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Research Article

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Novelty Impact Statement

- ✓ To produce chips by drying purple carrots,
- ✓ Determining the optimum drying process for purple carrot chips.
- ✓ To determine the effects of drying processes on energy consumption, physico-chemical and thermo-physical properties.

Abstract

In present study, effects of drying methods (continuous and intermittent) and pre-treatments (dipping into 25% salt, 25% vinegar, 25% (salt + vinegar), 10% *Pyraacantha coccinea* and 10% *Malus floribunda* solutions) on drying models, effective diffusion, dimensional traits, rehydration, color, shrinkage ratio, energy consumption, thermo-physical and some drying properties of carrot slices were investigated. Among the thin-layer drying models, Wang-Sing model yielded the best and Rational 1-parameter 2 model yielded the weakest estimations. Effective diffusion values varied between $2.96 - 9.12 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ in continuous drying method and between $2.61 - 5.59 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ in intermittent drying method. The greatest rehydration capacities were observed in samples dipped into 25% vinegar (82.88%) and 10% *Malus floribunda* (82.13%) solutions. The greatest volume change (92.60%) was observed in samples dipped into 10% *Pyraacantha coccinea* solution and dried by continuous drying method. The lowest volume change (72.92%) was observed in control samples of intermittent drying method. In terms of chroma values, the samples dried by intermittent drying after dipping into 25% salt and 25% vinegar solutions yielded the closest values to the fresh samples. As an alternative drying method in terms of chroma value, dipping into 10% *Pyraacantha coccinea* solution could also be selected in intermittent drying method. The greatest evaporation latent heat (ELH) value (10.62 kWh) was observed in samples dipped into 25% vinegar solution and the lowest ELH value (5.63 kWh) was observed in samples dipped into 25% (salt + vinegar) solution.

Keywords Carrot · Drying process · Pre-treatments · energy analysis · thermo-physical properties

Introduction

Carrot is highly rich in natural active substances, especially in carotenoid. Such attributes significantly increase antioxidant property that aid in removal of toxic substances from the body (Becerra et al. 2020; Wang et al. 2021). Carrot is not only consumed in fresh forms, but also dried and consumed as dietary product. Additionally,

dried carrots are rehydrated and used in soups, purees, creams and many other foodstuffs (Santos et al. 2021). Drying methods and the other processes significantly influence quality traits of final product.

Open-sun drying is the oldest natural drying method. Sun-drying is a low-cost practical process without CO₂ emission and does not require an artificial heat source. However, this method does not allow drying all times and everywhere, drying durations are quite long, desired moisture levels are not always achieved and drying materials are prone to decays and negative environmental (dust, wind, rain, insects, pesticides, etc.) (Purohit et al. 2006; Sharma et al. 2009; Taşkın et al. 2021). Conventional drying is commonly preferred by drying industry. This method of drying has high initial investment costs and energy consumption. However, better outcomes are achieved in terms of quality traits of final products through fast drying and homogeneous heat distribution (Morais et al. 2018; Yan et al. 2019; Boateng and Yang 2020). The amount of energy consumed in agri-food chain corresponds to 30% of the energy produced on a global scale (FAO 2011; Jha and Tripathy 2017; Jha and Tripathy 2021). Therefore, some pre-treatments are applied to agricultural products both to reduce energy consumptions and to preserve physical properties of the products. These pre-treatments help to minimize or terminate the negative effects that occur during drying processes (Lewicki and Gupta 1995; Soomro et al. 2020). Pre-treatments applied before drying reduce drying durations, accelerate inactivity of enzymes, reduce undesirable odor and putrefactions and aid in preservation of color and the other physical properties (Deng et al. 2019). Dipping into chemical or natural fruit juices that are not harmful to health is generally preferred as pre-treatment in drying experiments. Rojas et al. (2020) dipped apple slices into ethanol solution for 10, 20 and 30 minutes and subjected to ultrasound treatments, then dried ultrasound treated and untreated samples at constant drying temperature of 50 °C. The pre-treatment of dipping into ethanol solution decreased mass transfer resistance of the apple slices and reduced drying durations. Decreasing shrinkage was observed with increasing dipping durations. Ultrasound treatments provided positive contributions. Wang et al. (2010) dipped potato slices into salt (5, 10 and 15%) and sugar (30, 40 and 50%) solutions, then dried osmotically pre-dried samples in microwave-assisted freeze dryer. It was reported that pre-treatments increased drying rates. Especially in terms of drying duration and quality characteristics, dipping into >5% salt and >30% sugar solutions yielded better outcomes. Supmoon and Noomhorm (2013) dried potato slices with the use of jet air, jet air + infrared and convective drying methods at 5, 10 and 15 m s⁻¹ airflow rates, a constant drying air temperature of 85 °C and 0.16, 0.27 and 0.33 W cm⁻² electromagnetic wave densities. It was reported that jet air + infrared drying resulted in higher drying rate, less shrinkage, less hardness and less color change as compared to the other methods. It was reported that pre-treatment of dipping into natural fruit/product juices, which has been very popular recently, contributed to preservation of drying properties of the materials. Jha et al. (2021) experimented dipping into rice water in banana flower power production; Abano et al. (2013) experimented dipping into honey water to obtain dried mangoes; Hubockova and Banaout (2017) experimented dipping into *Sorbus aucuparia* (Rowan), *Diospyros kaki* (Persimmon), *Hippophae rhamnoides* (Buckthorn), *Actinidia deliciosa* (Fuzzy kiwifruit), *Rosa canina* (Rosehip) juices in dry apple fruit production and they all reported that pre-treatments preserved color values, accelerated mass transfer and reduced energy consumptions.

Intermittent drying is another method used to preserve fruit physical properties during drying processes (Sun et al. 2021). Intermittent drying method; it is a method obtained by changing the drying conditions (temperature, relative humidity, pressure, etc.) depending on time. It is the most energy efficient method among drying processes. This drying method is an important method that improves product quality without increasing the cost

of the dryer (Kurmar et al. 2014). Adrover et al. (2020) investigated the effects of continuous and intermittent drying methods on effective diffusion coefficient, shrinkage and mass transfer properties of pear fruit and reported better outcomes of some properties in intermittent drying. Jin et al. (2020) dried fresh walnuts in a conventional dryer using intermittent and continuous methods and reported better outcomes for drying rate, color quality and energy consumption characteristics in intermittent drying method. Franco et al. (2020) dried paddy samples by using intermittent and continuous methods at 30-240 minutes of tempering at 40, 50, 60 and 70°C temperatures and indicated that intermittent drying minimized thermal deformations encountered on paddy surfaces.

In this study, effects of pre-treatments (dipping into 25% salt, 25% vinegar, 25% (salt + vinegar), 10% *Pyracantha coccinea* (Firethorn) and 10% *Malus floribunda* (Japanese crabapple) solutions)) on drying model, effective diffusion, size properties, rehydration, color, shrinkage rate, energy consumption and thermo-physical properties of carrot chips were investigated with the use of continuous-intermittent drying methods.

Material and method

Drying Process and Equipment

Fresh carrots were supplied from a local market in Tokat province of Turkey. Carrots were preserved under refrigerator conditions (4 ± 0.5 °C) until the end of the study. Before the moisture content and drying processes, carrots were washed and sliced with a sharp knife in a circular form (3.5 ± 0.15 mm diameter). To determine the initial moisture content, carrot slices were dried in an oven (Şimşek Labor teknik brand-ST-055 model) at 70 °C until a constant weight change (Pixton and Warburton 1973). The initial moisture content of carrots was determined as 7.20 ± 0.10 (g moisture/g dry matter) in dry-basis. Drying processes to get carrot chips were carried out in an oven (Şimşek Labor teknik brand-ST-120 model) at 70 °C up to 5-8% moisture levels (wet-basis) with the use intermittent and continuous methods. Drying processes were also completed in 3 parallel with and without dipping pre-treatments. In intermittent drying process was conducted in accordance with the method of Saleh et al. (2020). Samples were initially dried up to 30% moisture level, then rested for 2 hours. Then, the product was dried again up to 5-8% moisture level. AND-brand GF-300 model precision balance (±0.01 g) was used to determine weight change of carrot slices.

Dipping Pre-treatments

Solutions were prepared for dipping carrot slices as; 1) for salt treatments, 125 g salt (NaCl) was dissolved in 375 ml distilled water; 2) for vinegar treatments, 125 ml vinegar was mixed with 375 ml distilled water in a 500 ml glass beaker; 3) for salt + vinegar treatments, 62.5 g salt (NaCl) and 62.5 ml vinegar were mixed and dissolved in 375 ml distilled water; 4) for *Pyracantha coccinea* (Firethorn) treatments, 100 g *Pyracantha coccinea* (Firethorn) fruit was chopped in 900 ml distilled water with a blender and juices were extracted and 500 ml of *Pyracantha coccinea* extract was taken into a glass beaker for dipping pre-treatments; 5) for *Malus floribunda* (Japanese crabapple) treatments, 100 g of *Malus floribunda* (Japanese crabapple) fruit was chopped in 900 ml distilled water with a blender and juices were extracted, 500 ml of *Malus floribunda* extract was taken

into a glass beaker for dipping pre-treatments. Carrot slices were dipped in the prepared solutions for 15 minutes at the same time. Following the dipping period, carrot slices were taken from the glass beakers at the same time and solutions on slice surfaces were dried with a paper towel. Soomro et al. (2020), dipped banana slices into honey solution for 10 minutes and Fathima-Zehla et al. (2018), dipped banana slices into salt solution for 30 minutes.

Moisture Content Calculations

Equation 1 was used to determine total moisture content of carrot slices.

$$N_{wb} = \frac{M_i \times M_f}{M_i} \times 100 \quad (1)$$

where; M_i : Initial weight (g), M_f : Final weight (g).

Drying Rate Calculations

Equation 2 was used to determine drying rate of carrot slices.

$$DS = \frac{M_t - M_{(t+dt)}}{dt} \quad (2)$$

where; M_t : moisture content at time t (g water g drying material⁻¹), dt: minutes, DR: drying rate (g water g drying material⁻¹).

Moisture Ratio

Time-dependent moisture removal from the product was calculated with the use of Equation 3.

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (3)$$

where; MR: Releasable moisture ratio, M; Instant moisture content [(kg water kg dry matter⁻¹)], M_e ; Equilibrium moisture content [(kg water kg dry matter⁻¹)], M_0 ; Initial moisture content [(kg water kg dry matter⁻¹)]. The following equations [4:7] were used to determine the best thin-layer drying model.

$$\text{Lewis} \quad MR = \exp(-k \cdot t) \quad \text{Lewis (1921)} \quad (4)$$

$$\text{Jena-Das} \quad MR = k \cdot \exp(-h \cdot t + j(t^{0.5}) + m) \quad \text{Jena and Das (2007)} \quad (5)$$

$$\text{Wang-Sing} \quad MR = 1 + k \cdot t + h \cdot t^2 \quad \text{Wang and Singh (1978)} \quad (6)$$

$$\text{Rational-1 parameter-2} \quad MR = 1/(1 + a \cdot x) \quad \text{SigmaPlot 10.} \quad (7)$$

where, h, j, k, m: model coefficients, t; time.

Effective Diffusion Values

Equation 8 was used to determine effective diffusion values of the carrot slices (Corzo et al. 2008).

$$\ln ANO = \ln \frac{8}{\pi^2} - \frac{\pi^2 \cdot D_{eff} \cdot t}{4L^2} \quad (8)$$

where; D_{ef} ; effective diffusion ($m^2 s^{-1}$), L; half of the product thickness (m).

Dimensional Measurements

Length (L, mm) and thickness (T, mm) values of fresh and dried carrot slices were measured with a digital caliper (± 0.01 mm). Resultant values were used to calculate volume values with the use of Equation 9.

$$S = \pi \times r^2 \times h \quad (9)$$

where; S: Volume (mm^3), h: slice height (thickness, mm).

Shrinkage Ratio

Shrinkage is among the most important problems encountered in chips production. Shrinkage is desired to be at minimum levels in chips production by drying. Equation 10 was used in present study to determine shrinkage ratio of carrot chips.

$$SR = \frac{r}{r_o} \times 100 \quad (10)$$

where; r: final diameter (mm), r_o : initial diameter (mm).

Rehydration Ratio and Capacity

The rehydration (water retake) ratio of capacity of dried carrot slices were determined with the use of Equation 11 and 12 (Chen et al. 2016).

$$RR = \frac{M_l}{M_i} \quad (11)$$

$$RC = \frac{M_l - M_i}{M_i} \times 100 \quad (12)$$

where; RR: rehydration ratio, RC: rehydration capacity, M_i : dry slice weight (g), M_f : water-absorbed slice weight (g).

Color Parameters

The CR400 model/Japan colormeter was used to measure the brightness (L), red/green (a) and yellow/blue (b) values of fresh and dried carrot slices. Resultant values were used to calculate chroma, hue and total color change values (Table 1). Chroma indicates the color tone of fresh and dry products. While chroma values are low in pale fruits, high values are calculated for vivid colors. Hue indicates the exact position of fresh and dry product color values on a 360° color radiant. At boundary angle values: 0° indicates red, 180° green, 90 ° yellow and 270° Blue. Total color change represents the value of heat-degraded total color pigments (non-enzymatic) in drying processes. Equations [13-15] were used to determine the calculated color values.

In Table 1, L^* , a^* and b^* values respectively represent brightness, redness and yellowness values of carrot slices.

Specific Moisture Extraction Rate (SMER)

Total energy consumed by the dryer in drying process of carrot slices was determined by using Polaxtor brand PLX-15366 model device. The specific moisture extraction rate (SMER) is determined through dividing the amount of moisture removed from the fruit during the drying process by the total amount of energy consumed. Equation 16 was used to determine the specific moisture extraction rate (Surendhar et al. 2019).

$$SMER = \frac{\text{Moisture removed during drying (kg)}}{\text{Total energy supplied to the dryer (kWh)}} \quad (16)$$

where; SMER: specific moisture extraction rate (kg/kWh).

Specific Energy Consumption (SEC)

Total energy required to dry one kilogram of carrot slices is expressed as specific energy consumption. Equation 17 was used to calculate specific energy consumption (Motevali et al. 2012).

$$SEC = \frac{E_t}{m_w} \quad (17)$$

where; SEC: specific energy consumption (kWh kg water⁻¹), E_t : total energy consumption (kWh), m_w : removed water quantity (kg).

Evaporation Latent Heat (ELH)

Evaporation latent heat indicates evaporation energy of moisture removed from the carrot slices during the drying process. Equation 18 was used to calculate this energy (Beigi et al. 2016).

$$Q_w = h_{fg} \times m_w \quad (18)$$

$$h_{fg} = 2.503 \times 10^6 - 2.386 \times 10^3 \times (T_d - 273.16) \\ 273.16 \leq T_d(K) < 338.72$$

$$h_{fg} = \sqrt{(7.33 \times 10^{12} - 1.60 \times 10^7 \times T_d^2)} \\ 338.72 \leq T_d < 533.16$$

where; Q_w : evaporation energy (kWh), h_{fg} : evaporation latent energy (kJ kg⁻¹), m_w : evaporated moisture quantity (kg). T_d : drying temperature (°K).

Energy Efficiency (EE)

Equation 19 was used to calculate the energy efficiency in drying process of carrot slices (Beigi et al. 2016).

$$n_e = \frac{Q_w}{E_t} \quad (19)$$

where; n_e : energy efficiency (%), Q_w : evaporation energy (kWh), E_t : total consumed energy (kWh).

Thermo-physical Properties (TP)

Specific heat, thermal conductivity, thermal diffusivity and density parameters were calculated as a function of dry-base moisture content of carrot slices in drying process. Equation 20 was used to calculate specific heat (Huang et al. 2013).

Specific heat

$$C_{p=837+3348\left(\frac{X}{1+X}\right)} \quad (20)$$

where; C_p : specific heat (J kg⁻¹°K⁻¹), X : dry-base moisture content (kg water kg dry matter⁻¹).

Thermal conductivity

Equation 21 was used to calculate thermal conductivity values (Ruiz-Lopez et al. 2004).

$$k = 0.49 - 0.44 \exp(-0.206X) \quad (21)$$

where; k : thermal conductivity (W m⁻¹°K⁻¹).

Thermal diffusivity

Equation 22 was used to calculate thermal diffusivity values (Ruiz-Lopez et al. 2004).

$$\alpha = \frac{k}{p \cdot C_p} \quad (22)$$

where; α : thermal diffusivity ($\text{m}^2 \text{s}^{-1}$), p : density (kg m^{-3}).

Density

Equation 23 was used to calculate density values (Perusello et al. 2013; Tzempelikos et al. 2015).

$$P_p = 147.95 \frac{X}{X_0} + 691.46 \quad (23)$$

Where; P_p : density (kgm^{-3}), X_0 : initial moisture content in dry-base ($\text{kg water kg dry matter}^{-1}$).

Uncertainty Analysis

Total uncertainty resulted from standard deviations encountered in drying process and measurement phases was calculated with the use of Equation 24 (Moffat, R.J. 1988; Anderson, A.M. 1995).

$$W_x = \sqrt{[(X_1)^2 + (X_2)^2 + (X_3)^2 + \dots + (X_n)^2]} \quad (24)$$

X_1 ; X_2 ; X_3 ; ... X_n indicate precision of measurement devices.

Statistical Analysis

Experimental data were subjected to analysis of variance with the use of SPSS17 statistical software and significant means were compared with the use of Duncan's multiple comparison test at $P < 0.05$ level.

Results and Discussion

Drying Durations

Intermittent and continuous drying methods and different dipping pre-treatments had significant effects on drying duration of carrot slices. In intermittent drying method, initially product moisture was brought to 30% level, then the product rested for 2 hours. Such a resting period prolonged drying durations in intermittent drying as compared to continuous drying method. Dipping pre-treatments reduced drying duration of carrot slices in both intermittent and continuous drying methods as compared to the control treatments, but only salt solution dipping pre-treatment of continuous drying method slightly prolonged drying duration. In continuous drying method, water in saline water solution rapidly evaporates and forms a thin layer on material surface, this layer then prevents moisture removal from the product. Drying duration and rate of carrot slices are presented in Figure 1.

Continuous drying method reduced drying duration by about 26.25% as compared to intermittent drying method. This situation is thought to have cooled the product due to the resting period and increased the drying time. In terms of dipping pre-treatments in both drying methods, the greatest reduction in drying duration (29.63%) was achieved with 25% vinegar solution, the second (25.93%) with 10% *Pyracantha coccinea* solution and the third (18.52%) with *Malus floribunda* solution. These findings revealed that pre-treatments of dipping into natural fruit extracts were effective in reducing drying duration of carrot slices. Dadan and Nowacka (2021) investigated the effects of a pre-treatment set consisting of ultrasound, ethanol and their combinations on drying duration of carrots. Dipping into ethanol for 5 and 15 s reduced drying durations only by 1.5-2.5%. Wang et al. (2021) investigated the effects of pre-treatments of dipping into different acid solutions on drying duration of carrot samples. While the drying duration of untreated samples was identified as 5.17 hours, drying durations of pretreated samples varied between 3.83-4.83 hours. There aren't any studies in literature about the effects of dipping pre-treatments in natural fruit juices on drying properties of carrot chips. However, Hubackova and Banout (2017) investigated the effects of dipping pre-treatments into *Diospyros kaki*, *Hippophae rhamnoides*, *Actinidia deliciosa*, *Rosa canina* fruit juices on darkening of apple slices. It was determined that color values were best preserved, darkening encountered the least and the overall visuality score was the highest in samples dipped into *Rosa canina* fruit juice.

Drying Models

Moisture release from the product during the drying processes was processed into Lewis, Jena-Das, Wang-Sing and Rational-1 parameter-2 models and the best thin-layer drying model was identified (Table 2). Lewis model predicted the best continuous drying method at 25% (salt+vinegar) pretreatment. Jena-Das model predicted the best continuous drying method at 25% (salt+vinegar) pretreatment. Wang Sing model predicted the best continuous drying method at 25% (vinegar) pretreatment. Rational-1 parameter-2 model predicted the best continuous drying method at 25% (salt+vinegar) pretreatment.

Effective Diffusion Data

The ln MR-time graphs of carrot slices are presented in Figure 3.

Effective diffusion values of carrot slices in continuous-intermittent drying methods and dipping pre-treatments are provided in Table 3.

Effective diffusion values of carrot slices in continuous method varied between $2.96 - 9.12 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$. Dipping pre-treatments had significant effects on effective diffusion values of the samples dried by continuous method. In continuous drying method, the greatest effective diffusion value was observed in samples dipped into 10% *Pyracantha coccinea* natural fruit juice. Dipping pre-treatments had also significant effects on effective diffusion values of the samples dried by intermittent method. Effective diffusion values of the samples dried by intermittent method varied between $2.61 - 5.59 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$. In intermittent drying method, the greatest effective diffusion value was observed in samples dipped into 25% vinegar solution. This value was close to effective diffusion value of the samples dipped into 10% *Pyracantha coccinea* natural fruit juice. Wiktor et al. (2019) reported effective diffusion values of ultrasound and electric combined pretreated carrot slices as between 8.8 -

11.5x10⁻¹⁰m² s⁻¹. Sarpong et al. (2019) reported effective diffusion values of carrot slices as between 8.9x10⁻⁹ - 1.7x10⁻⁸ m² s⁻¹. Present effective diffusion values complied with the previous reports.

Dimensional Data

Drying methods and dipping pre-treatments significantly influenced dimensional measurements. The L-length (diameter) and Thickness values of fresh and continuously dried samples are presented in Figure 4 and 5.

Average L (diameter) and T values of fresh carrot slices were respectively measured as 27.06 ±1.13 and 3.32±0.37 mm. Values of control samples dried by continuous method were respectively measured as 14.29±1.81 and 1.83±0.42 mm. The L and T values were respectively measured as 21.06±4.14 and 1.44±0.34 mm in samples dipped into 25% salt solution, 14.81±1.48 and 1.18±0.24 mm in samples dipped into 25% vinegar solution, 18.62±1.59 and 1.17±0.21 mm in samples dipped into 25% (Salt+Vinegar) solution, 14.40±1.77 and 0.87±0.15 mm in samples dipped into 10% *Pyracantha coccinea* solution, 13.55±1.54 and 1.19±0.21 mm in samples dipped into 10% *Malus floribunda* solution. Values of control samples dried by intermittent method were respectively measured as 21.06±4.14 and 1.44±0.34 mm. In intermittent drying, L and T values were respectively measured as 20.44±4.31 and 1.46±0.19 mm in samples dipped into 2% salt solution, 14.65±2.23 and 1.12±0.15 mm in samples dipped into 25% vinegar solution, 15.31±2.62 and 1.49±0.32 mm in samples dipped into 25% (Salt+Vinegar) solution, 17.48±3.81 and 1.24±0.18 mm in samples dipped into 10% *Pyracantha coccinea* solution, 17.90±2.76 and 1.33±0.21 mm in samples dipped into 10% *Malus floribunda* solution. Drying methods and dipping pre-treatments significantly influenced volume values of carrot slices. Volume values are provided in Table 4.

Except for samples dipped into salt solution, the greatest volume change was observed in samples dipped into the other solutions. In samples dipped into salt solution, hypertonic solution occupied micro-canals within the texture of carrot slices and let the volume change against shrinkage to be at lower levels.

Shrinkage Ratios

The dry/fresh diameter ratios of carrot samples (%) are presented in Figure 5. Greater values of this ratio indicate that slice diameters were less influenced by drying methods and dipping pre-treatments.

In continuous and intermittent drying methods, the greatest slice diameters were respectively obtained from the samples dipped into 10% *Malus floribunda* solution and 25% vinegar solution. Such a case was attributed to high acidity of *Malus floribunda* fruit and vinegar. High acidity values damaged the internal tissue structure of dried samples and increased the fragility with heat and decreased the elasticity coefficient of the fruit. Çakmak (2020) reported acidity (pH) value of *Malus floribunda* fruit as 2.91±0.02 and Hasan et al. (2021) reported average acidity of apple vinegar as 3.1. These values indicate quite high acidity levels.

Rehydration Data

Rehydration (water intake) ratio and capacity of dried carrot slices were calculated and results are presented in Figure 6.

In both drying methods, the lowest rehydration capacity was observed in samples dipped into 25% salt solution. These values were determined as 67.80% and 69.29% for continuous and intermittent drying methods, respectively. Salt solution created high pressure in the channels that contain the existing moisture, destroyed the channels and held less water in water absorption process. Among the pre-treatments, the highest rehydration capacities were determined in samples dipped into 25% vinegar (82.88%) and 10% *Malus floribunda* (82.13%) solutions for continuous and intermittent drying methods, respectively. Vinegar and natural fruit juices are more acidic and less dense than the salt solution, thus allowed easy moisture removal during drying, resulted in less damage on channels and increased the water absorption rate. Özbek (2021) dried carrot slices with the use radio frequency-assisted hot air, hot-air and freeze-drying methods and reported rehydration capacities as 86.95%, 83.55% and 88.51%, respectively.

Color Data

Color values of fresh and dried carrot slices are provided in Table 5.

Drying methods and dipping pre-treatments had significant effects on color value of fresh carrot slices ($p < 0.05$). In terms of L values of fresh samples, the best values were observed in samples dipped into 25% salt and 25% Salt+Vinegar solutions in continuous drying and in samples dipped into 25% salt solution in intermittent drying. In continuous drying, the differences in b values of control samples without any dipping pre-treatments and fresh samples were not found to be significant. In intermittent drying, b values of fresh samples were the best preserved in control and the samples dipped into 25% salt and 25% vinegar solutions. There were not significant differences in chroma values of the samples dipped into 25% salt and 25% vinegar solutions ($p > 0.05$). In terms of chroma values, intermittent drying and 10% *Pyracantha coccinea* solution could be preferred. Hue angles were significantly influenced from drying methods and dipping pre-treatments ($p < 0.05$). The closest hue value to the fresh product was achieved in control samples of intermittent drying. In both drying methods, 10% salt solution changed total color value the least. Doymaz (2017) reported average L, a and b values of fresh carrot samples as 60.04, 20.41 and 26.97, respectively. L values of pretreated and untreated samples decreased with drying processes. Besides, a and b values of dried samples increased. In terms of the effects of drying methods on L values, parallel findings were observed in present study. Thermal effects (non-enzymatic) darkened the color of carrot slices. Drying pre-treatments may increase resistance of redness (a) and yellowness (b) color pigments against thermal destruction or may result in development of a weak resistance and result in more or less destruction of color pigments. Rojas et al. (2021) dried pretreated carrot slices and reported decreasing L, b and hue values and increasing a values. Present findings comply with those earlier ones.

SMER, SEC, ELH and EE Values

Specific moisture extraction rate (SMER), specific energy consumption (SEC), evaporation latent heat (ELH) and energy efficiency values of carrot slices are provided in Table 6.

As can be inferred from Table 6, drying methods and dipping pre-treatments influenced SMER, SEC, ELH and EE values. SMER values were greater in continuous drying than in intermittent drying. In other words, greater energy removal was achieved in continuous drying with the same energy value. It was determined that greater

energy was required in intermittent drying to remove the moisture from the product. The amount of energy required to evaporate the moisture (ELH) varied with the drying methods and dipping pre-treatments. The greatest ELH (10.62 kWh) was observed in samples dipped into 25% vinegar solution and the lowest ELH (5.63 kWh) was observed in samples dipped into 25% (Salt+Vinegar) solution. In general, intermittent drying with all dipping pre-treatments yielded lower efficiency values than the continuous drying. The greatest energy efficiency (1.38%) was obtained from the control samples and the lowest value (0.38%) was obtained from the samples dipped into 225% (Salt+Vinegar) solution in intermittent drying. Kılıç (2021) dried carrot slices with the use of infrared method and reported energy consumptions for 180, 210 and 240-minute drying durations respectively as 1.032, 1.315 and 1.691 kWh. Mohammadi et al. (2020) dried carrot slices at 600 W, 1 kW and 2 kW microwave powers and reported SMER values as between 4.203 - 2.202 kg kWh⁻¹ and SEC values as between 0.87 - 1.635 MJ kg⁻¹. Azimi-Nejadi and Salar Hoseini (2019) dried carrot slices (3.5, 5, 7 and 9 mm) at 200, 400, 600 and 800 W microwave powers and reported specific energy consumptions as between 0.680 - 2.591 MJ kg⁻¹.

TP Values

Specific heat, thermal conductivity, thermal diffusivity and density values of dried carrot slices are provided in Table 7.

Thermophysical properties of carrot slices were influenced from drying methods and dipping pre-treatments. In continuous drying method, the highest specific heat, thermal conductivity, thermal diffusivity and density values were obtained from the samples dipped into 25% vinegar solution. In intermittent drying method, the greatest specific heat, thermal conductivity, thermal diffusivity and density values were obtained from the control samples without any dipping pre-treatments. Thermo-physical properties changed with changing moisture levels during the drying process. In continuous drying, specific heat values varied between 890.96 - 837.20 J kg⁻¹K⁻¹, thermal conductivity values between 0.39 - 0.06 W m⁻¹K⁻¹, thermal diffusivity values between 5.40 - 0.96x10⁻⁷ m² s⁻¹ and density values between 839.41 - 692.71 kg m⁻³. In intermittent drying, specific heat values varied between 860.95 - 837.26 J kg⁻¹K⁻¹, thermal conductivity values between 0.39 - 0.05 W m⁻¹K⁻¹, thermal diffusivity values between 5.40 - 0.99x10⁻⁷ m² s⁻¹ and density values between 839.41 - 693.16 kg m⁻³. Koç et al. (2008) dried quince slices with the use of different drying methods and determined moisture-dependent changes in product density. Densities varied between 1050 - 1000 kg m⁻³ in hot-air tray drying and between 950 - 400 kg m⁻³ in freeze drying. Mariani et al. (2008) dried banana fruits at 17 - 65 °C drying temperatures and reported thermal diffusivity values as between 2.49x10⁻¹⁰-1.88x10⁻⁷ m² s⁻¹. Kumar et al. (2018) reported average thermal diffusivity of potato slices as 0.89±0.01 10⁻⁶ m² s⁻¹ and average thermal conductivity value as 1.82±0.14 W m⁻¹K⁻¹. Present findings on thermo-physical properties comply with those earlier findings.

Correlation Tests

Correlations between color and some physical characteristics of carrot slices dried by continuous and intermittent drying methods are provided in Table 7 and Table 8.

There were generally positive correlations between color parameters of carrot slices dried by continuous drying method, but there were significant negative correlations between hue and redness (a) and between total color change and the other color parameters. In continuous drying method, the greatest correlation (0.973**) was determined between % diameter change and length values. There were generally positive correlations between color parameters of carrot slices dried by intermittent drying method, but there were significant negative correlations between hue - redness (a) and between total color change - the other color parameters. In intermittent drying method, the highest (0.973**) was again determined between % diameter change and length values.

Uncertainty Analysis

Uncertainty analysis was conducted with the use of precision values of measurement tools and equipment used throughout the drying processes. Precision values of the present measurement tools and equipment are provided in Table 9.

Data were processed into Equation 24 and noncontrollable uncertainty value was calculated as 2.324. Kumar et al. (2015) reported uncertainty in a drying study as 1.06.

Conclusion

In present study, effects of drying methods (continuous and intermittent) and pre-treatments (control and dipping into 25% salt, 25% vinegar, 25% (salt + vinegar), 10% *Pyracantha coccinea* and 10% *Malus floribunda* solutions) on energy, thermo-physical and some drying properties of carrot slices were determined. Continuous drying method reduced drying duration of carrot slices by an average of 26.25% as compared to intermittent drying method. In both drying methods, pre-treatment of dipping into 25% vinegar solution yielded the greatest reduction (29.63%) in drying duration. Among the thin-layer drying models, Wang-Sing model yielded the best and Rational 1-parameter 2 model yielded the weakest estimations. Effective diffusion values varied between $2.96 - 9.12 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ in continuous drying method and between $2.61 - 5.59 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ in intermittent drying method. The greatest volume change (92.60%) was observed in samples dipped into 10% *Pyracantha coccinea* solution and dried by continuous drying method. The least volume change (72.92%) was observed in control samples of intermittent drying method. The highest rehydration capacities were observed in samples dipped into 25% vinegar (82.88%) and 10% *Malus floribunda* (82.13%) solutions. In terms of chroma value, the samples dried by intermittent drying after dipping into 25% salt and 25% vinegar solutions yielded the closest values to the fresh samples. As an alternative drying method in terms of chroma value, dipping into 10% *Pyracantha coccinea* solution could also be selected in intermittent drying method. The highest ELH value (10.62 kWh) was observed in samples dipped into 25% vinegar solution and the lowest ELH value (5.63 kWh) was observed in samples dipped into 25% (salt + vinegar) solution.

Credit Authorship Contribution Statement

Muhammed Taşova: Maintaining laboratory studies, processing all data and writing articles.

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Conflict of Interest Statement

The author in the study has no conflict of interest with any other author.

Availability of Data

The data set used in the analysis of this study can be accessed from the author if deemed appropriate.

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TABLES

TABLE 1 Calculated color equations

Color value	Eşitlik	No
Chroma	$C = (a^2 + b^2)^{1/2}$	Ramallo and Mascheroni (2012) (13)
Hue	$h^\circ = \tan^{-1}\left(\frac{b}{a}\right)$	Alemrajabi et al. (2012) (14)
Color change	$\Delta E = \sqrt{(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2}$	Tan et al. (2001) (15)

TABLE 2 Drying model data

Model	Pre-treatments	Drying method	Model constant	R ²	P
Lewis	Control	Continues	k= -0.3209	0.9290	<0.0001
	25% Salt		k= 0.4541	0.9672	<0.0001
	25% Vinegar		k= 0.6972	0.9831	<0.0001
	25% (Salt+Vinegar)		k= 0.5418	0.9951	<0.0001
	10% <i>Pyracantha coccinea</i>		k= 0.8543	0.9890	<0.0001
	10% <i>Malus floribunda</i>	Intermittent	k= 0.6501	0.9832	<0.0001
	Control		k= 0.7523	0.9895	<0.0001
	25% Salt		k= 0.6796	0.9863	<0.0001
	25% Vinegar		k= 0.7801	0.9890	<0.0001
	25% (Salt+Vinegar)		k= 0.5569	0.9810	<0.0001
	10% <i>Pyracantha coccinea</i>		k= 0.6133	0.9878	<0.0001
	10% <i>Malus floribunda</i>		k= 0.5872	0.9666	<0.0001
	Control		k= 1.0179	0.9799	<0.0001
			h= 0.6283		
			j= 0.3589		
			m= 0.0137		
			k= 1.0016		

Jena-Das	Continues	25% Salt	h= 0.6313 j= 0.3530 m= 0.0137	0.9672	<0.0001
		25% Vinegar	k= 1.0144 h= 0.7588 j= 0.0978 m= 0.0099	0.9840	<0.0001
		25% (Salt+Vinegar)	k= 0.9940 h= 0.6719 j= 0.2717 m= -0.0051	0.9953	<0.0001
		10% <i>Pyracantha coccinea</i>	k= 1.0094 h= 0.8356 j= -0.0562 m= 0.0057	0.9893	<0.0001
		10% <i>Malus floribunda</i>	k= 1.0145 h= 0.7356 j= 0.1443 m= 0.0112	0.9843	<0.0001
		Control	k= 0.9961 h= 0.7851 j= 0.0446 m= 0.0232	0.9899	<0.0001
	Intermittent	25% Salt	k= 0.9995 h= 0.7473 j= 0.1215 m= 0.0130	0.9865	<0.0001
		25% Vinegar	k= 1.0054 h= 0.7985 j= 0.0166 m= 0.0125	0.9895	<0.0001
		25% (Salt+Vinegar)	k= 0.9987 h= 0.6838 j= 0.2479 m= 0.0070	0.9810	<0.0001
		10% <i>Pyracantha coccinea</i>	k= 1.0075 h= 0.7160 j= 0.1835 m= 0.0150	0.9885	<0.0001

		k= 1.0098		
10% <i>Malus floribunda</i>		h= 0.7035	0.9875	<0.0001
		j= 0.2083		
		m= 0.0158		
Wang-Sing	Control	k= -0.3189	0.9990	<0.0001
		h= 0.0254		
	25% Salt	k= -0.3821	0.9846	<0.0001
		h= 0.0413		
	25% Vinegar	k= -0.4942	0.9999	<0.0001
		h= 0.0618		
	25% (Salt+Vinegar)	k= -0.4051	0.9813	<0.0001
		h= 0.0434		
	10% <i>Pyracantha coccinea</i>	k= -0.5992	0.9996	<0.0001
		h= 0.0907		
	10% <i>Malus floribunda</i>	k= -0.4688	0.9997	<0.0001
		h= 0.0555		
Wang-Sing	Control	k= -0.4135	0.9156	<0.0001
		h= 0.0385		
	25% Salt	k= -0.4475	0.9787	<0.0001
		h= 0.0481		
	25% Vinegar	k= -0.4952	0.9902	<0.0001
		h= 0.0582		
	25% (Salt+Vinegar)	k= -0.3974	0.9747	<0.0001
		h= 0.0398		
	10% <i>Pyracantha coccinea</i>	k= -0.4166	0.9936	<0.0001
		h= 0.0416		
	10% <i>Malus floribunda</i>	k= -0.4070	0.9954	<0.0001
		h= 0.0401		
Rational-1 parameter-2	Control	a= 0.8066	0.8921	0.1159
	25% Salt	a= 0.8419	0.9534	0.0004
	25% Vinegar	a= 1.5104	0.9070	0.0207
	25% (Salt+Vinegar)	a= 1.1513	0.9693	<0.0001
	10% <i>Pyracantha coccinea</i>	a= 1.9486	0.9311	0.0369
	10% <i>Malus floribunda</i>	a= 1.3531	0.9071	0.0175
	Control	a= 1.8791	0.9246	0.0018
	25% Salt	a= 1.5557	0.9416	0.0006

25% Vinegar		a= 1.8602	0.9243	0.0100
25% (Salt+Vinegar)	Intermittent	a= 1.1681	0.9527	<0.0001
10% <i>Pyracantha coccinea</i>		a= 1.3373	0.9141	0.0033
10% <i>Malus floribunda</i>		a= 1.2521	0.9109	0.0031

TABLE 3 Effective diffusion values of carrot slices

Pre-treatments	Drying methods	Effective diffusion (m ² s ⁻¹)
Control		5.76x10 ⁻⁹
25% Salt		2.96x10 ⁻⁹
25% Vinegar	Continues	7.62x10 ⁻⁹
25% (Salt+Vinegar)		3.03x10 ⁻⁹
10% <i>Pyracantha coccinea</i>		9.12x10 ⁻⁹
10% <i>Malus floribunda</i>		6.96x10 ⁻⁹
Control		3.85x10 ⁻⁹
25% Salt		2.61x10 ⁻⁹
25% Vinegar	Intermittent	5.59x10 ⁻⁹
25% (Salt+Vinegar)		2.53x10 ⁻⁹
10% <i>Pyracantha coccinea</i>		5.32x10 ⁻⁹
10% <i>Malus floribunda</i>		5.10x10 ⁻⁹

TABLE 4 Volume values of carrot slices

Pre-treatments	Drying methods	Volume (mm ³)	Volume change
Fresh		1909.92±255.99	-
Control		303.57±126.81	84.11%
25% Salt		437.98±162.22	77.06%
25% Vinegar	Continues	208.68±66.21	89.07%
25% (Salt+Vinegar)		328.80±129.14	82.79%
10% <i>Pyracantha coccinea</i>		141.40±37.59	92.60%
10% <i>Malus floribunda</i>		172.45±45.46	90.97%
Control		517.20±188.50	72.92%
25% Salt		499.32±206.52	73.86%
25% Vinegar	Intermittent	188.16±52.65	90.10%
25% (Salt+Vinegar)		270.13±75.68	85.86%
10% <i>Pyracantha coccinea</i>		308.06±126.30	83.87%
10% <i>Malus floribunda</i>		346.55±136.83	81.86%

679 **TABLE 5** Color values of carrot slices

Drying methods	Dipping pre-treatments	L	a	b	C	hue
Continue	Fresh	52.04±1.34a	15.58±2.90g	30.83±4.70a	34.55±5.48a	63.29±1.1
	Control	42.24±1.67ef	16.11±1.10g	17.93±1.69g	24.13±1.60e	47.99±2.1
	25% Salt	48.30±2.03b	18.66±1.48f	23.34±3.08cde	29.90±3.19cd	51.19±2.1
	25% Vinegar	44.19±1.14cde	21.32±1.32abcd	20.87±1.10ef	29.84±1.65cd	44.41±0.1
	25% (Salt+Vinegar)	48.84±1.82b	18.99±2.32ef	25.18±3.10bcd	33.56±3.30ab	48.65±3.4
	10% <i>Pyracantha coccinea</i>	42.75±1.76def	22.11±1.62ab	22.11±2.61e	29.18±2.64cd	49.23±3.1
	10% <i>Malus floribunda</i>	42.58±1.68def	19.57±1.46def	20.86±2.14ef	28.62±2.48cd	46.76±1.4
Intermittent	Control	44.54±2.34cd	19.59±1.81def	26.65±2.30b	33.11±2.54ab	53.65±2.1
	25% Salt	49.08±1.97b	21.65±1.83abc	26.27±2.41b	34.07±2.70a	50.47±2.2
	25% Vinegar	41.14±1.84f	22.66±0.98a	27.42±1.22b	35.58±1.25a	50.43±1.5
	25% (Salt+Vinegar)	34.76±1.71g	19.24±0.80ef	19.16±1.80fg	27.17±1.73d	44.79±1.1
	10% <i>Pyracantha coccinea</i>	45.22±2.79c	20.65±1.99bcde	25.83±2.15bc	33.08±2.85ab	51.38±1.1
	10% <i>Malus floribunda</i>	42.92±2.18def	20.19±1.59cdef	23.22±2.69de	30.80±2.75bc	48.88±2.7

680

681 **TABLE 6** Energy data

Drying methods	Dipping pre-treatments	SMER (kg kWh ⁻¹)	SEC (kWh kg ⁻¹)	ELH (kWh)	EE (%)
Continues	Control	0.00212	472.57	8.93	1.38
	25% Salt	0.00091	1103.96	6.60	0.59
	25% Vinegar	0.00223	449.23	10.62	1.46
	25% (Salt+Vinegar)	0.00138	727.10	10.06	0.90
	10% <i>Pyracantha coccinea</i>	0.00167	600.55	7.08	1.09
	10% <i>Malus floribunda</i>	0.00146	684.21	7.20	0.96
Intermittent	Control	0.00073	1362.80	9.24	0.48
	25% Salt	0.00082	1213.82	7.95	0.54
	25% Vinegar	0.00096	1046.93	8.08	0.62
	25% (Salt+Vinegar)	0.00058	1721.58	5.63	0.38
	10% <i>Pyracantha coccinea</i>	0.00086	1159.07	8.46	0.56
	10% <i>Malus floribunda</i>	0.00089	1119.70	8.79	0.58

682

683 **TABLE 7** Correlation data for continuous drying method

a	b	C	hue	ΔE	Length	Thickness	Volum e	% Diamete r change	
0.517**	0.750**	0.720**	0.388**	-	-0.035	-0.002	0.011	-0.048	L
				0.590**					
	0.647**	0.867**	-0.274*	-0.229	0.082	-0.337*	-0.096	0.065	a

0.941**	0.551**	-	0.000	-0.190	-0.065	0.000	b
		0.576**					
	0.237	-	0.035	-0.272*	-0.085	0.027	C
		0.478**					
		-	-0.070	0.136	0.041	-0.053	hue
		0.476**					
			-0.012	0.307*	0.151	-0.011	ΔE
				0.080	0.786**	0.973**	Length
					0.639**	0.098	Thicknes
							s
						0.782**	Volume

684 **TABLE 8** Correlation data for intermittent drying method

a	b	C	hue	ΔE	Length	Thickness	Volum	%	
							e	Diamete	
								r change	
0.440**	0.687**	0.665**	0.555**	-0.777**	0.306*	0.208	0.309*	0.306*	L
	0.609**	0.799**	-0.004	-0.233	0.518**	0.009	0.399**	0.455**	a
		0.963**	0.787**	-0.634**	0.340*	0.293*	0.388**	0.306*	b
			0.593**	-0.555**	0.426**	0.227	0.426**	0.379*	C
				-0.646**	0.059	0.356**	0.198	0.068	hue
					-0.176	-0.169	-0.210	-0.193	ΔE
						0.080	0.786**	0.973**	Length
							0.639**	0.098	Thickn
									ess
								0.782**	Volume

685 **: significant at p<0.01, *: significant at p<0.05. Minus (-) signs indicate negative and plus (+) signs
686 indicate positive correlations.

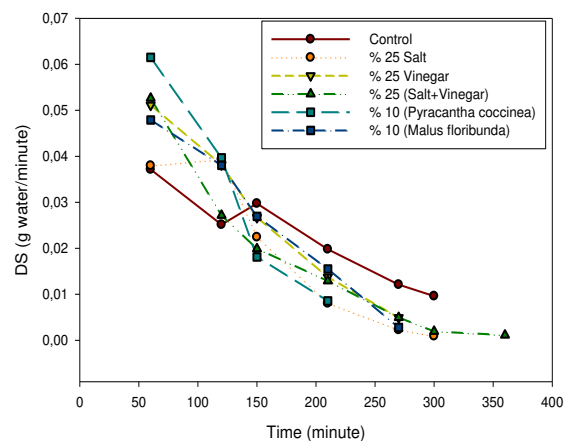
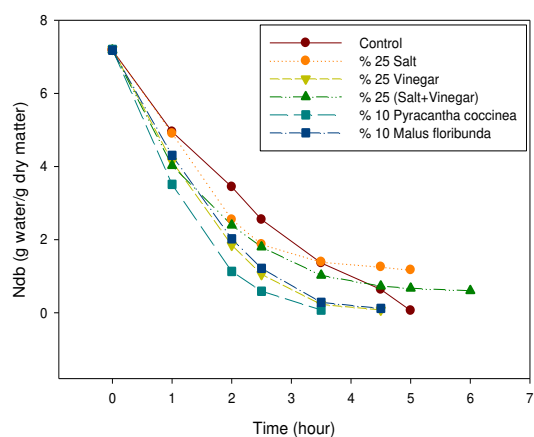
687

688 **TABLE 9** Precision values

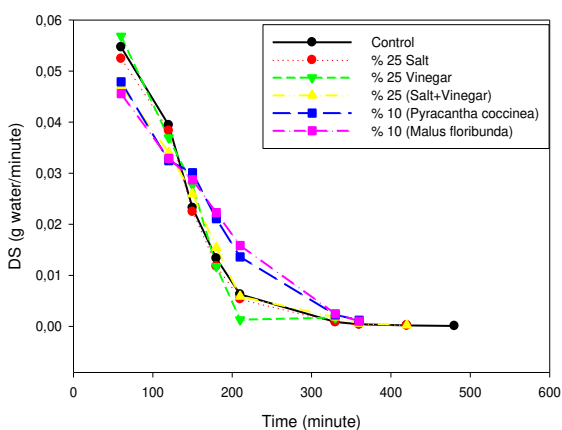
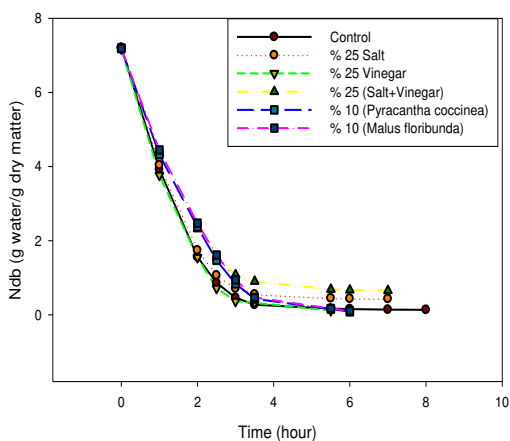
Measurement tools	Precision values
Power analyzer	±% 2 kWh
Weighing device	± 0.001 g
Caliper	± 0.2 mm
Color-meter (for ΔE)	± 0.6
Glass measure	± 1 ml

689

690 **FIGURES**



a) Continuous drying data



b) Intermittent drying data

FIGURE 1 Drying curves of carrot slices

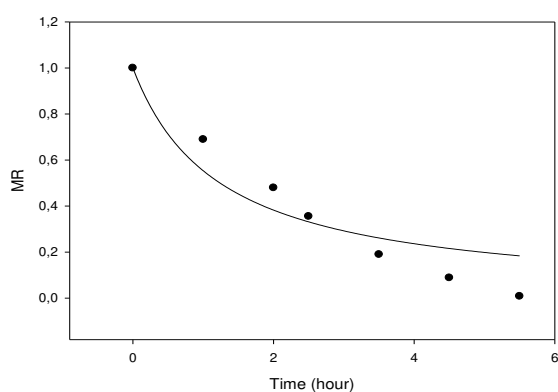
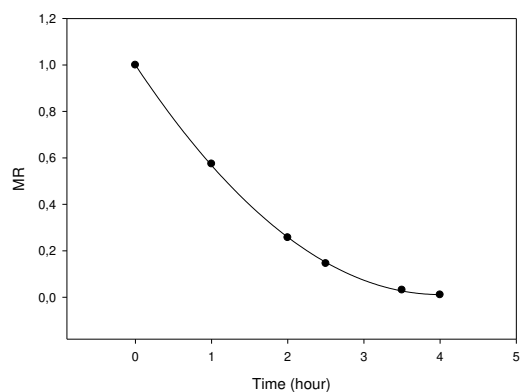
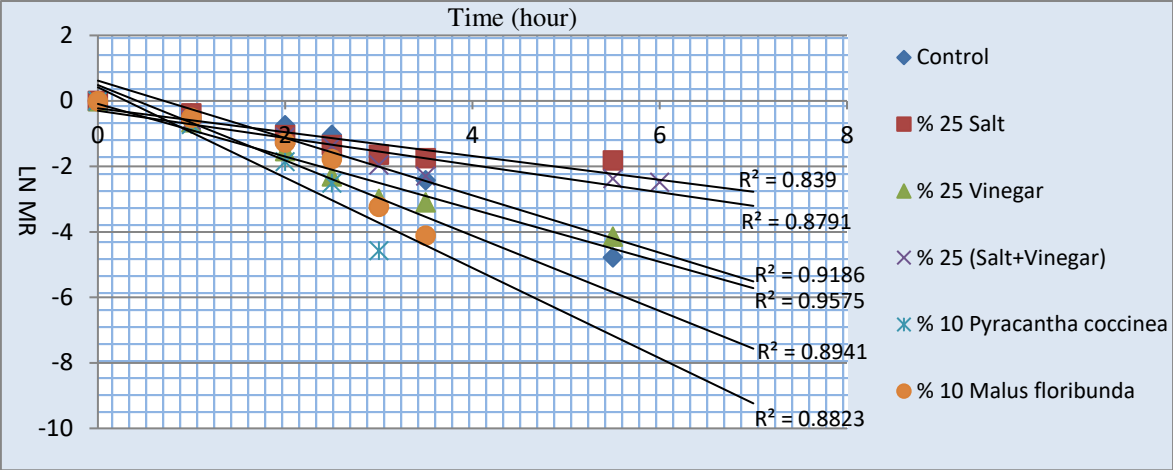
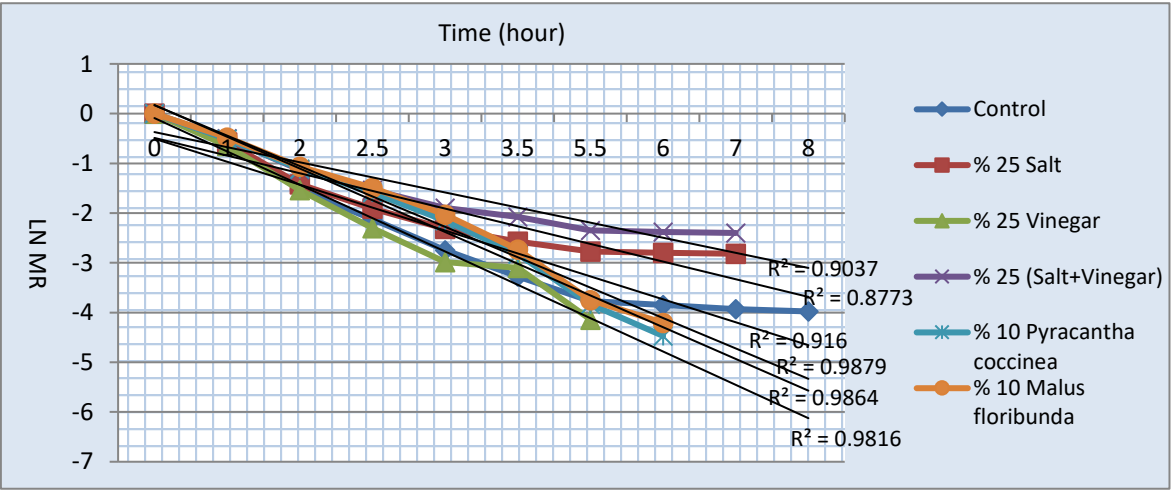


FIGURE 2 The best (left) (Wang-Sing) and the worst (right) (Rational 1-parameter 2) estimation models

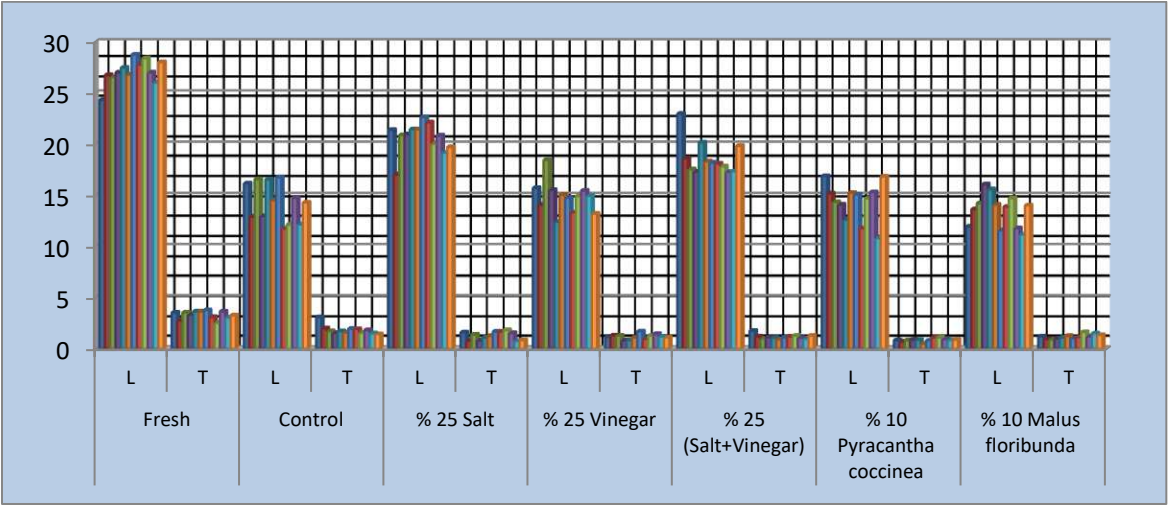


a) Continuous drying method

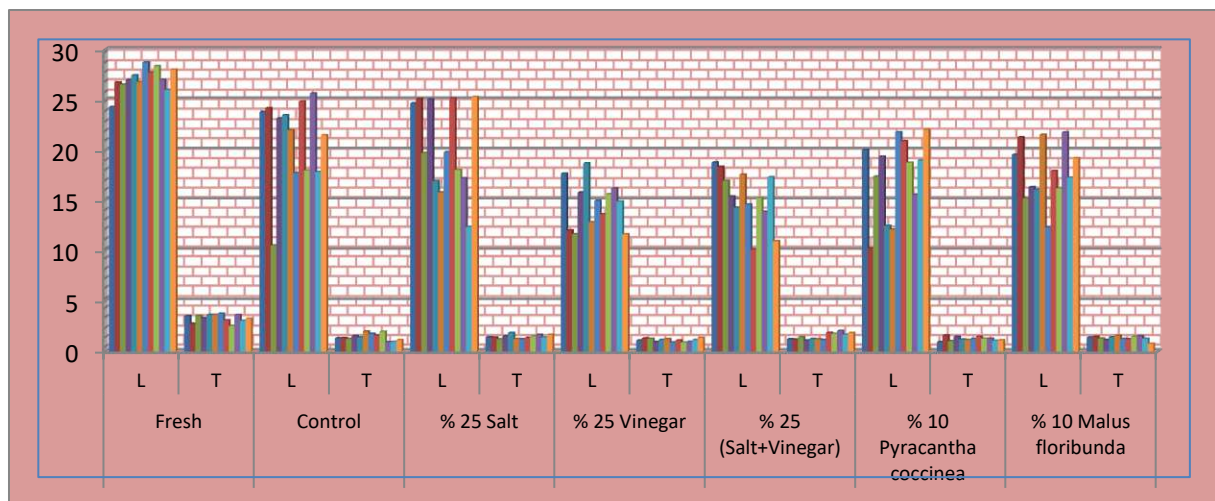


b) Intermittent drying method

FIGURE 3 lnMR-time graphs

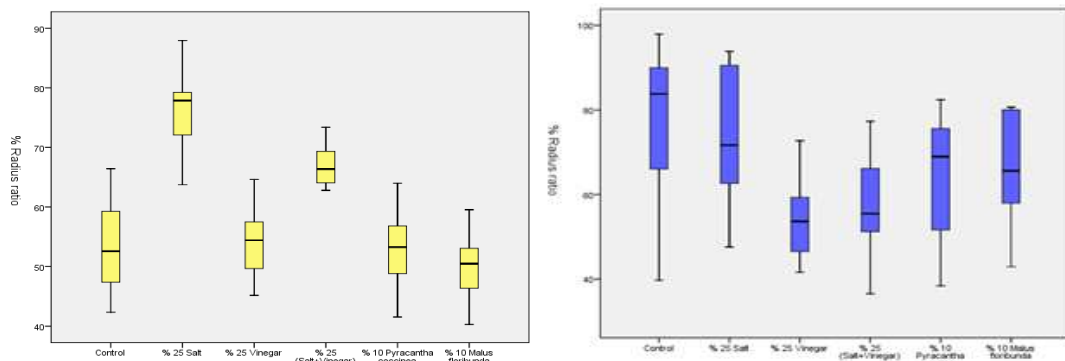


a) Continuous drying method



b) Intermittent drying method

FIGURE 4 Length (diameter) and thickness values of dried carrot slices



a) Continuous drying method

b) Intermittent drying method

FIGURE 5 Diameter ratios of dried carrot slices

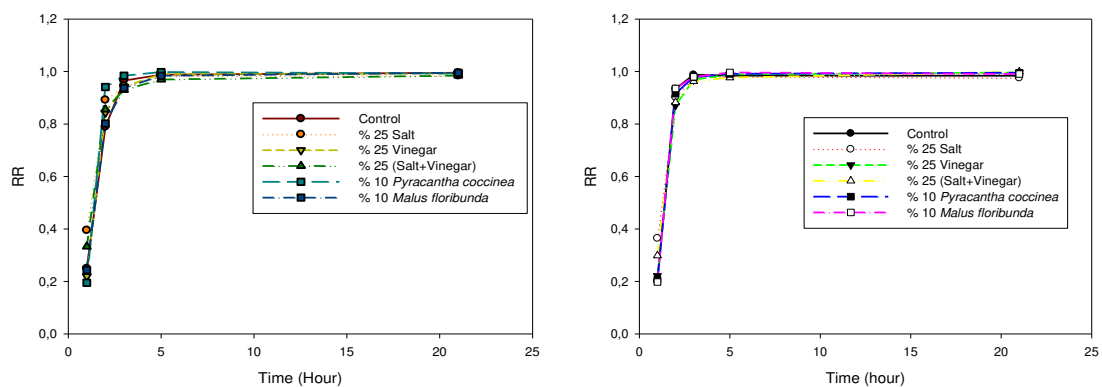
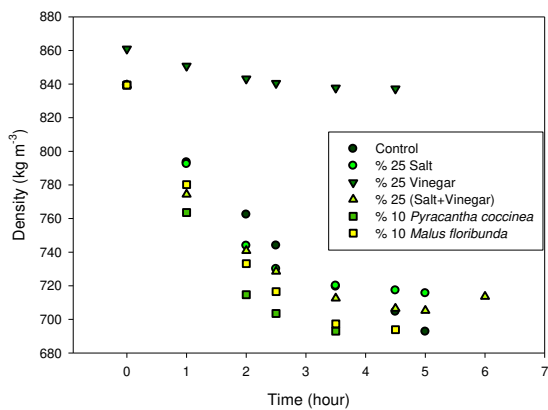
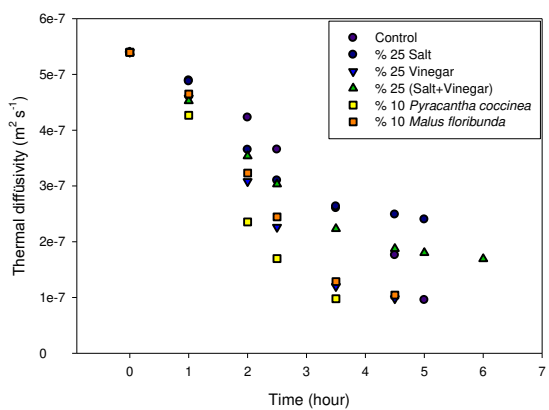
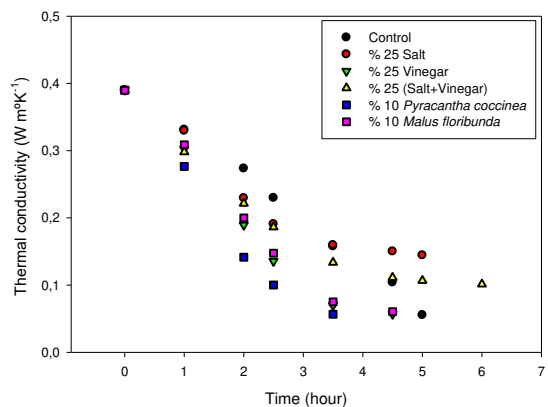
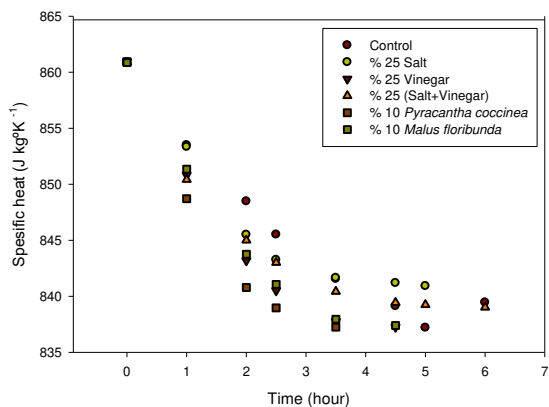
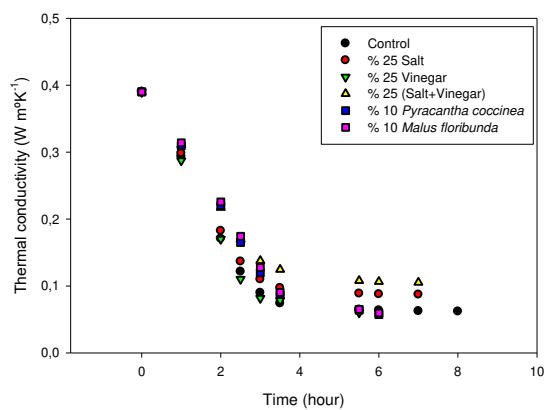
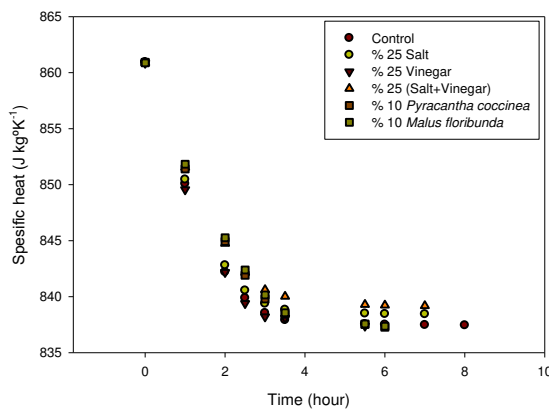
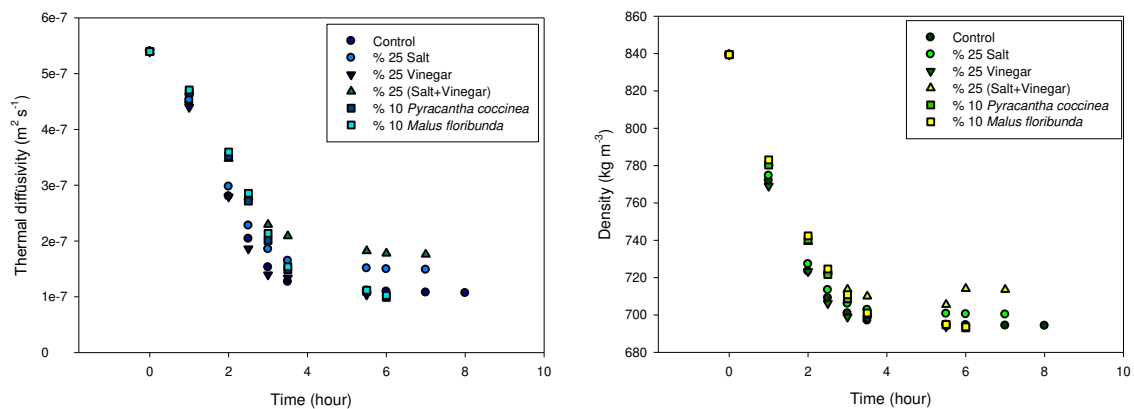


FIGURE 6 Rehydration ratio of dried carrot slices a) continuous drying (left), b) intermittent drying (right)



a) Continious drying method





b) Intermittent drying method

FIGURE 7 Thermo-physical properties of carrot slices dried with continuous and intermittent methods