Received: 18 February 2021 | Revised: 10 May 2021 | Accepted: 30 May 2021

DOI: 10.1111/jfpe.13776

ORIGINAL ARTICLE

Journal of Food Process Engineering WILEY

Drying kinetics, heat quantities, and physiochemical characteristics of strawberry puree by Refractance Window drying system

Shivmurti Shrivastav | Pravin M. Ganorkar | Krupal M. Prajapati | Devansh B. Patel

Department of Food Processing Technology, A.D. Patel Institute of Technology, Anand, Gujarat, India

Correspondence
Pravin M. Ganorkar, Department of Food Processing Technology, A.D. Patel Institute of Technology, PO Box 52, New Vallabh Vidyanagar, Vitthal Udyognagar, Anand 388121, Gujarat, India.
Email: pmganorkar@rediffmail.com

Funding information
Ministry of Food Processing Industries, Grant/Award Number: Q-11/5/2018-R&D

Abstract

Attempts were made to understand the drying kinetics, different heats involved, and change in physiochemical properties during Refractance Window (RW) drying of strawberry puree on an in-house fabricated RW drier. RW drying of puree was conducted at 75°C water temperature with 1.5 mm thickness. The drying was carried out from initial moisture content 614% (db) to 5.1% (db) with1.2 m/s exhaust air velocity. RW drying took place only in the falling rate period. The sensible heat of strawberry puree, convective heat loss from puree surface to air, and convective heat loss from the bottom surface (hot water to air) of the dryer were 70, 205, and 61.96 W, respectively. The evaporative capacity of 5.28 kg m^{-2} hr^{-1} was calculated at experimental parameters. This confirms that the drying system is advantageous. RW dried strawberry puree was rehydrated as exact of fresh strawberry puree considering total solids. Total phenolic content and ascorbic acid were significantly ($p < .05$) reduced from 246.33 mg gallic acid equivalent (GAE) (fresh strawberry puree) to 204.67 mg GAE per 100 g (reconstituted RW dried strawberry puree); 33.31–28.54 mg/100 g, respectively. Color characterization through L^*, a^*, b^*, darkness factor (b^*/a^*), chroma (C), and hue angle (h^*) revealed that reconstituted RW dried puree sample was darker compared with fresh puree.

Practical Applications

Among various drying methods of fruit purees, hot air drying is the most widely used. It results in an unpleasurable taste and color. During the falling rate drying period, the less thermal conductivity of fruit puree restricts heat transfer in conventional drying. Refractance Window (RW) drying adopts low-temperature drying for less time, which leads to advantages like effective and economical drying. RW drying technology can be promising at the commercial level in product quality and much-reduced production cost.

1 | INTRODUCTION

A high-quality product with a low cost is a significant challenge in the area of drying. Different drying methods like hot air drying, vacuum drying, freeze-drying, fluid bed drying, microwave drying, heat pump drying, superheated steam drying, and so forth, aims to provide a good quality product. However, energy consumption to complete the process is high. We know that drying is the major energy-intensive process that adds to the food industry's operating cost. The processing time of drying varies from 2 hr in tray drying to 24 hr in freeze-drying with different operating parameters. Some drying methods offer excellent quality products in terms of its shape, color, vitamins retention, flavor, and so forth, but the cost is several times higher compared to tray drying, which may not give high-quality products. Conventional drying technologies have been used in the food industry for decades to prevent microbial growth and deteriorative chemical reactions; to minimize logistic and storage costs (Nindo & Tang, 2007). It is now more essential to all of us during the current pandemic "COVID-19" to provide the consumer's processed products containing more nutrients and health-promoting bioactive compounds.

Refractance Window (RW) drying emerged as one of the viable and effective drying technology with immense potential in the area of fruits and vegetable powder. This RW drying system works at atmospheric pressure with a maximum temperature of 95°C. The RW drying method has become eye-catching for applications in the food industry, mainly because the dried products are of high quality and the equipment is relatively inexpensive. RW drier equipment cost and operational cost is in the tune of one-third to half of the freeze drier, considering drying of equal quantity of product (Nindo & Tang, 2007; Ochoa-Martínez, Quintero, Ayala, & Ortiz, 2012). The thermal energy of water is transferred through conduction, convection, and radiation to the product. This drying technique considered a thin layer drying system of puree or paste. Therefore, the present research aimed to study the drying kinetics and investigate the effect of RW drying system on characteristics like water activity, color, pH, % acidity, TSS (^{0}Bx), total phenolic content (TPC), and vitamin C. The RW dried puree was rehydrated and compared characteristics with fresh strawberry puree.

2 | MATERIALS AND METHODS

2.1 | Experimental setup

Setup of RW dryer was fabricated at GIDC, Vitthal Udhyognagar, Anand (Figure 1). This setup was used to dry the strawberry puree. The overall dimension of the dryer was 200 × 70 × 157 cm. The main component of the experimental setup was a conveyor belt of mayler sheet (Food grade polyester film without use of plasticizer) of 250 μ (M/s Ganapathy Industries, Bengaluru, India), two electric heaters of 1.5 kW each, water circulating pump of 0.25 hp (240 V, three-phase), screw feeder of variable feed rates, cooling chamber, stainless steel (SS306) roller to maintain the thickness of the product, scraper to remove a dried product from plastic sheet, hood with suction blowers and exhaust fans with a data logger. RW dryer consists of a water tank to hold about 20 L of water. A PID temperature controller controlled the temperature of the water. The total effective area of drying was divided into two units, that is, one was a heating unit of 150 × 60 cm size, and another was the cooling unit of 48 × 60 cm size. The variable thickness and uniform distribution of material from 1 to 3 mm was maintained by stainless steel roller. The LED bulb of 10 W was provided in the drying chamber for clear visibility of the product. The data logger attached with RW dryer was used to monitor hot water temperature, product temperature, relative humidity of the drying chamber, cold-water temperature, and thickness of the material. These data signals are multiplexed and transferred through software installed on PC. The temperature of the cooling chamber was maintained at about 25°C. Chromel-Alumel (K type) thermocouples were used to monitor the temperature at different points. An exhaust

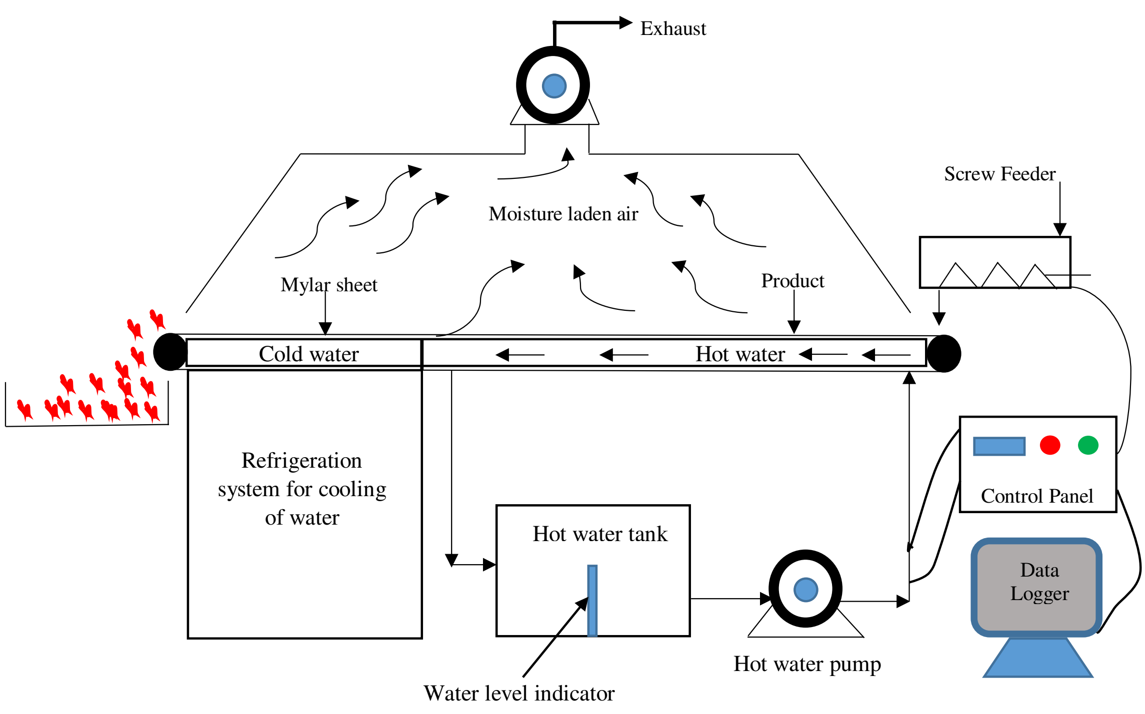

FIGURE 1 Schematic diagram of Refractance Window drying experimental setup

fan was provided at the top of the drying chamber to remove the water vapors generated in the drying chamber during drying. The sheet thickness was significantly less, causing the product temperature elevation to hot water temperature very quickly. Thin plastic film, infrared transmission matching with water absorption spectrum, and heating medium hot water, combine promotes quick drying (Nindo & Tang, 2007; Smith, 1994). When the plastic boundary is in close contact with water on the one side and moisture-rich material on the other side, the infrared transmission is more substantial. Water has high absorption for infrared with wavelengths of 3.0, 4.7, 6.0, and 15.3 mm. When high moisture puree is spread on top of the thin plastic conveyor belt, refraction at the plastic–puree interface is reduced, causing the radiant thermal energy to exceed through the plastic into the product. The puree's absorptivity is influenced by the thickness and moisture content (Nindo & Tang, 2007; Ratti & Mujumdar, 1995; Sandu, 1986). The cooling zone suddenly reduces the product's temperature to 25°C to effectively and smoothly scrap the product from the mayler sheet.

2.2 | Materials

Strawberry fruits were purchased from the local supermarket. It was selected to maintain the homogeneity of the sample in terms of color, size, and freshness with reference to visual inspection. The samples were then thoroughly washed with tap water to remove any foreign matter and contamination from the surface. Surface moisture is removed with the help of blotting paper and, after that, immediately stored at refrigerated temperature (5 ± 0.3°C). The total time taken to complete the above process was about 15 min. Strawberry fruits were taken out from the refrigerator, and the puree was prepared using a domestic food blender (Make Sumeet, Model XL3 550W, 230V AC-50 Hz) to get the puree's homogeneous mass. Strawberry puree of about 500 ± 10 g was packed in linear low-density polyethylene and stored in a deep freezer (Make Remi, Model RQVD 400 plus, Capacity 400 L) at about −18°C until all the drying experiment completes.

2.3 | Drying procedure

Before starting the experiments, the sample was thawed, and initial moisture content was determined by vacuum oven method at 70°C and absolute pressure 13.6 kP (AOAC, 2000). During drying, circulating water temperature was maintained at about 75 ± 2°C and product temperature at 70 ± 2°C with K-type thermocouples. Thawed strawberry puree of 500 g was spread with a thickness of 1.5 mm maintained on mayler sheet. Initial moisture content of strawberry puree was about to 86% (wb). Air velocity from the exhaust is kept at about 1.2 m/s. The puree was dried up to 0.051 kg of H_2O/kg of dry solids with RW dryer. An analytical weighing balance of 0.0001 g least counts (AX-200, Shimadzu, Japan) was used to take the weight of samples during experiments. The drying rate of strawberry puree was calculated using the following formula (Altay, Hayaloglu, & Dirim, 2019).

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt}$$

where M_{t+dt} is the moisture content at $t+dt$ (kg of H_2O/kg of dry solids) and t is the drying time in seconds.

Experiments were carried out at ambient air conditions of 35–38°C room temperature and 62–65% relative humidity. All experiments were replicated thrice.

2.4 | Heat quantities in Refractance Window dryer

Heat quantities are essential for an accurate audit of energy consumption. After heating the water to about 75°C, heat gained by the strawberry puree and losses to the surrounding need to be evaluated. This section will calculate (a) the sensible heat of strawberry puree, (b) convective heat loss from puree surface to air, (c) convective heat loss from the bottom surface of hot water to air, and (d) radiation losses due to heating of dryer surfaces.

2.4.1 | Sensible heat of strawberry puree

During the calculation of sensible heating of strawberry puree, it is required to calculate the energy supplied for sensible heating of puree. The following equation was used to find out the total energy supplied to the product (Kakac, Hongton, & Anchasa, 2012; Singh & Heldman, 2009)

$$Q_1 = m_p x\, C_p\, x \Delta T \tag{1}$$

where m_p is the mass of the strawberry puree to be processed (kg/hr) and C_p is the mean specific heat capacity of strawberry puree.

The processing machinery or equipment are performed under a wide range of temperatures, either cooling or heating. Specific heat capacity is one of the critical thermal properties for calculating thermal energy analysis of any production processes and for the design of thermal process equipment. The mean specific heat capacity of strawberry puree is 3,263 J kg^{-1}°C (Budzaki & Šeruga, 2014). ΔT is the temperature difference (°C).

2.4.2 | Convective heat loss from puree surface to air

During the drying process, a continuous flow of air took place with the help of exhaust. The drying chamber of RW dryer was installed with an exhaust fan at the top for the removal of moisture-laden air. Due to the exhaust fan, it was categorized into a forced convection system. The convective condition of air over the strawberry puree was established either laminar or turbulent by calculating the Reynolds number (N_{Re}); (Kakac et al., 2012; Singh & Heldman, 2009)

$$N_{Re} = \frac{\rho_a v_a D}{\mu_a} \tag{2}$$

where ρ_a is the density of air (kg/m^3), v_a is the mean air velocity (m/s), D is the width of belt (m), and μ_a is the kinematic viscosity of air (m^2/s).

The properties of air like density (ρ_a), kinematic viscosity (μ_a), thermal conductivity (k), coefficient of volumetric thermal expansion (β), thermal diffusivity (α), and Prandtl's number (N_{pr}) were calculated at bulk temperature $\left(T_b = \frac{T_a + T_\infty}{2}\right)$. It was established from the calculation that the convection of air inside the drying chamber lies in the range of laminar flow. Therefore, the convective heat transfer coefficient (h_1) between the air and strawberry puree obtained from the laminar flow correlations by calculating the Nusselt number (N_{Nu1}) from the given equations (Kakac et al., 2012; Singh & Heldman, 2009)

$$N_{Nu1} = 0.664(N_{Re})^{\frac{1}{2}}(N_{pr})^{\frac{1}{3}} \text{ for the condition } 0.6 \le N_{pr} \le 10 \tag{3}$$

$$N_{Nu1} = \frac{h_1 D}{k} \tag{4}$$

Then, heat loss from the surface of the puree was estimated as:

$$Q_2 = A_1 h_1 (T_p - T_a) \tag{5}$$

2.4.3 | Convective heat loss from the bottom surface of hot water to air

The calculation of heat loss under said condition was done by considering the natural convection condition because no mechanical means were installed at the bottom. Rayleigh number (N_{Ra}) was determined to satisfy the condition of natural convection. Therefore, the convective heat transfer coefficient (h_2) between the air and the bottom plate of the hot water was calculated (Nindo, Feng, Shen, Tang, & Kang, 2003).

$$N_{Nu2} = 0.27(N_{Ra})^{1/4} \tag{6}$$

$$N_{Ra} = \frac{g\beta(T_s - T_\infty)D^3}{\mu\alpha}\left(N_{Ra} < 10^{10} \text{for natural convection}\right) \tag{7}$$

$$N_{Nu2} = \frac{h_2 D}{k} \tag{8}$$

where g is the acceleration due to gravity (m/s^2), β is the coefficient of volumetric thermal expansion of air (K^{-1}), α is the thermal diffusivity of air (m^2/s), T_s is the bottom surface temperature of dryer (K), and T_∞ is the surrounding air temperature (K).

Then, heat loss from the bottom surface of the dryer was estimated as:

$$Q_3 = A_2 h_2 (T_s - T_\infty) \tag{9}$$

2.4.4 | Radiation losses due to heating of dryer surfaces

It was noted that the heated surface of the dryer also contributed the thermal radiation losses. The central portion of radiation was from the plate's bottom surface and from the surface of puree. It was considered that the radiation absorption by puree and pure water is equal due to high moisture content in the puree and absorbs additional infrared radiation at wavelengths of 3.0, 4.7, 6.0 μm, and above 12 μm, which contribute to less than 5% of infrared radiation (Sandu, 1986). The radiation heat loss was estimated using Equation (10) (Kakac et al., 2012; Singh & Heldman, 2009).

$$Q_4 = \varepsilon\sigma A_s F_{s-w}\left(T_s^4 - T_\infty^4\right) \tag{10}$$

The dryer wall is completely enclosed, so the view factor (F_{s-w}) for belt surface to dryer wall is nearly 1.0 (Nindo et al., 2003). Despite only 5% contribution of radiation heat to the total thermal energy for dehydration of food through mylar (plastic) sheet during the RW drying process, higher drying rate, more nutrient retention, and low aroma and flavor loss (Kaur, Saha, Kumari, & Datta, 2017). Therefore, the heat loss by radiation from the puree surface and from the bottom of the dryer was significantly less.

2.4.5 | Physiochemical characteristics of strawberry puree

According to mass balance calculations, 14.73 g of RW dried strawberry sample was rehydrated with distilled water at 37°C to maintain the moisture content of about 86% (wb). After rehydration, the total mass of the sample was found to be 99.24 g. The reconstituted sample was compared with the fresh strawberry puree sample. The water activity of the sample was measured by a portable water activity meter (HC2-AW, Rotronics, Switzerland). pH was measured by a portable digital pH meter (Make EI and Model 181E). The percent titratable acidity (expressed as citric acid) was determined by titration with 0.1 N NaOH solution using phenolphthalein as an indicator (Ranganna, 2000). Total soluble solid (^{0}Bx) was determined by handheld refractometer (Make ERMA and Model REF103). TPC was measured by the method of Yulian, Radosveta, Nadezhda, Ivan, and Anna (2019), and results were expressed as mg of gallic acid equivalents (GAE) per 100 g of puree. Ascorbic acid content was determined by using method 967.21 of AOAC (2000). The International Commission on Illumination parameters L^*, a^*, and b^* were measured by chroma meter (Konica Minolta, CR-400, Japan). Instrument was calibrated with a standard ceramic white plate (L^* = 83.5, $a^* = 0.1394$, $b^* = 0.3360$) prior to color measurement. The average

L^*, a^*, and b^* values were obtained from three replications readings which were taken from five different locations in the sample. By using the following equations, Chroma (C) value, hue angle (h^*), and total color difference (ΔE^*) were calculated (Pathare, Opara, & Al-Said, 2013).

$$C = \sqrt{a*^2 + b*^2} \tag{11}$$

$$h* = \tan^{-1}\left(\frac{b*}{a*}\right) \tag{12}$$

$$\Delta E* = \sqrt{\Delta a*^2 + \Delta b*^2 + \Delta L*^2} \tag{13}$$

3 | STATISTICAL ANALYSIS

Parameter data were analyzed with Daniel's XL Toolbox Version 5.08 using one-way analysis of variances with Tukey comparison of means values. Differences between mean values with probability $p < .05$ were recognized as statistically significant differences.

4 | RESULTS AND DISCUSSION

The moisture content of fresh strawberry was investigated about 614% (db). All experiments were conducted at 35°C room temperature and 65% relative humidity. Figure 2a shows the change of moisture content (kg of H_2O/kg of dry solids) with time. In this drying technique, strawberry puree moisture content was reduced to 0.051 kg of H_2O/kg of dry solids in 30 min. This rapid reduction of moisture content is due to less thickness (1.5 mm) of material. A similar trend has been reported by Ochoa-Martínez et al. (2012). It is noticeable from Figure 2a,b that there were no constant drying periods throughout the drying experiments. All drying took place in the falling rate period only. Figure 2a shows the exponential decay behavior in the removal of moisture content. The same tendency of results was revealed by Puente-Díaz, Spolmann, Nocetti, Zura-Bravo, and Lemus-Mondaca (2020). Figure 2b states that the drying rates were very high up to 10 min of drying, and after that, drying rates were almost constant. Similar results were reported by Abonyi, Tang, and Edwards (1999). The reason for no constant drying rate periods may be the thin layer of strawberry puree spread on the surface of mayler sheet. This less thickness evaporates water very fast. From Figure 2c, the temperature seems to be lower as the drying proceeds. The temperature of the product ranges from 70 to 62°C. A decrease in temperature could be the effect of blower, which takes the air vapor mixture from the drying zone and the evaporative cooling effect creates on the surface of the product. After the appropriate strawberry puree temperature, a thermal equilibrium was maintained between the heat transfer from the circulating water to the puree surface and thermal energy removal due to surface moisture evaporation (Nindo et al., 2003).

The thermal energy transfer from the puree to the ambient air is primarily by convection and through evaporative cooling of the food

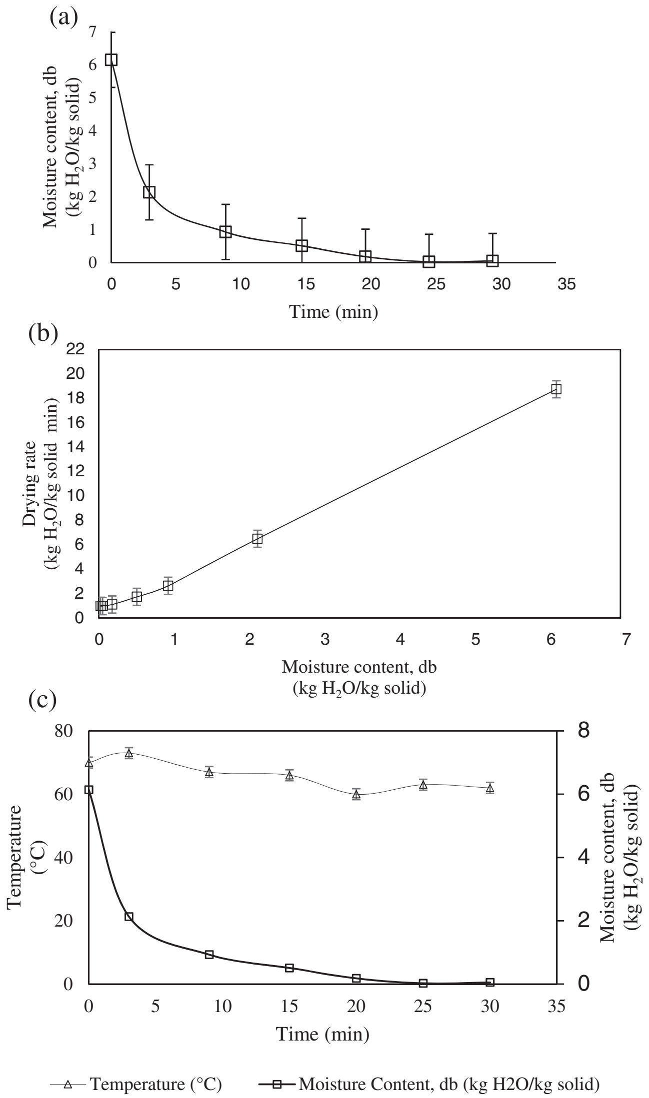

FIGURE 2 (a) Refractance Window drying curve (moisture content vs. drying time) and (b) Refractance Window drying curve (drying rate vs. moisture content) and (c) moisture–temperature profile of Refractance Window drying

material. This evaporation is very intense and constitutes a significant part of energy consumption in RW drying. In the last stage of RW drying, when the product is almost dry, heat transfer by conduction becomes predominant, and the rate of heat transfer to the product slows as the product dries further. The cooling section at the discharge end of the RW dryer is intended to reduce the product temperature, preferably to below the glass transition temperature of the product, to facilitate product removal (Nindo & Tang, 2007). Thermophysical and transport properties of the RW dryer system are presented in Table 1. Data given in Table 1 were used to calculate the different heat quantities in the dryer. When the dryer is working, there was some heat gain and heat loss in the system. There was sensible heat gain by the strawberry puree and convective heat loss from puree surface to air, convective heat loss from the bottom surface of hot water to air, and radiation losses due to heating of dryer surfaces. The sensible heat of the strawberry puree estimated from initial

TABLE 1 Thermophysical and transport properties used in calculation of heat quantities in Refractance Window dryer

Property	Value	Source	Property	Value	Source
m_p	2 kg/hr	Experimental data	T_b	325.5 K	Experimental value
C_p	3,263 J kg$^{-1\circ}$C	Budzaki and Šeruga (2014)	N_{Re}	39,928	Calculated value
ρ_a	1.042 kg/m^3	Singh and Heldman (2009)	N_{pr}	0.73	Calculated value
v_a	1.2 m/s	Experimental data	N_{Nu1}	119	Calculated value
D	0.6 m	Experimental data	N_{Nu2}	84	Calculated value
μ_a	18.79 × 10^{-6} m^2/s	Singh and Heldman (2009)	N_{Ra}	9.42 × 10^9	Calculated value
k	0.0274 W m^{-2} K^{-1}	Singh and Heldman (2009)	h_1	5.43 W m^{-2} K^{-1}	Calculated value
g	9.81 m/s^2	Kakac et al. (2012)	h_2	1.53 W m^{-2} K^{-1}	Calculated value
β	3.10 × 10^{-3} K^{-1}	Kakac et al. (2012)	ε	0.22 for steel, 0.95 for puree	Nindo et al. (2003)
α	26.3 × 10^{-6} m^2/s	Kakac et al. (2012)	σ	5.67 × 10^{-8} W m^{-2} K^{-4}	Nindo et al. (2003)
T_s	348 K	Experimental data	F_{s-w}	1.0	Nindo et al. (2003)
T_∞	303 K	Experimental data	Q_1	76 W	Calculated value
T_p	345 K	Experimental data	Q_2	205 W	Calculated value
T_a	303 K	Experimental data	Q_3	61.96 W	Calculated value

product temperature to endpoint product temperature was 76 W. Convective heat loss from the surface of puree to air was calculated by using different correlations. Air exhaust was provided at the top with 1.2 m/s air velocity. Reynolds numbers were calculated to establish whether the flow of air above the puree was laminar or turbulent. Estimating Reynolds number by using Equation (2) was found 39,928, which is in the range of laminar flow. Equations (3) and (4) were utilized to calculate Nusselt number and convective heat transfer coefficient, 119 and 5.43 W m^{-2} K^{-1}, respectively. The amount of heat loss from the surface of the puree was estimated to be 205 W. Considering the natural convection between the bottom surface of the dryer to air, the convective heat transfer coefficient was calculated with Equations (6)–(8) was 1.53 W m^{-2} K^{-1}. The higher value of convective heat transfer coefficient reveals that the process was under forced convection, whereas a low value implies the current of air under natural convection. Then, heat loss from the bottom surface of the dryer was estimated at 62 W. Radiation losses due to heating of dryer surfaces can be calculated with Equation (10). In line with the literature, the infrared radiation is less than 5%, which interjects to a minimal value of radiation losses as drying proceeds, both conductive and radiative flux decrease due to an increase in the product temperature. Thus, conductive flux is primarily responsible for temperature rise in the sample. The surface temperature of the puree with and without radiation effects is about the same. Thus, radiation effects are indeed small, and they do not contribute significantly in the process (Ortiz-Jerez, Gulati, Datta, & Ochoa-Martínez, 2015). Hence, the heat loss by radiation from the puree surface and bottom of the dryer was zero. The evaporative capacity of RW experiments was evaluated from the drying rate results. The puree of 1.5 mm thickness and the heating water temperature was 75°C, and evaporative capacity was calculated 5.28 kg m^{-2} hr^{-1}. This result was in agreement with the result reported by Zotarelli, Carciofi, and Laurindo (2015) with 2 mm thickness 5.21 kg m^{-2} hr^{-1} evaporative capacity during the drying of mango puree.

TABLE 2 Characteristics of Fresh strawberry puree and RW dried—reconstituted puree

Strawberry puree	Fresh puree	Reconstituted RW dried puree
Water activity	0.946 ± 0.006^a	0.958 ± 0.004^a
pH	3.64 ± 0.025^b	3.68 ± 0.020^b
Total soluble solids (^{0}Bx)	8.8 ± 0.2^c	8.7 ± 0.2^c
Titratable acidity (%, expressed as citric acid)	0.68 ± 0.03^d	0.64 ± 0.02^d
Total phenolic content (mg GAE/100 g)	246.33 ± 4.16^e	204.67 ± 6.51^f
Ascorbic acid content (mg/100 g)	33.31 ± 1.21^g	28.54 ± 1.27^h

Note: Mean value of three determinations is reported. Values followed by different superscript alphabets in a row are significantly different ($p < .05$). Abbreviation: RW, Refractance Window.

4.1 | Effect of RW drying on quality characteristics of strawberry puree

Effect of RW drying on some chemical characteristics of strawberry puree is presented in Table 2. The data revealed no significant difference ($p > .05$) observed in water activity, pH, total soluble solids, and titratable acidity of fresh and RW dried—reconstituted sample. However, significant differences ($p < .05$) were found in TPC and ascorbic acid content. TPC and ascorbic acid content are responsible for the antioxidant activity of food (Sadowska, Świderski, & Hallmann, 2020). RW dried and reconstituted strawberry puree contained 204.67 mg GAE and 28.54 mg/100 g TPC and ascorbic acid content, respectively. The reduction in the phenolic compound content of samples during RW drying can be attributed to partial degradation of lignin, the liberation of phenolic compounds, phenolic acid derivatives, and the initiation of phenolic compounds thermal degradation at a higher

TABLE 3 Color values for strawberry puree

Samples	L^*	a^*	b^*	b^*/a^*	C	h^*
Fresh puree	26.68 ± 0.48^{b}	29.46± 0.50^{c}	16.60 ± 0.42^{c}	0.56	33.81	29.40
RW dried	36.71 ± 0.48^{c}	18.82 ± 0.65^{a}	6.11 ± 0.21^{a}	0.32	19.79	17.98
Reconstituted puree	24.9 ± 0.28^{a}	27.52 ± 0.31^{b}	12.34 ± 0.51^{b}	0.45	30.16	24.15
% Retention	93.33	93.41	74.33	80.35	89.20	82.14
Total color difference (ΔE^*)	5.007					

Note: Mean values followed by different superscript alphabets in a column shows samples are significantly different ($p < .05$). ΔE^* value shows the color difference between fresh puree and reconstituted RW dried puree.
Abbreviation: RW, Refractance Window.

temperature (Méndez-Lagunas, Rodríguez-Ramírez, Cruz-Gracida, Sandoval-Torres, & Barriada-Bernal, 2017). Ascorbic acid loss is temperature dependent, which increases with increasing dehydration temperature. Ascorbic acid is more sensitive to heat, oxygen, and light (Muratore, Rizzo, Licciardello, & Maccarone, 2008). So, loss of ascorbic acid is related to high sensitivity to oxidation by the heating process. Processing can alter and often reduces fruit and vegetable antioxidants, such as vitamin C and polyphenols, including anthocyanins, due to oxidation, thermal degradation, and other events that lead to lower levels of antioxidants in processed food compared with the fresh product (Kalt, 2005).

4.2 | Effect of RW drying on color values

Appearance is an important quality attribute of a food product. It includes size, shape, gloss, texture, and color. The visual appearance of food products is influenced by food color, consequently effects on food product acceptance and preference (Pathare et al., 2013).

The color change in fresh strawberry puree and RW dried—reconstituted strawberry puree are depicted in Table 3. The color change is characterized by determining values like L^*, a^*, b^*, darkness factor (b^*/a^*), chroma (C), and hue angle (h^*). The fresh strawberry puree had a significant ($p < .05$) brighter color (higher L^*) than RW dried puree. Other color values (a^* and b^*) had also shown declined trend. From % retention value, the highest decline was observed in b^* value compared with L^* and a^* value in the present investigation. These results contradict the earlier reported results for dried strawberry puree by Abonyi et al. (2002). The contradiction may be attributed to drying parameters. Strawberry puree thickness in the drying chamber was maintained at 1.5 mm in the present investigation while 1 mm by Abonyi et al. (2002). This also affected drying time. The final moisture content of dried puree was found to be 7.23% (wb) in the investigated sample while 9.9% (wb) in earlier reported literature. Beyond doubt, puree exposed to high temperature for more time in the present investigation. Moreover, strawberry containing more reactive polyphenols (leucoanthocyanins and flavanols) is more prone to color deterioration during processing and storage (Abers & Wrolstad, 1979). Biological variety variation in compositional content finally affects the processed strawberry product. Chroma (C) value, being the quantitative parameter of the color attribute, determines the degree of difference of a hue compared to a gray color with the same lightness. C value significantly decreased from 33.81 to 30.16. It indicates that the color intensity of dried—reconstituted puree perceived by humans shall be less than fresh samples. The conventional color name is associated with hue. Hue angle (h^*) value significantly decreased from 29.40 to 24.15. The lower hue angle represented a higher yellow character in RW dried puree sample compared with the fresh sample. Total color difference (ΔE^*) indicates the magnitude of color difference between dried and fresh samples. As ΔE^* value is more than 3, the magnitude of color difference between fresh puree and RW dried—reconstituted puree is very distinct (Pathare et al., 2013). Hue is related to the perceived color name. An angle of 90° represents a yellow hue. Objects with higher hue angles are greener, while lower angles are more orange-red (Gnanasekharan, Shewfelt, & Chinnan, 1992). RW dried sample's darkness can be attributed to increasing nonenzymatic browning (NEB) rate in the presence of glucose, fructose, and malic acid. The NEB rate increases as water is removed during a drying process and reaches a maximum at intermediate moisture contents (18–25%, db) (Holdsworth, 1971).

5 | CONCLUSION

RW drying study demonstrated that the drying of strawberry puree falls only in the falling rate period, and no constant drying period was observed. The thin layer drying process provides high drying rates and evaporative capacity to produce fruit flakes or powder. Natural and forced convective heat transfer coefficients were also evaluated at different locations in the dryer. Significant reduction in TPC, ascorbic acid, and the color value was observed in RW dried—reconstituted sample. However, RW drying technology is stepping ahead firmly with the advantages of less energy consumption and better product quality than other drying technologies. Detailed RW dried product physical characteristics like bulk density, particle density, bulk porosity and hygroscopicity, and so forth can be measured. Moreover, a comparative study among conventional drying techniques with RW drying can be explored.

ACKNOWLEDGMENTS

The authors are thankful to the Ministry of Food Processing Industries, Government of India for financial support of the present research work vide File No. Q-11/5/2018-R&D.

CONFLICT OF INTEREST

The authors report no conflict of interest.

AUTHOR CONTRIBUTIONS

Shivmurti Shrivastava: Conceived the idea of the present manuscript and wrote the manuscript. **Pravin M. Ganorkar**: Supervised the analytical work, statistical analysis and formatted the manuscript as per journal guidelines. **Krupal M. Prajapti** and **Devansh B. Patel**: Carried out experimental work along with a literature review.

DATA AVAILABILITY STATEMENT

All required data are available in the manuscript. On the basis of provided data, scientific interpretations and calculations have been made and the same has been incorporated into the manuscript.

ORCID

Pravin M. Ganorkar https://orcid.org/0000-0001-9944-2535

REFERENCES

Abers, J. E., & Wrolstad, R. E. (1979). Causative factors of color deterioration in strawberry preserves during processing and storage. *Journal of Food Science*, *44*, 75–81. https://doi.org/10.1111/j.1365-2621.1979.tb10008.x

Abonyi, B. I., Feng, H., Tang, J., Edwards, C. G., Chew, B. P., Mattinson, D. S., & Fellman, J. K. (2002). Quality retention in strawberry and carrot purees dried with Refractance Window system. *Journal of Food Science*, *67*, 1051–1056. https://doi.org/10.1111/j.1365-2621.2002.tb09452.x

Abonyi, B. I., Tang, J., & Edwards, C. G. (1999). Evaluation of energy efficiency and quality retention for the Refractance Window TM drying system. Research Report, Washington State University, Pullman, WA.

Altay, K., Hayaloglu, A. A., & Dirim, S. N. (2019). Determination of drying kinetics and energy efficiency of purple basil (*Ocimum basilicum* L.) leaves using different drying methods. *Heat and Mass Transfer*, *55*, 2173–2184. https://doi.org/10.1007/s00231-019-02570-9

AOAC (Ed.). (2000). *Official methods of analysis of Association of Official Analytical Chemists International* (17th ed.). Gaithersburg, MD, USA: AOAC International.

Budzaki, S., & Šeruga, B. (2014). Specific heat of strawberry and raspberry puree. *Journal of Food Processing and Preservation*, *38*, 2240–2245. https://doi.org/10.1111/jfpp.12397

Gnanasekharan, V., Shewfelt, R. L., & Chinnan, M. S. (1992). Detection of color changes in green vegetables. *Journal of Food Science*, *57*, 149–154. https://doi.org/10.1111/j.1365-2621.1992.tb05444.x

Holdsworth, S. D. (1971). Dehydration of food products—A review. *Journal of Food Technology*, *6*, 331–370. https://doi.org/10.1111/j.1365-2621.1971.tb01623.x

Kakac, S., Hongton, L., & Anchasa, P. (2012). *Heat exchangers selection rating and thermal design* (3rd ed.). New York: CRC Press, Taylor & Francis Group.

Kalt, W. (2005). Effects of production and processing factors on major fruit and vegetable antioxidants. *Journal of Food Science*, *70*, 11–19. https://doi.org/10.1111/j.1365-2621.2005.tb09053.x

Kaur, G., Saha, S., Kumari, K., & Datta, A. K. (2017). Mango pulp drying by Refractance Window method. *Agricultural Engineering International: CIGR Journal*, *19*(4), 145–151.

Méndez-Lagunas, L., Rodríguez-Ramírez, J., Cruz-Gracida, M., Sandoval-Torres, S., & Barriada-Bernal, G. (2017). Convective drying kinetics of strawberry (*Fragaria ananassa*): Effects on antioxidant activity, anthocyanins and total phenolic content. *Food Chemistry*, *230*, 174–181. https://doi.org/10.1016/j.foodchem.2017.03.010

Muratore, G., Rizzo, V., Licciardello, F., & Maccarone, E. (2008). Partial dehydration of cherry tomato at different temperature and nutritional quality of the products. *Food Chemistry*, *111*, 887–891. https://doi.org/10.1016/j.foodchem.2008.05.001

Nindo, C. I., Feng, H., Shen, G. Q., Tang, J., & Kang, D. H. (2003). Energy utilization and microbial reduction in a new film drying system. *Journal of Food Processing and Preservation*, *27*, 117–136. https://doi.org/10.1111/j.1745-4549.2003.tb00506.x

Nindo, C. I., & Tang, J. (2007). Refractance Window dehydration technology: A novel contact drying method. *Drying Technology*, *25*, 37–48. https://doi.org/10.1080/07373930601152673

Ochoa-Martínez, C. I., Quintero, P. T., Ayala, A. A., & Ortiz, M. J. (2012). Drying characteristics of mango slices using the Refractance Window™ technique. *Journal of Food Engineering*, *109*, 69–75. https://doi.org/10.1016/j.jfoodeng.2011.09.032

Ortiz-Jerez, M. J., Gulati, T., Datta, A. K., & Ochoa-Martínez, C. I. (2015). Quantitative understanding of Refractance Window™ drying. *Food and Bioproducts Processing*, *95*, 237–253. https://doi.org/10.1016/j.fbp.2015.05.010

Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology*, *6*, 36–60. https://doi.org/10.1007/s11947-012-0867-9

Puente-Díaz, L., Spolmann, O., Nocetti, D., Zura-Bravo, L., & Lemus-Mondaca, R. (2020). Effects of infrared-assisted Refractance Window™ drying on the drying kinetics, microstructure, and color of physalis fruit purée. *Food*, *9*, 343. https://doi.org/10.3390/foods9030343

Ranganna, S. (2000). Proximate constituents. In *Handbook of analysis and quality control for fruit and vegetable products* (2nd ed., pp. 9–10). New Delhi: Tata McGraw-Hill Publishing.

Ratti, C., & Mujumdar, A. S. (1995). Infrared drying. In A. S. Mujumdar (Ed.), *Handbook of industrial drying* (pp. 567–588). New York, NY: Marcel Dekker.

Sadowska, A., Świderski, F., & Hallmann, E. (2020). Bioactive, physicochemical and sensory properties as well as microstructure of organic strawberry powders obtained by various drying methods. *Applied Sciences*, *10*, 4706. https://doi.org/10.3390/app10144706

Sandu, C. (1986). Infrared radiative drying in food engineering: A process analysis. *Biotechnology Progress*, *2*, 109–119.

Singh, R. P., & Heldman, D. R. (2009). *Introduction to food engineering* (4th ed.). Burlington, MA: Academic Press.

Smith, T. M. (1994). Heat transfer dynamics. *Tappi Journal*, *77*, 239–245.

Yulian, T., Radosveta, N., Nadezhda, P., Ivan, I., & Anna, L. (2019). Biopreservation of Fresh Strawberries by Carboxymethyl Cellulose Edible Coatings Enriched with a Bacteriocin from Bacillus methylotrophicus BM47. *Food technology and biotechnology*, *57*(2), 230–237. https://doi.org/10.17113/ftb.57.02.19.6128.

Zotarelli, M. F., Carciofi, B. A. M., & Laurindo, J. B. (2015). Effect of process variables on the drying rate of mango pulp by Refractance Window drying. *Food Research International*, *69*, 410–417. https://doi.org/10.1016/j.foodres.2015.01.013

How to cite this article: Shrivastav, S., Ganorkar, P. M., Prajapati, K. M., & Patel, D. B. (2021). Drying kinetics, heat quantities, and physiochemical characteristics of strawberry puree by Refractance Window drying system. *Journal of Food Process Engineering*, *44*(9), e13776. https://doi.org/10.1111/jfpe.13776