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Influence of Convective Drying Temperatures on the Moisture Removal Kinetics and Physicochemical Characteristics of Japanese Persimmon (*Diospyros kaki*) Peel Powders

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Abstract:

Persimmon peel is an excellent source of antioxidants, phenolic compounds, and other phytochemicals, making it a valuable byproduct rather than a food waste. This study evaluates the effects of air-drying temperatures from 40 to 70 °C on the drying kinetics, physico-chemical properties, color, yield, turbidity, particle morphology, thermal stability, functional groups, antioxidant capacity, and total phenolics of persimmon peel. Drying was conducted at air temperature between 40 °C to 70 °C with a constant air velocity of 2.7 ms^{-1}. The results indicated that higher air temperatures led to a decrease in drying time with the process occurring primarily during the falling rate period. Seven thin-layer drying models were analyzed using the coefficient of determination and root mean square error, and the Weibull model was determined as the best fit for characterizing the drying kinetics of persimmon peel. The antioxidant capacity dropped while the overall phenolic content increased with higher drying temperatures. Although drying temperatures did not have a significant effect on morphological and functional characteristics and thermal stability, the color changes were noticeable. Despite the larger color changes, 60 °C produced the optimum combination of antioxidant and phenolic chemicals.

Key words: Diospyros kaki peel, Thin layer kinetics, Phenolic compounds, Radical scavenging activity, Powder morphology

1. Introduction

Japanese persimmon (Diospyros kaki) is a seasonal fruit native to East Asia known for its high concentration of medicinal chemicals. It includes significant amounts of ascorbic acid, carotenoids, condensed tannins, gallic acid, terpenoids, polyphenols, steroids, flavonoids, dietary fiber, and important minerals, as well as other phenolic compounds with known medicinal properties[1,2]. Unfortunately, persimmons have a concise life span accompanied by a short growing season with high market prices. To address this issue, dried persimmons have been produced for preservation while generating large amounts of by-products such as pulp, calyx, seeds, and peels [3]. Persimmon by-products, especially seeds and peels, show higher radical scavenging potential *in vitro* and inhibit lipid peroxidation *in vivo* [3]. The peel is comparatively rich in bioactive compounds with a higher concentration of carotenoids and polyphenols than its pulp[4,5,6] .The skin of Japanese persimmon is notably abundant in essential phenolic components, including p-coumaric, Caffeic acid,gallic , and ferulic acid, which are found in substantial quantities [4]. Proanthocyanidins (PAs), which consist of concentrated tannins, exhibit antioxidant properties and are plentiful in the peel[7] .The dried peels have a significantly higher carotenoid content (340 mg/100 g) than other fruits including banana [7], apple[44] and persimmon flesh[5] . As a result, dried persimmon peel can be used as a powdered ingredient in products of the nutraceutical, pharmaceutical, and cosmetic industries, while cutting waste and harness

Dehydration is commonly practice method in the food process industry, involving the moisture removal from the sample to enhance quality, extend shelf life, and inhibit microbial growth [8]. This process involves complicated heat and mass transfer mechanism that must be understood to achieve a better-quality product. Previous studies highlight that external factor such as temperature, time, drying air velocity, direction, as well as the internal structure are the main parameters which influence the physical and chemical changes [2]. These changes can happen under an extreme condition which need to be controlled well. Therefore, studying the drying kinetics will allow us to understand these phenomena quantitatively. Despite the kinetics, thin layer modeling of food samples is a necessary to understand the fundamental phenomena of transport mechanisms and scale up the process[9,10]. Previous studies have evaluated semi-theoretical and empirical models for vegetable and fruit drying as well as for by-products such as cucumber[11], carrot [12], apple [13,14], pumpkin[15], peach [16], apricot[17] , pomegranate peel[18], banana peel [19], papaya peel[20], and sesame seeds [21] .

Although, Many studies have discovered the processing attributes of persimmons flesh with the aim of improving quality of the final product[22,23,24,25,26], there is a significant research gap which needs to address the drying kinetics and quality aspects of persimmon peel.

Examine the drying behavior of persimmon peel, which is crucial for optimizing processes to achieve higher levels of biochemical compounds, which can be valuable for pharmaceutical, food additive, and other food-related industries. This research aim was to study the effects of drying conditions on the kinetics of drying and the quality characteristics of Japanese persimmon (*Diospyros kaki* cv. Fuyu) peel using a forced convective dryer on a laboratory scale. Drying was carried out across a wide temperature range (40–70°C) with the drying air velocity maintained at 2.7 ± 0.1 ms^{-1} to assess the variables involved in the drying process. The physicochemical and functional properties, such as phenolic content, antioxidant activity, powder morphology, thermal stability, and functional groups etc. were extensively analyzed.

2. Materials and Methods

2.1 Sample preparation

Persimmon fruits (Diospyros kaki. cv. Fuyu) were obtained from the JA Chikuzen commercial scale farm, Asakura city, Fukuoka, Japan. Selected healthy fruits were properly cleaned with distilled water. Fruit weight between 195-205 g samples were selected for the experiment. Samples were stored at a 4°C refrigerator until the end of experiment, around 2-3 days. Persimmons were peeled using mechanical peeler and cut in the dimension of 33.5 ± 0.5 mm (length), 15.75 ± 0.5 mm (width), and 1.7 ± 0.5 mm (thicknesses). To determine the initial moisture content, the peel was dried in an oven at 105 ± 0.5°C for 24 hours. Before drying, the oven was set to for an hour to balance the internal temperature.

2.2 Drying procedure

This study's drying setup was a pilot-scale cylindrical chamber, which has previously been used by Tanaka et al., (2015)[27]. for thin layer drying of rice grains. Experiments were conducted at 40, 50, 60, and 70 °C temperatures with a constant air speed of 2.7 m/s and regulated relative humidity of 20%.

The drying setup consisted of a low temperature humidifier (TPAV-120-20, Isuzu Seisakusho, Japan) to keep drying conditions of temperature and relative humidity (RH) constant. The persimmon peels were dried using a simple cylindrical forced convection chamber composed of a 3mm thick polyvinyl chloride pipe with an internal diameter of 83mm. The drying air is drawn into the cylindrical dryer by a fan at the bottom and then send upward.

For each experiment, 15 ± 0.5 g of persimmon peel samples were evenly distributed in a thin layer within the cylindrical chamber. Sample weight was monitored every 10 minutes, and the drying process ended when the weight change was less than 0.001 g (wet basis). All drying experiments were carried out in a total of three and the average moisture content at each time interval was used to create the drying curves. The persimmon peel revealed an average initial moisture level of 72.4 ± 0.2% (wet basis). The dry weight of samples was analyzed by further drying at 105 ± 0.5 °C for 24 hours in an oven dryer.

2.3 Thin layer kinetics and characteristics

The moisture content (MC) of the drying samples was evaluated using Eq. (1), and the moisture ratio (MR) was calculated using Eq. 2 [19]

$$MC = \frac{W_t - W_d}{W_d} \quad (1)$$

where, W_t represents total weight (g); W_d represents dry mass (g); *MC* represents sample moisture content (g water/g dry matter)

$$MR = \frac{X - X_e}{X_0 - X_e} \quad (2)$$

where *MR* represent dimensionless moisture ratio, *X* represent the moisture amount at *t* time (g water/g dry matter); X_0 represent the initial moisture amount of fresh sample (g water/g dry matter); X_e represent the equilibrium moisture amount (g water/g dry matter)

The drying rate (*DR*) of persimmon peel was estimated using Eq. (3)

$$DR = \frac{(M_{t1} - M_{t2})}{(t_1 - t_2)} \quad (3)$$

where t_1 and t_2 depict drying times (min); M_{t1} and M_{t2} depict moisture amount of the samples at time 1 and time 2, g (water/g dry matter) respectively.

2.4 Nonlinear regression calculations

The moisture level data were simulated using seven thin-layer models as detailed in Table 1. Model optimization was performed by fitting the data using the nonlinear least squares regression analysis carried out in R language (version 4.2.1). The determination of coefficient (R^2) Eq. (4) and root mean square error (*RMSE*) Eq. (6), were used to assess the accuracy of fit[25,20] .

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR_{pre,i}} - MR_{exp,i})^2} \quad (4)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2} \quad (5)$$

2.5 Estimation of the effective moisture diffusivity (Deff) and the energy of activation

Effective moisture diffusivity represents the moisture transmission within a material that is mostly influenced by its water content and temperature[28] .The sample's effective diffusivity was estimated by fitting the Crank equation (Eq. (6)) to the experimental data using a 10-term approximation.

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-\frac{(2n+1)^2 \pi^2 D_{eff} t}{4L_0^2}\right) \qquad (6)$$

where D_{eff} represents the effective diffusivity (m^2/s); L_0 represents the half thickness of the sample (m). Further modified equation can be written considering first term series as following:

$$\ln MR = \frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4L_0^2} \qquad (7)$$

Diffusivities were calculated by plotting experimental drying data in terms of ln MR against the drying time t in Eq. (8) as follows;

$$Slope = \frac{D_{eff} t}{4L_0^2} \qquad (8)$$

The Arrhenius equation (Eq. 9) was used to assess the influence of drying temperature on effective diffusivity. Activation energies were calculated using the slope of the Ln curve (Def) as a function of temperature in absolute terms inverse (1/T).

$$D_{eff} = D_0 \exp\left(\frac{-E_a}{RT}\right) \quad (9)$$

where D_0 denotes the pre-exponential factor of the Arrhenius equation (m^2/s); E_a denotes the activation energy (kJ/mol); T denotes the absolute temperature (K), and R denotes the universal gas constant (kJ/mol K).

2.6 Physiological Properties

2.6.1 Powder yield

Dried persimmon peels were ground using a mechanical grinder for 40 seconds. The weight difference between before and after drying was used to calculate the powder yield using the Eq. 10 described by Zhang et al. (2024)[29]. Here, M_1 represents the mass of the persimmon peel before drying, and M_2 represents the mass of the peel after drying.

$$Yield(\%) = \frac{M_1}{M_2} \times 100\ (\%) \quad (10)$$

2.6.2 Total turbidity

The turbidity of powder were measured by a UV spectrophotometer modeled UV-1800 instrument from Japan at 900 nm considering purified water as a blank [30].

2.6.3 Water solubility index (WSI) and water absorption index (WAI)

As described in Santhalakshmy et al, (2015)[30], WSI (water soluble index) and WAI (water absorption index) were analyzed. To begin, 2.5 g of powder from each treatment was added to 30 mL of distilled water at 30 °C to a beaker. The mixture was agitated for 30 minutes and then centrifuged at 5100 rpm for 10 minutes. After centrifugation, the solution was carefully transferred into a petri dish and dried at 60°C. The dried extract was expressed as a percentage of the total dry solids in the 2.5 g fresh sample which is corresponding to the WSI. The moist material that remained after separation was dried overnight in an oven. Then WAI was determined by the proportion of dry solid to the amount of dry sample used.

2.6.4 Glass transition temperature

The glass transition temperature (Tg) was determined using the differential scanning calorimeter model of the X-DSC7000, Japan following the approach given by Santhalakshmy et al., (2015)[30], with some modifications.The powder particles around 3 mg were taken into aluminum pans, capped with lids and weighed.

The device was calibrated with indium ($T_{melting}$ = 156.6 °C) and dry nitrogen was employed as the purge gas at a flow rate of 70 $mL.min^{-1}$. Samples were warmed at a rate of 10 $°C.min^{-1}$ from -20 to 350 °C and then cooled to 25 °C at the same heating rate. An empty pan served as a reference. Additionally, thermogravimetric measurements (TGA) were conducted using a thermogravimetric analyzer modeled TG/DTA7300 from Japan.

2.6.5 Color of peel powders dried at different treatments.

The color of the powder particles was detected by using colorimeter modeled Hunter Associates Laboratory Inc., Reston, VA, USA. The Lightness(L*), redness (a*) and yellowness (b*) values were recorded, and total color difference (ΔE) was analyzed by following formula outlined in Eq. 11,

$$\Delta E = \sqrt{(a^* - a_0)^2 + (b^* - b_0)^2 + (L^* - L_0)^2} \quad (11)$$

The BI was evaluated according to the Eq. (12) as reported by Zang et al. (2024)[29].

$$BI = \frac{100 \times (X - 0.31)}{0.17} \quad (12)$$

$$X = \frac{a* + 1.75 \times L*}{5.645\, L* + a* - 0.3012\, b*}$$

2.6.6 Functional groups analysis.

The FTIR spectrum of powder samples were obtained using FTIR instrument (FT/IR-4700, Jasco international Co. Ltd, Tokyo, Japan). The spectra were recorded in transmittance mode from 4000 to 400 cm^{-1} the resolution was 0.44 cm^{-1}.

2.6.7 Particle morphology analysis

The powder morphology of persimmon peel was analyzed using Scanning Electron Microscope modeled SU3500, Hitachi high technologies, Tokyo, Japan. A sample size of approximately 2.35 mg was selected. The samples were attached on metal stubs using two-sided tape and coated with a thin layer of gold before being observed. Observations were made at a voltage of 15 kV, with magnifications of 1500× and 2000×.

2.7. Chemical Composition Analysis

Approximately 2.0 g of peel powder was mixed with 20 mL of 80% methanol and stirred in a water bath set to 40°C for 60 minutes. After cooling, the mixture was centrifuged at 1500×g for 15 minutes. The was then collected and used to measure the total phenolic content, total flavonoid content, and antioxidant activity.

2.7.1 Total phenolic contents

The total phenolic content of powder was determined using the procedure outlined by Chuab et al. (2008)[31]. In brief, 200 µL of persimmon extract was combined with 2mL of 7.5% sodium carbonate and 800 µL of diluted Folin-Ciocalteu reagent. Mixed solution was kept at room temperature for 15min. The resulting mixture was then diluted with distilled water until it reached a final volume of 7 mL. The data were presented as milligrams of the equivalent of gallic acid (GAE) per gram of dry weight.

2.7.2 Antioxidant Activity

The antioxidant capacity (DPPH) of the fruit peel powder was tested using the method explained in Abdel-Naeem et al. (2022)[32]. In brief, 100 µL of the sample extract was combined with 3.9 mL of a 0.0634 mM DPPH solution in 95% methanol, followed by homogenization for 10 seconds. The entire mixture was then kept at room temperature for 30 minutes in the dark. The absorbance of the solution was measured at 515 nm against a blank containing methanol without DPPH, using a spectrophotometer (V-530, Jasco International Co. Ltd, Tokyo, Japan). The DPPH radical scavenging activity, reported as a percentage, was computed using the equation below, with a DPPH concentration of 2.5 mg in 100 mL of methanol solution.

3. Results and discussion

3.1 Drying curves

The persimmon peel was dried at 40, 50, 60 and 70 °C as thin layer under the constant air velocity of 2.7 ms^{-1} using a laboratory developed setup. Figure 1 illustrates the graph of moisture ratio against time for persimmon peel samples for drying period. As shown in figure, the average water content of persimmon peel reduced gradually as the drying time reached to equilibrium moisture contents of 0.0902, 0.0871, 0.061, and 0.0287 g water/g (dry basis) for 40, 50, 60, and 70 °C drying temperature, respectively. The period of drying necessary to reach a final equilibrium moisture content of the peel was 610, 550, 390, and 230 minutes at temperatures of 40, 50, 60, and 70°C, respectively. It may be noted that increasing the drying temperature accelerates the drying process and drastically shortens drying time. The rapid fall in moisture ratio was due to the peels receiving a high air heat supply rate (2.7 ms-1), resulting in accelerated moisture migration. This finding is comparable to that of persimmon slices drying shown in prior investigations[23,26].

The drying time decreased by 9.8%, 29.09%, and 41.02% with each 10˚C rise in temperature from 40 to 70˚C. Increasing the temperature increase by 10 ˚C from 60 to 70 significantly reduces drying period by 41.02%. The graph in Figure 1 also indicates the moisture ratio drops steadily during the drying process. The diffusion process slowed; thus, it took more than two-thirds of the total drying time to remove the latter half of the moisture ratio. Figure 2 demonstrates that the steady rate period was not clearly recognized during the drying process of the persimmon peel.

At the beginning of each curve, the sudden warmup period could be seen as external drying air temperature is higher than material. even though that, sample did not show the surface evaporation period resulting a falling period without constant drying period. As drying progresses, the surface of sample seems to have dried and moisture content has been decreased to its minimum moisture content which is controlled by liquid diffusion [9]. This relates to the beginning of the first declining rate period. The higher the temperature (e.g., 70°C), the steeper the slope, indicating faster drying. This phase corresponds to the material reaching a lower moisture content, where internal diffusion becomes the limiting factor. The slope decreases more gradually, particularly at lower temperatures (e.g., 40°C). Towards the end of the curves, the moisture ratio becomes very low, and the drying rate is minimal. This period shows a near-constant moisture ratio or a prolonged decrease. At 70°C, the process is faster, and the curve reaches a near-horizontal state quicker than at 40°C, where drying is more protracted.

3.2 Modelling of drying curves

The moisture data collected under various dehydration conditions were calculated into a dimensionless moisture ratio, as previously stated, and then modeled to seven chosen thin-layer drying kinetics as shown in Table 1. The model parameters were obtained by investigating gaps between experimental and predicted values. Table 2 displays the findings of the nonlinear regression analysis.

The best model for characterizing the thin layer drying properties of peel was chosen based on the highest R^2 and lowest RMSE values. In general, the R^2 values for the Lewis, Page, Modified Page, Henderson and Pabis, Logarithmic, Midilli et al., and Weibull models were greater than 0.99. The error deviation of R^2 and RMSE values ranged from 0.9955 to 0.99974, and 0.00362 to 0.01516. Overall, the Weibull model produced the highest R^2 value with the lowest RMSE for all drying conditions. The R^2 value and RMSE values of the Weibull model for all drying temperatures ranged from 0.99912 to 0.9997 and 0.00394 to 0.00528, respectively.

3.3 The effective moisture diffusivity

The study only demonstrated the falling rate throughout the drying process, showing that internal mass resistance was the dominating mechanism, allowing for controlled drying duration. As a result, the effective diffusivity (D_eff) values at various dehydration temperatures were calculated using Eqs. (8) and (9). Figure 3 depicts a plot of ln (MR) vs drying time (t, min), as described in Eq. (8). In this study, two distinct declining rate periods were identified, with a constant slope. Thereby the effective diffusion coefficients were determined. The values were determined by calculating the slope of Figure 3, taking into account total and separate the falling rate periods. The average effective diffusivity values of persimmon peel after dehydrating at temperatures from 40°C to 70°C varied between 5.15383 × 10^{-10} and 1.936 × 10^{-9} m^2/s (Table 3). As expected, D_eff was increased with increasing drying temperature.

The effective diffusivities for food items range from 10-11 to 10-9 m^2s^{-1}[13]. These findings are consistent with previous research and comparable to the values reported for persimmon, which range from 2.6 ×10^{-10} to 5.4 ×10^{-10} m^2s^{-1} at 0.8 ms^{-1} air flow and temperatures ranging from 50 to 80 ˚C, as reported by Telis- Romero et al. (2001)[45]. Moreover, Doymaz, (2012) reported as 7.05 ×10^{-11} m^2/s to 2.34 ×10^{-10} m^2s^{-1} for 50-70 °C drying temperatures[23].

The effective diffusivity values during the first falling rate period was differed from 1.261×10^{-9} to 3.781×10^{-9} m^2s^{-1}, while the effective diffusivity in the second falling rate period was differed from 3.419×10^{-10} to 1.189×10^{-9} m^2s^{-1} (Table 3). This observation is consistent with the conclusion that the rate of diffusion is proportional to the sample temperature, and that the first falling period has higher moisture diffusivity than the second falling period. As drying progresses into the second falling rate period, the moisture content decreases, resulting in a lower driving force for moisture movement. As a result, the effective diffusivity reduces during the second falling rate period which shows similar observation by Pinheiro et al. (2023)[33].

3.4 Activation energy

Activation energy measures how sensitive Deff is to temperature and the amount of energy required for moisture diffusion inside samples[28].Figure 4 depicts Ln(Deff) as a function of the inverse of the absolute temperature. The result demonstrates a linear relationship derived from the Arrhenius-type equation. In this study, the activation energy of persimmon peels for the whole drying period was found to be 38.45 $kJmol^{-1}$, which shows close results by Doymaz (2012) as 43.26 $kJmol^{-1}$. According to Mphahlele et al. (2019), the value of activation energy should be within the range of 12.7–110 $kJmol^{-1}$ for food. Further, activation energy for 1st and 2nd falling periods was calculated as 32.72 $kJmol^{-1}$ and 36.06 $kJmol^{-1}$. The findings are beneficial for modeling and thereby optimize the drying process. Information will be used for future research on how these drying conditions effect the biochemical and national compounds off final product and to optimize the commercial viability.

3.5 Physiological Properties

3.5.1 Powder yield

The yield of persimmon peel under different dehydration treatments are shown in Table 4. The dehydration temperatures did not significantly affect the yield, which ranged from 27.57% to 27.85%.

3.5.2 Total turbidity

Turbidity values differed significantly between samples obtained at various temperatures, as seen in Table 4. Samples dried at 70°C had the greatest turbidity value (2.22±0.15), followed by samples at 60°C, 50°C, and 40°C. The least value was 1.55.

3.5.3 Water solubility index (WSI) and water absorption index (WAI)

The particle reconstitution, known as WSI, can be used to investigate the impact of process factors on performance. Table 4 shows that samples dried at 70°C had the highest water solubility index (47.17±0.12%), while samples dried at 40°C had the lowest (41.93±0.10%). Drying at 40°C resulted in the highest water absorption index (48.53±0.23%) and the lowest water solubility index (41.93±0.10). These findings show that increasing the intake temperature increases the water solubility index while decreases the water absorption index. Santhalakshmy et al. (2015) reported a similar tendency in their spray drying of jamun fruit juice powder[30].

3.5.4 Color analysis.

The color parameters of peel powder are shown in Figure 5 and Table 4. The L^* value grew when the dehydration temperature climbed from 40°C to 60°C, but decreased as it was increased to 70°C. In contrast, the a^* values decreased while the b^* values grew with higher drying temperatures. The highest L* value was obtained in samples dried at 60°C, while the highest a* and b* values were recorded at 40°C and 60°C, respectively.

The rise in lightness (L*) when the inlet drying temperature was increased from 40°C to 60°C could be attributed to a reduction in enzymatic browning, which was most likely induced by polyphenol oxidase deactivation at high temperatures. However, the subsequent drop in L* value with increasing temperature could be attributed to non-enzymatic browning, such as the Maillard process, which occurs at higher temperatures[34] .The consistently high b* readings across all samples point to a higher degree of yellow in the dried peel.

The lower a value seen in peels dried at higher temperatures compared to lower temperatures show that enzymatic browning is more important in the formation of redness than non-enzymatic browning[34] .These findings are in line with those of Al-Muhtaseb et al. (2010), who discovered that the L value of tomato pomace increased as the drying temperature rose from 40°C to 70°C, but dropped at 80°C[35]. Abano et al. (2011) and Afrin et al. (2022) found similar patterns in L*, a*, and b* values while drying tomato and orange pomace[34,36].

3.5.5 SEM analysis

The morphological characteristics of powder particles dried at temperatures differ from 40°C to 70°C are shown in figure 6. As observed in SEM, there are significant changes in shape, size, and surface features within the sample and between the samples. At lower temperatures, such as 40°C, the particles were relatively larger and exhibited irregular, rough surfaces with folding and wrinkling[37,31]. As the drying temperature increased, the particles became progressively more compact, with a noticeable reduction in size and a transition toward spherical shapes. At 70°C, the powders exhibited the most spherical and uniform morphology, along with a higher extent of dimensional reduction. The surfaces appeared relatively smoother, although they still retained some degree of textural irregularity due to rapid moisture removal and shrinkage at elevated temperatures. At 60°C, some larger particles were observed, potentially due to uneven shrinkage or localized moisture retention during the drying process. Further, particles were displayed a mixture of rough surfaces, fibrous strands, and certain crystalline or flaky structures, indicating temperature effect on the internal moisture distribution and structural rearrangement. Afrin et al. (2022) reported comparable results for hot air-dried orange peel[34]. These results show that drying temperature has a considerable impact on particle morphology, including size, shape, and surface features. Higher temperatures caused faster drying, more structural shrinkage, and the formation of compact, spherical particles, whereas lower temperatures produced larger, more irregular structures. Temperature, moisture content, and structural changes all influence the ultimate characteristics of dried particles.

3.5.6 Thermal Analysis

Figure 7 depicts the thermal stability of peels dried at various temperatures. The results show complex thermal profiles and comparable tendencies among the samples. The total mass loss ranged between 56- 63%, with no significant influence observed from the drying temperatures. The first weight loss occurred between 50°C and 150°C, likely due to the high-water content in the samples. The second mass loss occurred between 180°C and 220°C, which was associated with the degradation of volatile substances such as oils and pigments. The third weight loss occurred between 250°C and 400°C, corresponding to the breakdown of cellulose and hemicellulose. Furthermore, we discovered three decomposition peaks at 65.8-108°C, 170-230°C, and 270-400°C. The rise between 170 and 230 °C could be caused by the breakdown of pectin and hemicelluloses, while the peak points between 270 and 400 °C corresponds to the breakdown of cellulose[34]. The glass transition temperature (Tg) could not be accurately determined during the persimmon peel drying process. The lack of a clear Tg curve could be due to the material's higher water content and weaker thermal stability, which can overlap or hide the transition during thermal analysis[38].

3.5.7 Functional groups Analysis

The FT-IR spectrum identify the functional groups contained in the powders and determine the effect of different drying settings on the alterations that occur during processing. As seen in Figure 8, the drying temperatures had no major effect on the molecular structures. The absorbance peak at 3300 cm^{-1} corresponds to O-H stretch vibrations, while the intensity band at 2930 cm^{-1} belongs to C-H bending vibrations of -CH2 and -CH3 groups[39] .Furthermore, lower temperatures (40 and 50) revealed more C-H bonds than higher temperatures. The peaks at 1643.05 and 1635.34 cm^{-1} were attributed to the vibrations of bending absorbed -OH molecules of water inside the powder structure, related to the interaction between water and peel particles. [40]. The fingerprint region revealed a double band peak at 1417.72-1405.85 cm-1, which corresponds to the C-H bending vibrations of -CH3 methyl molecule groups [40].The deeper peak was reflected at 980 cm-1 wavelengths, indicating the presence of alcohol groups .Carboxylic acid, which is mostly contributed by pectin, cellulose, or lignin found in peel powder, aids in the treatment of a variety of ailments such as ulcers, headaches, and wounds. Similarly, the hydroxyl group in pomace is responsible for anionic impurity adsorption[34, 41].

3.6 Total Phenolic content and Antioxidant activity

Figure 9 depicts the total phenolic content and antioxidant activity of dried peel after various temperature treatments. Thermal treatment led to a considerable drop in peel antioxidant content. (119.96% db), as seen in fig. 9. As the dehydration temperature increased, the antioxidant content gradually decreased and recorded the lowest value at 70 °C (44.26% db.). In contrast, drying at 40 °C retained the highest antioxidant content followed by 60 °C. At 60°C, the shorter drying time likely minimized the exposure to thermal degradation, preserving antioxidants more effectively. Zhao et al. (2021) reported a similar observation, where persimmon slices dried at 60 °C showed stronger radical scavenging activity than those dried at 50 °C and 70 °C [2]. This was attributed to the higher gallic acid content found in the slices dried at 60°C. According to Olajuyigbe & Afolayan., (2011), phenolic compounds and flavonoids are the primary constituents in most plants known to exhibit antioxidant activity [42]. Therefore, higher phenolic content is often associated with increased antioxidant activity. Interestingly, our study demonstrated a contrasting result which showed higher phenolic content at 70 °C followed by 60°C. overall, 60 temperature effect achieved comparatively higher antioxidant and total phenolic content. Similar observations were found in literatures for persimmon, pomegranate peel where antioxidant activity was linked to specific bioactive compounds, such as gallic acid, which function as free radical scavengers during oxidation [2,43].

4. Conclusion

The drying properties of persimmon peel were examined at various drying temperatures. Seven semi-theoretical thin layer drying models describing the drying kinetics of peel were tested. Higher temperatures accelerated the drying of persimmon peel while reducing the duration. The Weibull model, which is based on Fick's diffusion rule, successfully characterized the fluctuation in the MR. The Crank equation yielded effective moisture diffusivities ranging from 5.154×10^{-10} to 1.936×10^{-9} m^2s^{-1}, 1.261×10^{-9} to 3.781×10^{-9} m^2s^{-1} for the first falling rate period, and 3.419×10^{-10} to 1.189×10^{-9} m^2s^{-1} for the second falling period. The calculated activation energy was 38.45 kJmol-1. According to the findings of the current study, drying temperature has positive as well as negative impacts on the properties of dried persimmon peel. When testing different drying temperatures, there were no significant differences in yield, thermal stability, or FTIR readings. However, greater drying temperatures resulted in increased turbidity (2.222) and water solubility (47.17%) at 70°C. A drying temperature of 60 °C is recommended because it provides a good balance for maintaining antioxidant and phenolic components but producing more obvious color changes than the other temperature treatments.

CRediT authorship contribution statement

M. A. Reshaka Kavindi: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft. **Mohammad Hamayoon Wardak:** Data curation, Investigation. **Fanze Meng:** Data curation, Investigation. **Francis Ngwane Nkede:** Data curation, Investigation **Fumina Tanaka:** Validation, Visualization, Writing – review & editing. **K. S. P. Amaratunga:** Supervision, writing-review, editing. **Fumihiko Tanaka:** Funding acquisition, Resources, Supervision, Visualization, writing – review & editing

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on reasonable requests through the corresponding author.

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