traded than most vegetables (Griffiths et al., 2002) as a seasoning, a food component as well as in medical applications. Dried onions are a product of great significance in world trade produced either as flaked, minced, chopped or powdered forms (Arslan and Özcan 2010). Generally, onions are dried for efficient storage and processing (Sawhney and others 1999; Sarsavadia 2007) but also to reduce bulk handling, facilitate transportation, allow for their use during the off-season (Mota and others 2010). However, the use of dried onions, which have a decreased mass compared to fresh onions, requires that an efficient and effective dehydration method be developed and employed. The color and flavor of dried onions are considered the most important quality attributes affecting the degree of acceptability of the product by the consumer. The non-enzymatic browning reactions, measured in terms of an optical index and the loss in pungency, measured in terms of thiolsulphinate or pyruvate concentration, are considered the dominant factors in quality deterioration during drying and storage of dried onions (Vidyavati and others 2010).

Drying is one of the oldest methods of food preservation. It is a difficult food- processing operation, primarily because of undesirable changes in quality causing serious damage to the dried product resulting from the removal of water from the product especially when using conventional air drying. The major disadvantages of hot air drying of foods are low energy efficiency and lengthy drying times during the falling rate period. Because of the low thermal conductivity of food materials during this period, heat transfer from the surface into the interior of foods during conventional heating is limited (Kocabiyik and Tezer 2009). The desire to eliminate this problem, prevent significant quality loss and achieve rapid and effective thermal processing has resulted in increased use of infrared radiation and microwave for food drying.

Application of infrared radiation heating is gaining popularity in food processing because of its definite advantages over conventional heating. Faster and efficient heat transfer, lower processing cost, uniform product heating and better organoleptic and nutritional value of processed material are some of the important features of infrared radiation drying (Celma and others 2009 and Baysal and others 2003) The combined infrared radiation and hot air heating is considered to be more efficient than only infrared drying alone or convective hot air drying alone as it provides a synergistic effect. Combined infrared radiation and hot-air convection drying has been reported to conserve energy and to improve quality of various agricultural products (Meeso and others 2008; Wanyo and others 2011 and Praveen Kumar and others 2005).

Microwave drying on its part, is more rapid, more uniform and more energy efficient than hot-air convection and infrared radiation drying and in former, removal of moisture is accelerated and the rate of heat transfer from the surface into the interior of the solid material is significantly decreased due to the absence of convection (Wang and Sheng 2006). In addition, because of the concentrated energy of a microwave system, the floor space required is only 20–35% of that required for conventional heating and drying equipment (Mongpraneet and others 2002; Nindo and others 2003; Benlloch-Tinoco and others 2011 and Sachidananda Swain and others 2012). More to that, microwave drying effectively improves the final quality of agricultural products such as grains (Walde and others 2002), vegetables (Lombrana and others 2010 and Ozkan and others 2007) and fruits (Varith and others. 2007).

Mathematical modelling of drying processes and kinetics is a tool for process control and can be used to choose suitable method of drying a specific product. The developed models can be used to design new drying systems, determine optimum drying conditions and to accurately predict simultaneous heat and mass transfer phenomena during the drying process. Several researchers have developed models to describe the drying behavior of agricultural products (Ertekin and Yaldiz 2004; Kashaninejad and others 2007; Khazaei and Daneshmandi 2007). Taking into account the above-mentioned considerations, this study was designed with the objectives to (1) compare the dehydration characteristics of onion slices using two dehydration methods viz: microwave and infrared radiation drying; (2) determine the drying characteristics and quality degradation in terms of color and rehydration ratio of onion slices subjected to the two drying methods; and (3) examine and compare the applicability of four different thin-layer models to the simulation of moisture loss in onion slices during drying.

MATERIALS AND METHODS

Materials

Fresh onions procured in bulk from the local market and stored in a refrigerator at 4 ^{o}C were used in the present investigation. To prepare the onions for the drying experiments, they were removed from the refrigerator and allowed to equilibrate in the ambient environment before being hand peeled. The onions were then cut into slices of approximately 5 ±0.1 mm thick using a sharp stainless steel knife. The direction of cut was perpendicular to the vertical axis of onion bulbs. A micrometer was used to check the thickness and uniformity of each slice at three different locations, and acceptance was based on consideration of the average value and the deviation of each value from the desired thickness. A sample of approximately 100 g of onion slices ranging from 5 to 8 cm in diameter and 5±0.1 mm in thickness was then carefully set up as a single layer on the drying tray for use in the drying experiment. The initial moisture content of the onion slices, expressed in g water /g dry matter basis was measured by the oven drying method at an air temperature of 105 ^{o}C and a drying period of 24 h (AOAC 1990). The initial moisture content of the onion slices was found to be about 7.3 g water /g dry matter.

Drying Equipment

Microwave drying was performed in a 230-V, 50-Hz, and 2900-W laboratory digital microwave oven (WEG-800A, Jinan, China). The microwave oven has the capability of operating at different microwave stages, from 100 to 1000 W. The area on which microwave drying was performed was 32 × 37 × 20 cm in size and consisted of a rotating glass plate 28 cm in diameter at the base of the oven. The glass plate rotates 5 times per min and the direction of rotation can be changed by pressing the on/off button. Time adjustment was performed with the aid of the oven's digital clock.

An experimental dryer with an infrared radiation heat source is shown schematically in Figure 1. The drying chamber was made of 8 mm thick plywood (lined inside with an aluminum foil) of length 40 cm, 40 cm in breadth and 60 cm high, with a single door opening at the front. Air was forced through the dryer using an axial flow blower at a controlled velocity adjusted using an air control valve. The actual velocity was measured using a vane anemometer sensor with an accuracy of ± 0.1 m/s placed 2 cm above the drying tray. Two infrared heaters were operated at 230 V with a maximum power of 500 W. The sample tray was 40 cm by 40 cm and was constructed of wire mesh. The sample tray was kept 15 cm below the infrared heater throughout the experiment. Two spiral-type electrical heaters with heating capacities of 500 W each were used to control air temperature. These electrical heaters were turned off and on separately via a temperature controller to maintain air temperature within ± 0.1 ^{o}C of the set value.

Drying Procedures

Microwave Drying

Drying trials were carried out at three microwave generation power levels: 300, 500, and 700 W. The onion slices (100 g) selected from uniform and healthy plants. Three drying trials were conducted at each power level. The values obtained from these trials were averaged and the drying parameters determined. The rotating glass plate was removed from the oven every 30 s during the drying period and moisture loss determined by weighing the plate using a digital balance (Mettler Toledo PM30, Germany) with 0.01 g precision.

Infrared Radiation Drying

The infrared dryer was run empty for approximately 0.5 h to equilibrate the instrument relative to pre-set experimental drying conditions before each trial. Approximately 100 g of onion slices were uniformly spread on a tray and placed inside the dryer. The drying experiments were conducted at infrared radiation intensity levels of 3000, 4000 and 5000 W/m^2 and a constant drying air temperature of 35 ^{o}C and constant air velocity of 0.5 m/s (Sharma and others 2005). The mass of the onion was measured using a digital electronic balance (±0.01 g) at intervals of 15 min during the drying experiment.

During the drying process, all weighing processes were completed within 10 s. The drying time was defined as the time required reducing the moisture content of the product to 7 % on a wet basis.

Quality Evaluation

For quality evaluation purposes, similar drying experiments were conducted separately under the same microwave and infrared drying conditions.

Color

Sample color was measured before and after drying using a Hunter Lab Color Flex A60-1010-615 model colorimeter (Hunter Lab., Reston, VA). The total color difference between fresh and dried onion slices δE was defined in equation (1) as follow:

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

Where the subscript “o” refers to the color reading of fresh onion slices and L, a, and b indicate the brightness, redness and yellowness of the dried sample, respectively. Fresh onion slices were used as a reference and a larger δE denotes a greater change in color due to drying. The browning index (BI), indicating the purity of the brown color of the onion slices was calculated using equations (2) and (3) (Maskan 2001) as follow:

$$BI = \frac{100(x - 0.31)}{0.17} \tag{2}$$

$$x = \frac{a + 1.75\ L}{5.64\ L + a - 3.01\ b} \tag{3}$$

Rehydration Ratio (Rr)

The rehydration ratio of dried onion slices was determined according to EL-Mesery and Mwithiga (2012a) by immersing 10 g of dried sample in 50 ml of water at a temperature of 35 ^{o}C and after 5 h, samples were drained and weighed. The rehydration ratio was calculated as the ratio of the mass of the rehydrated sample to that of dry sample using equation (4) as follow:

$$\mathrm{Rr} = \frac{\text{mass after rehydration}}{\text{mass before rehydration}} \tag{4}$$

Analysis

A number of theoretical, semi-theoretical and empirical drying models have been reported in the literature. The most frequently used type of model for thin layer drying is the lumped parameter type, such as the Newton equation (EL-Mesery and Mwithiga 2012b; Liu and Bakker-Arkema 1997; Kingsly and others 2007). The moisture ratio during drying is determined using equation (5) i.e.

$$MR = \frac{M - M_e}{M_i - M_e} \tag{5}$$

Where M is the moisture content of the product at any time, M_e is the equilibrium moisture content, M_i is the initial moisture content all in kg $_{water}$/kg $_{dry\ matter}$, k is the drying constant (in units of 1/min) and t is the drying time in min. In this analysis, it was assumed that the moisture gradient driving force during drying is a liquid concentration gradient;

meanwhile the effect of heat transfer was neglected as a simplifying assumption. For all experimental conditions, the value of $(M-M_e)/(M_i-M_e)$, a dimensionless moisture content was obtained. Because samples were not exposed to uniform relative humidity and temperature continuously during drying, the moisture ratio was simplified as recommended by Akgun and Doymaz (2005), Doymaz (2004) and Goyal and others (2007) and expressed as follow:

$$MR = \frac{M}{M_i} \tag{6}$$

Mathematical Modeling of the Drying Curves

For mathematical modeling, the equations in Table 1 were tested to select the best model for describing the drying curve equation of the onion slices. The moisture ratio of the onion slices during drying was calculated using equation (6). The goodness of fit of the tested mathematical models on the experimental data was evaluated using coefficient of determination (R^2) [equation (7)] and chi-square test (χ^2) [equation (8)] with higher R^2 values and lower χ^2 values indicating a better fit (Goyal and others 2006) as follow:

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp.i}-MR_{Pre.i}\right)^2}{\sqrt{\left[\sum_{i=1}^{N}\left(MR_{exp.i}-MR_{Pre.i}\right)^2\right]*\left[\sum_{i=1}^{N}\left(MR_{exp.i}-MR_{Pre.i}\right)^2\right]}} \tag{7}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp.i}-MR_{pre.i}\right)^2}{N-n} \tag{8}$$

Where $MR_{exp.i}$ is the i^{th} experimental moisture ratio, $MR_{pre.i}$ is the i^{th} predicted moisture ratio, N and n are the number of observations constants, respectively.

Table 1: Mathematical Models Applied to the Drying Curves

No.	Model	Equation	References
1	Newton	MR = exp (-Kt)	Ayensu (1997)
2	Henderson and Pabis	MR = a.exp(-Kt)	Henderson & Pabis (1961)
3	Page	MR = exp (-Kt^n)	Page (1949)
4	Modified Page	MR = exp [-(Kt)^n]	Ozdemir & Devres (1999)

RESULTS AND DISCUSSIONS

Drying Characteristics of Onion Slices

Onion slices with initial moisture content of 7.31 g water/g dry solids were dried following two different drying methods i.e. microwave and infrared drying to a final moisture content of 0.07 g water/g dry matter.

Microwave Drying

Microwave drying trials were conducted at output power levels of 200, 300 and 400 W and the influence of each microwave power level on moisture ratio over drying time presented in Figure 2. The drying time decreased as microwave power level was increased. The times required for the moisture content of onion slices to decrease from 85 to 7 % (w.b) were 25, 20 and 17 min at microwave output power levels of 200, 300 and 400 W, respectively. The effect of microwave power level of decreasing drying time was observed by (Soysal 2004; Funebo and Ohlsso 1998; and Okzen and others 2007). The results indicate that mass transfer is more rapid at higher microwave power levels because more heat is generated within the sample, creating a larger vapor pressure differential between the interior and the surface of the product (Sarimeseli 2011 and Arikan and others 2012).

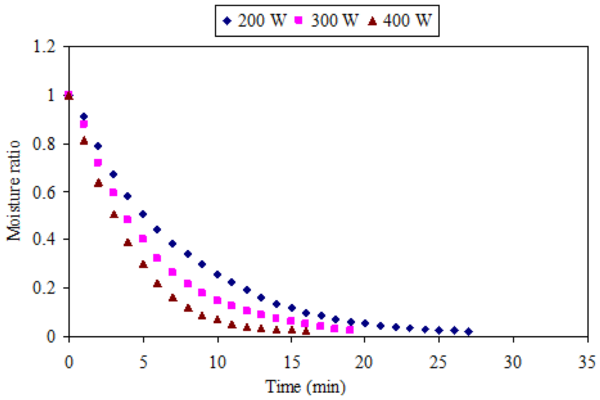

Figure 1: Variation in Moisture Ratio Overtime of Microwave Drying of Onion Slices at Different Microwave Power Levels

Infrared Radiation Drying

Infrared drying trials were conducted at radiation intensity levels of 3000, 4000 and 5000 W/m^2 with an air temperature of 35 °C and an air velocity of 0.5 m/s. A graph of moisture ratio versus drying time during the infrared drying of onion slices at different radiation intensity levels is presented in Figure 1. From the data, it is clear that moisture ratio decreased over drying time. Furthermore, infrared radiation intensity level had an effect on the change in moisture ratio of onion slices. The results also showed that when infrared radiation intensity level increases, the time taken to dry onion slices greatly decreased. Accordingly, the drying times required to reduce the moisture content of onion slices to approximately 7 % (w.b) were 480, 375 and 210 min when infrared radiation intensity levels of 3000, 4000 and 5000 W/m^2, respectively, were applied. A decrease in drying time with increased infrared radiation intensity level has also been reported by Kocabiyik and Tezer (2009) and Pitchaporn and others (2011).

Evaluation of the Models

The four different MR models used to predict the moisture content as a function of drying time are presented in Table 1. The coefficient of determination (R^2) and the reduced chi-square (χ^2) were used to assess how well the models characterized the drying curves. The estimated parameters and statistical analysis of the models for a given set of drying conditions are shown in Table 2. An analysis of variance indicated that the microwave power and infrared radiation intensity levels significantly affected the drying parameters. Higher microwave power and infrared radiation intensity levels are associated with significant decrease in drying time and moisture ratio which was much more noticeable in microwave than infrared drying. This has been demonstrated in the studies of Azzouz and others (2002), Vega and others (2007) and Sharma and others (2005).

Table 2: Estimated Coefficients and Statistical Analysis of Three Thin-Layer Drying Models

Model	Drying Methods	Model Constant		R^2	χ^2
	Microwave Drying	**k (min^{-1})**			
Newton	200 W	0.225		0.996	0.000991
	300 W	0.257		0.995	0.000240
	400 W	0.310		0.997	0.000384
	Infrared Drying				
	3000 W/m^2	0.0181		0.991	0.000721
	4000 W/m^2	0.0211		0.998	0.000637
	5000 W/m^2	0.033		0.995	0.000562

Table 2: Contd.,

Hendeson & Pabis	**Microwave Drying**	**k (min^{-1})**	**a**		
	200 W	0.189	0.959	0.995	0.000771
	300 W	0.250	0.917	0.997	0.000960
	400 W	0.293	0.861	0.990	0.000974
	Infrared Drying				
	3000 W/m^2	0.160	0.981	0.994	0.000631
	4000 W/m^2	0.0193	0.956	0.998	0.000931
	5000 W/m^2	0.0230	0.924	0.997	0.000702
Page	**Microwave Drying**	**k (min^{-1})**	**n**		
	200 W	0.197	1.19	0.998	0.000161
	300 W	0.301	1.14	0.999	0.000134
	400 W	0.393	1.08	0.998	0.000219
	Infrared Drying				
	3000 W/m^2	0.020	1.23	0.998	0.000201
	4000 W/m^2	0.029	1.20	0.999	0.000181
	5000 W/m^2	0.041	1.15	0.999	0.000100
Modified Page	**Microwave Drying**	**k (min^{-1})**	**n**		
	200 W	0.181	1.19	0.992	0.000988
	300 W	0.350	1.14	0.991	0.000760
	400 W	0.401	1.08	0.993	0.000684
	Infrared Drying				
	3000 W/m^2	0.015	1.23	0.996	0.000921
	4000 W/m^2	0.025	1.20	0.994	0.000699
	5000 W/m^2	0.028	1.15	0.992	0.000961

On the other hand, among the four models, the Page model provided the best fit to the microwave and infrared radiation drying data as indicated by a higher R^2 and lower chi-square χ^2 than those of the other models. Figure 2 and 3 compare the experimental data with the four models for microwave and infrared radiation drying, respectively. The predicted moisture content using the Page model showed moisture content values in a banded pattern along a straight line. The data illustrate the suitability of this model for describing the drying characteristics of onion slices. Several authors have reported good results from the application of the Page model to the drying kinetics of foods (EL-Mesery and Mwithiga 2012b; Doymaz 2005; Ozkan and others 2007; Arslan and Ozcan, 2008; Kumar and others 2006).

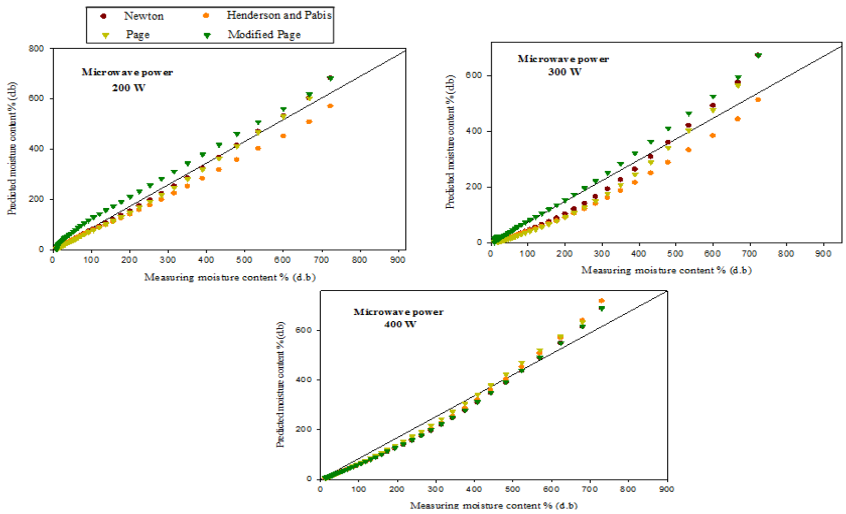

Figure 2: Comparison between Measured and Predicted Onion Slices Moisture Content, Using Various Models, for Various Microwave Power Levels

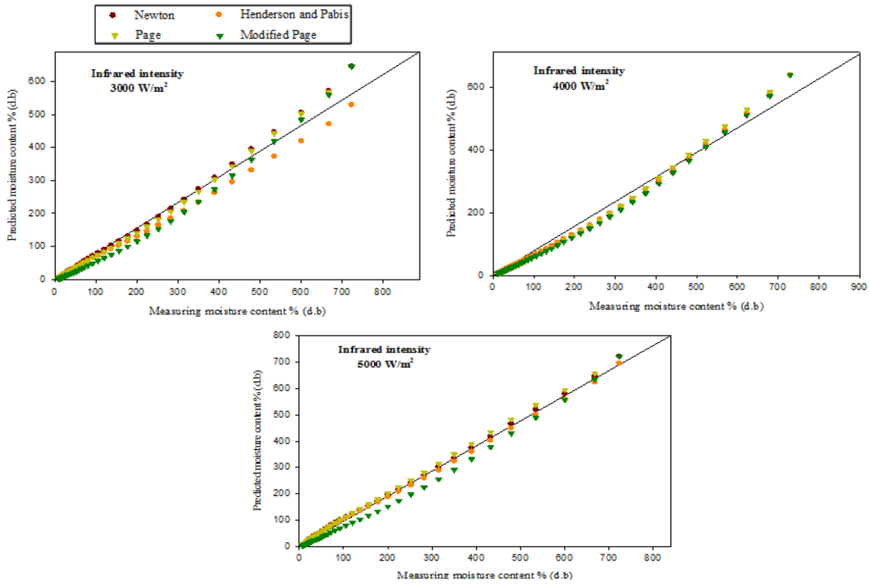

Figure 3: Comparison between Measured and Predicted Onion Slices Moisture Content, Using Various Models, for Various Infrared Radiation Intensity Levels, an Air Temperature of 35 ^{o}C and an Air Velocity of 0.5 m/s

Color Assessment

The total color difference (δE) and browning index of onion slices, calculated from Eqs. 1, 2 and 3 are colorimetric parameters used extensively to characterize the variation of colors in foods during processing. The total color difference and browning index results obtained with the microwave and infrared drying methods are presented in Table 3.

Microwave drying prevented color damage during drying. Infrared-dried onion slices were significantly darker in color than microwave-dried samples. This difference may be due to the longer drying time used in infrared drying (Summu et al., 2005). It is clear that microwave drying maintained the color quality of fresh onion slices better than infrared drying (Chua and Chou 2005 and Arikan et al., 2012).

Table 3: Color and Browning Change of Onion Slices Dried at Selected Processing Conditions Drying

Drying Methods	Total Color Change (δE)	Browning Index (BI)
Microwave Drying		
200 W	19.13	16.61
300 W	20.86	13.53
400 W	19.99	15.09
Infrared Drying		
3000 W/m^2	23.93	19.95
4000 W/m^2	24.08	20.57
5000 W/m^2	25.05	21.94

Rehydration Ratio

The rehydration characteristics of a dried product are widely used as indicators of quality. Rehydration is a complex process that is influenced by both physical and chemical changes associated with drying and the treatments preceding dehydration (Lewicki 1998; Feng and Tang 1998). The rehydration ratio was found to increase with increasing microwave output power and infrared radiation intensity levels. As found, increasing the microwave power level from

200 to 400 W increased rehydrations ratio from 5.93 to 6.87. Data also indicated that increasing infrared radiation intensity from 3000 to 5000 kW/m^2 exhibited an increase in rehydration ratio from 4.31 to 5.18. Thus, the rehydration ratios for microwave-dried slices were higher than those for infrared-dried slices.

CONCLUSIONS

This study characterized the influence of drying conditions on the drying behavior of onion slices using infrared radiation and microwave drying. It was found that the drying rate increases substantially with the microwave power level or infrared intensity level used. The Page model was found to be more suitable for predicting the drying behavior of onion slices, with the values for R^2 above 0.99 and with the lowest values of χ^2 0.00017 for both drying methods. A comparison of microwave and infrared drying times indicate that irrespective of the power or radiation intensity applied, microwaving is an effective method of shortening the time required for drying to the desired moisture content without charring the samples. Moreover, microwave drying had less influence on the color and rehydration ratio of the finished product than infrared drying.

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