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Determination of Vacuum and Air Drying Characteristics of Celeriac Slices

İlknur Alibaş[*]
Uludag University, Faculty of Agriculture, Department of Biosystems Engineering, 16059 Bursa, TURKEY

ABSTRACT

Celeriac slices (*Apium graveolens* L. var. *rapaceum*) weighing 100 g with moisture of 14.39 on a dry basis (kg[H2O].kg-1[DM]) were dried using vacuum drying. Drying was continued until leaf moisture fell to 0.1 on a dry basis (kg[H2O].kg-1[DM]). Six different pressures (0.1, 3, 7, 10, 13 and 17 kPa) and three different temperatures (55, 65, and 75°C) were used in the vacuum drying process. Air drying experiments were carried out at three different temperatures, 55, 65, and 75°C. In this study, measured values were compared with predicted values obtained from Page's semi-empirical equation. The drying periods lasted 70-300 and 220-340 minutes for vacuum and air drying, respectively. Energy consumption was 1.01-2.00 and 0.84 -1.07 kWh for vacuum and air drying, respectively. Vacuum drying at 0.1 kPa and 75°C provided the optimal results with respect to drying period, colour, and energy consumption.

Key Words: Air drying; celeriac; colour; energy consumption; vacuum drying.

INTRODUCTION

Celeriac (*Apium graveolens* L. var. *rapaceum*) is a rich source of mineral salts and dietary fibre. It also contains microelements, small amounts of vitamins, and phenolic compounds (Anonymous 2009). Celeriac is the starchy root of a plant similar to celery, although it has more starch, fibre, iron, and B vitamins, about the same amount of vitamins A and C, and less sodium and potassium. It also contains calcium and phosphorus. Celeriac oil has a calming effect and is a traditional remedy for skin complaints and rheumatism. It is also a diuretic (Anonymous 2008).

Drying is a storage method that enables the extension of the consumption period of celeriac while maintaining its nutrition content. Drying is a process of removing the moisture in the product, down to a threshold value, by evaporation (Alibas-Ozkan *et al.,* 2007).

Different drying methods are used in the drying of fruits and vegetables. Hot-air drying is the most common method in the drying of foodstuffs. However, this method leads to serious quality loss such as a reduction in the taste, colour, and nutritional content of the dry product. It also leads to a change in the water absorbance capacity and shifting of the solutes from the internal part of the drying material to the surface because of the long drying period and high temperature (Bouraout *et al.,* 1994, Yongsawatdigul and Gunasekaran 1996, Feng and Tang 1998, Lin *et al.,* 1998, Drouzas *et al.,* 1999, Maskan 2000). The most common technique in this regard is convective drying. However, this method has a number of disadvantages, such as a very long drying period and high energy consumption. Hot-air drying method also leads to serious problems such as the loss of flavour, colour, and nutritional content of the product, a decline in the density and water absorbance capacity and shifting of the solutes from the internal part of the drying material to the surface due to the long drying period and high temperature.

The most common method used in the drying of heat-sensitive products is the vacuum drying method. Vacuum drying is widely used to dry various heat-sensitive products in which the colour, structure, and vitamins are impaired with increasing temperatures (Methakhup *et al.,* 2005). Vacuum drying results in better product quality with respect to characteristics such as flavour, fragrance, and rehydration (Drouzas and Schubert 1996). Vacuum drying also has advantages such as a reduction in processing temperature, improvement in the drying rate, and a reduction in shrivelling (Montgomery *et al.,* 1997). The vacuum drying process has been successfully used for the drying of fruit, vegetables, and heat-sensitive products. A high quality product is obtained due to the retention of flavour and nutritive value in the structure of materials. A drawback, however, is an increase in the cost of processing (Tsami *et al.,* 1998).

Elustondo *et al.* (2001) used pressure, temperature, and air speed values of 10-20 kPa, 60-90°C, and 2-6 ms^{-1}, respectively, in the vacuum drying of foodstuffs. Devahastin *et al.* (2004) attempted to vacuum-dry cubed carrots using 7-10 kPa pressure and 60-80°C temperature values. Methakhup *et al.* (2005) attempted to vacuum-dry the samples used in the drying of Indian gooseberry flake using temperatures of 65 and 75°C and 7, 10, and 13 kPa pressures. They determined that the optimum working conditions regarding the colour change in dry product and the energy consumption during drying was 75°C temperature and 7 kPa pressure. Jaya and Das (2003) attempted to dry 2, 3, and 4 mm thick mango slices using 65, 70, or 75°C temperatures and 30-50 mmHg pressure. Malczewski and Kaczmarek (1989) dried various seeds with vacuum or hot air and found that the

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[*] Corresponding author: ialibas@uludag.edu.tr

energy efficacy of vacuum drying is 30% higher compared with hot air drying. Alibas (2007) used pressure and temperature of 20-50 mmHg and 50-75°C, respectively. Markowski and Bialobrzewski (1997) used temperatures between 25 and 50°C and pressure values of 10±0.2 kPa in the vacuum drying of celeriac slices with 10 mm thickness and 57 mm diameter. That study determined that the taste and colour parameters of celeriac retained a high quality after vacuum drying.

The aim of this study was to i) evaluate the efficacy of vacuum and air drying techniques for celeriac slices, ii) compare the measured findings obtained during the drying of celeriac with the predicted values obtained with Page's thin layer drying semi-empirical equation, iii) examine the changes in the colour values of the product after drying, and iv) determine the optimum drying level in the vacuum and air drying of celeriac slices with respect to energy consumption, power, colour, and drying period.

MATERIALS AND METHODS

Samples

Fresh celeriac plants (*Apium graveolens* L. var. *rapaceum*) were obtained from the Yenisehir county of Bursa. They were stored at 4 ± 0.5°C until the drying process. Four different 100 g samples were kept in the drying oven at 105°C for 24 h, after which the moisture content of celeriac was 14.39 ± 0.09 on a dry basis (Soysal 2004, Alibas 2006).

Drying equipment and drying method

Fresh celeriac slices were pre-treated in a steam cooker (Raks Buharlim, Manisa, Turkey) before drying to reduce enzymatic changes. In order to prevent colour changes, the cooker was set to produce 100°C steam and the collard leaves were exposed to steam for 60 s (Alibas 2006).

After this stage, to produce the least amount of darkening in the drying process, celeriac slices were dipped into a 2% citric acid solution.

Vacuum drying treatment was performed in a laboratory type vacuum oven (Nuve EV 0180, Turkey) at 220 V ~, 50 Hz, 3.5 A, and 800 W. The temperature of the vacuum oven has a sensitivity of 1°C, with a max temperature of 250°C. The area on which vacuum drying was carried out was 300 x 200 x 250 mm in size. A digital vacuum-meter that indicates the vacuum value in kPa was used. Time adjustment was done with the aid of a programmable clock located on the oven. Six different pressures of 0.1, 3, 7, 10, 13, and 17 kPa and three different temperatures of 55, 65, and 75°C were used in vacuum drying. Thus, sixteen different pressure-temperature combinations were obtained in drying trials. A laboratory type vacuum pump (Carpanelli MMDE80B4, Italy) was used in the vacuum drying trials. Its operating conditions were 220/240 V ~, 50/60 Hz, and 5.1/4.8 A. The vacuum pump was increased to the smallest pressure (0.1 kPa) within 20 sec.

The convective oven (Ecocell MMM 55, Turkey) had the capability of operating at three different temperature stages at 55, 65, and 75°C. A laboratory type convective oven with technical features of 230 V ~, 50 Hz, 5.6 A, and 1300 W was used. The space in which air drying was carried out was 400 x 390 x 350 mm in size. Time adjustment was done using a programmable clock located on the oven.

The samples used in this study were cut using a cutting machine (Graef ECO146, Germany) at a uniform thickness. Slices were 57 ± 0.2 mm in diameter and 3 ± 0.2 mm in height (Białobrzewski 2006). Three different experimental designs were used for each method.

The celeriac slices to be dried were 100 ± 0.09 g in weight and selected from uniform and healthy plants. Two different drying trials were conducted for each drying technique, the values obtained from these trials were averaged, and the drying parameters were determined. Celeriac slices that were being dried were removed from the oven periodically (every 10 min) during the drying period and the moisture loss was determined by weighing the plate using a digital balance (Sartorious EX 2000A, Germany) with 0.01 g precision (Alibas 2007). All weighing processes were completed in 10 s during the drying process. The energy consumption of vacuum oven and vacuum pump was determined using a digital electric counter (Kaan, Type 101, Turkey) with 0.01 kWh precision. The drying process continued until the moisture content of celeriac fell to 0.1 ± 0.005 on a dry basis.

The following common semi-empirical Page's equation [Eq. (1)] was used to describe the thin layer drying kinetics of celeriac slices (Maskan 2000, Soysal 2004, Alibas 2006).

$$MR = \frac{X - X_e}{X_0 - X_e} = \exp(-kt^n) \qquad (1)$$

Where M_R is the moisture ratio, X is the moisture content kg[H2O].kg-1[DM], X_0 is the initial moisture content, X_e is the equilibrium moisture content kg[H2O].kg-1[DM], t is the time in min, k is the drying constant in min^{-1}, and n is the dimensionless exponent. The equilibrium moisture content (X_e) was assumed to be zero for vacuum drying (Drouzas 1999, Maskan 2000).

Colour parameters

The colour of celeriac slices was determined by two readings on the two symmetrical faces of slice in each replicate using a Minolta CR 400 colorimeter (Konica-Minolta, Osaka, Japan) calibrated with a white standard tile. The colour brightness coordinate "*L*" measures the whiteness value of a colour and ranges from black at 0 to white at 100. The chromaticity coordinates "*a*" measures red when positive and green when negative and the chromaticity coordinate "*b*" measures yellow when positive and blue when negative. The chroma "*C*" [Eq. (2)] and hue angle "*α*" [Eq. (3)] were calculated from the values for *L*, *a*, and *b* and used to describe the colour change during drying (Soysal 2004, Alibas 2006).

$$C = \sqrt{a^2 + b^2} \qquad (2)$$

$$\alpha = \tan^{-1}(b/a) \qquad (3)$$

Data analysis

The research was conducted using randomized plots and a factorial experimental design. Determination of the investigated components was carried out in three replicates. Mean differences were tested for significance using an LSD (MSTATC) test at a 1% level of significance.

Non-linear regression analysis was performed using NLREG (NLREG version 6.3) to estimate the parameters *k* and *n* of the semi-empirical Page equation [Eq. (1)]. Regression results include the coefficients for the equation and coefficient of determination R^2.

RESULTS AND DISCUSSION

Vacuum Drying Curves

The moisture-time diagram of celeriac along the vacuum drying period on a dry basis is shown in Fig 1. As seen in Fig 1, a reduction in drying time occurred with increasing temperature and decreasing pressure. The time required for the lowering of moisture content of celeriac slices to 0.1 from 14.39 on a dry basis varied between 70 and 300 minutes depending on the pressure and temperature. A marked decline in the drying period of celeriac slices was observed with increasing temperature and decreasing pressure (Methakhup *et al.,* 2005, Alibas 2007, Arévalo-Pinedo and Murr 2007). Drying time at 55°C was found to be 180, 210, 230, 260, 290, and 300 min for 0.1, 3, 7, 10, 13, and 17 kPa, respectively. At 65°C, drying time was 120, 140, 160, 200, 220, and 230 min for 0.1, 3, 7, 10, 13, and 17 kPa pressures, respectively. At 75°C, it was found to be 70, 90, 110, 160, 180, and 190 min for 0.1, 3, 7, 10, 13, and 17 kPa pressures, respectively. The extent of drying at 55°C and 17 kPa, with the longest drying period, was 4.29 times higher than the drying process at 75°C and 0.1 kPa, with the shortest drying period. When the air drying process was conducted at 55°C was compared with the drying processes at 55°C temperature and 0.1, 3, 7, 10, 13, and 17 kPa pressure, the drying period was shortened by 1.88, 1.62, 1.48, 1.31, 1.17, and 1.13 times, respectively. Similarly, when the drying was performed at 75 °C with 0.1, 3, 7, 10, 13, and 17 kPa pressures and compared with air drying at 75°C, the drying period was reduced by 3.14, 2.44, 2.00, 1.38, 1.22 and 1.16 times, respectively. The increase in temperature during vacuum drying had an important effect on the reduction of drying time. Cui *et al.* (2007) dried carrot slices in three vacuum levels: 30, 51 and 71 mbar. It was established that the drying time decreased as the vacuum level increased. Also, evaporation was observed to be more in high vacuum levels than low vacuum levels. Per and Rodier (2002) dried porous media in two different vacuum levels: 1.1 and 7 kPa. It was found out that the drying time decreased when drying process was carried out in the vacuum level of 1.1 kPa compared to the drying time at the 7 kPa vacuum level. Methakhup *et al.* (2005) dried Indian gooseberry flake at the 7, 10 and 13 kPa vacuum values by combining them with temperatures of 65 ve 75°C. It was observed that reducing the pressure caused the drying time to reduce. In addition, the closest drying method to fresh product in terms of colour and ascorbic acid was achieved at the pressure level of 7 kPa and 75°C. Jaya and Das (2003) dried mango pulb at the pressure levels of 30 and 50 mmHg and at 65, 70 and 75°C. As a result, drying process at the pressure level of 30 mmHg lasted shorter than the drying process at the pressure level of 50 mmHg. Also, it was detected that the drying time decreased as the temperature increased. Alibas (2007) dried nettle leaves at the pressure levels 20 and 50 mmHg at 50 ve 75 °C. It was found out that the drying time at the vacuum level of 20 mmHg was shorter than at the 50 mmHg vacuum level. Also, it was determined that increasing the temperature caused the drying time to decrease substantially.

In the vacuum drying experiments with 100 g celeriac slices dried with three different temperature regimes and seven different pressures, 92.92 (± 0.4) g was lost from each sample. The vacuum drying rates (kg [H_2O] kg^{-1}[DM] min^{-1}) obtained in unit time under different temperature and pressures are given in Fig 2. Depending on the vacuum drying conditions, the average drying rates of celeriac slices ranged from 0.0260 to 0.1134kg [H_2O] kg^{-1}[DM] min^{-1} between 55°C and 17 kPa and 75°C and 0.1 kPa, respectively. The increase in temperature for the same pressure leaded to increments in the drying rate (Péré and Rodier 2002, Jaya and Das 2003, Cui *et al.,* 2004, Methakhup *et al.,* 2005 Alibas 2007, Arévalo-Pinedo and Murr 2007) . Pressure also had a notable effect on drying rate (Alibas 2007). The drying rate increased with decreasing pressure for a given temperature (Péré and Rodier 2002, Xu and Sun 2004, Alibas 2007).

Air Drying Curves

The moisture-time diagram of celeriac along the air drying period on a dry basis (kg[H2O].kg-1[DM]) is given in Fig 3. According to Fig 3 the air drying time was found to be 340, 270, and 220 min for 55, 65, and 75°C, respectively. A marked decline was observed in the drying period with increasing temperature. Drying time is reduced when the temperature is decreased in the drying process done with hot air (Doymaz and Pala 2002, Alibas 2006, Alibas 2007, Demir *et al.,* 2004, Doymaz 2004, Alibas 2009, Alibas 2010).

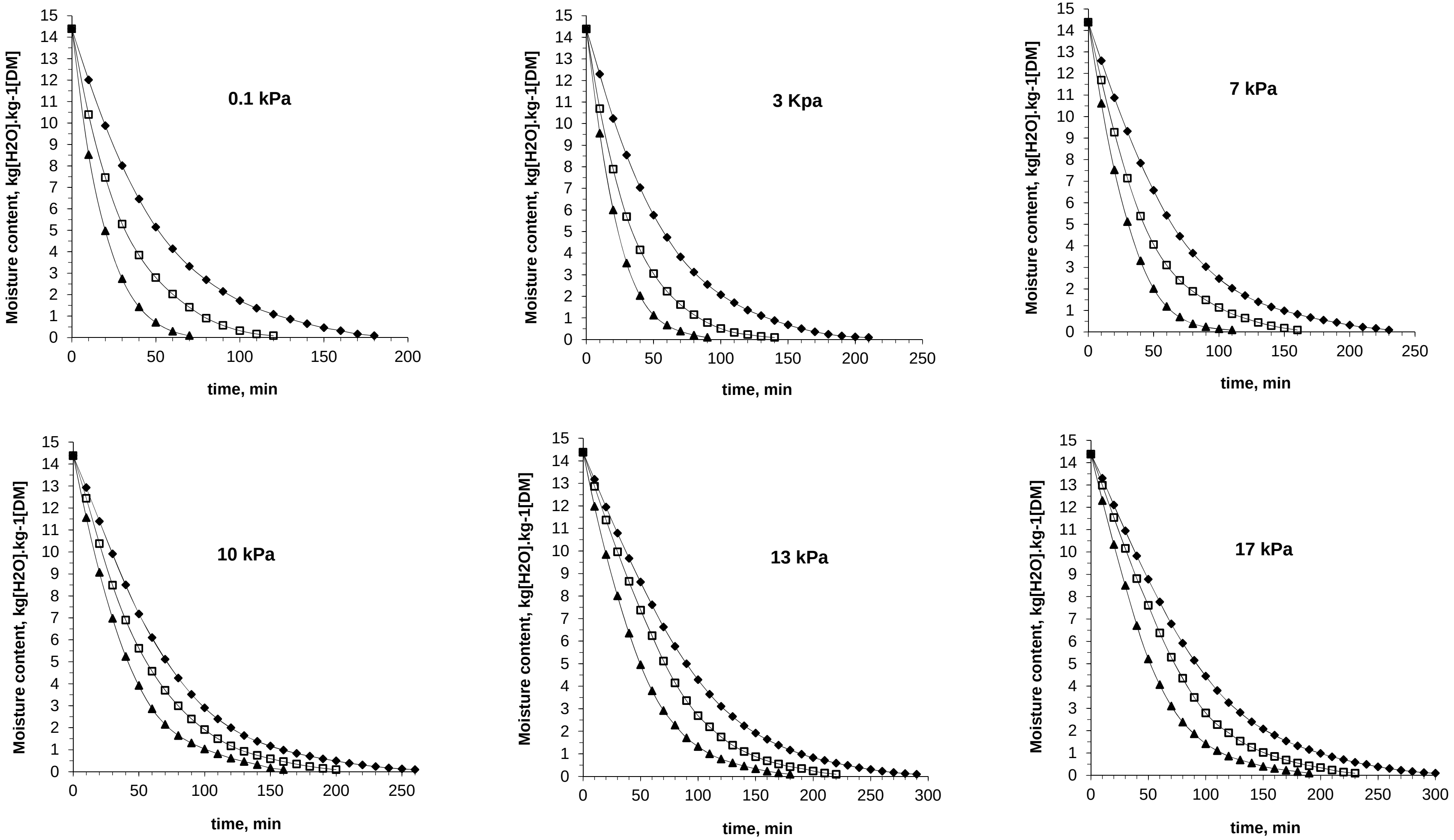

Figure 1. The vacuum drying curve of celeriac slices on dry basis (kg[H2O].kg-1[DM]); ▲, 75°C; □, 65°C; ♦, 55°C.

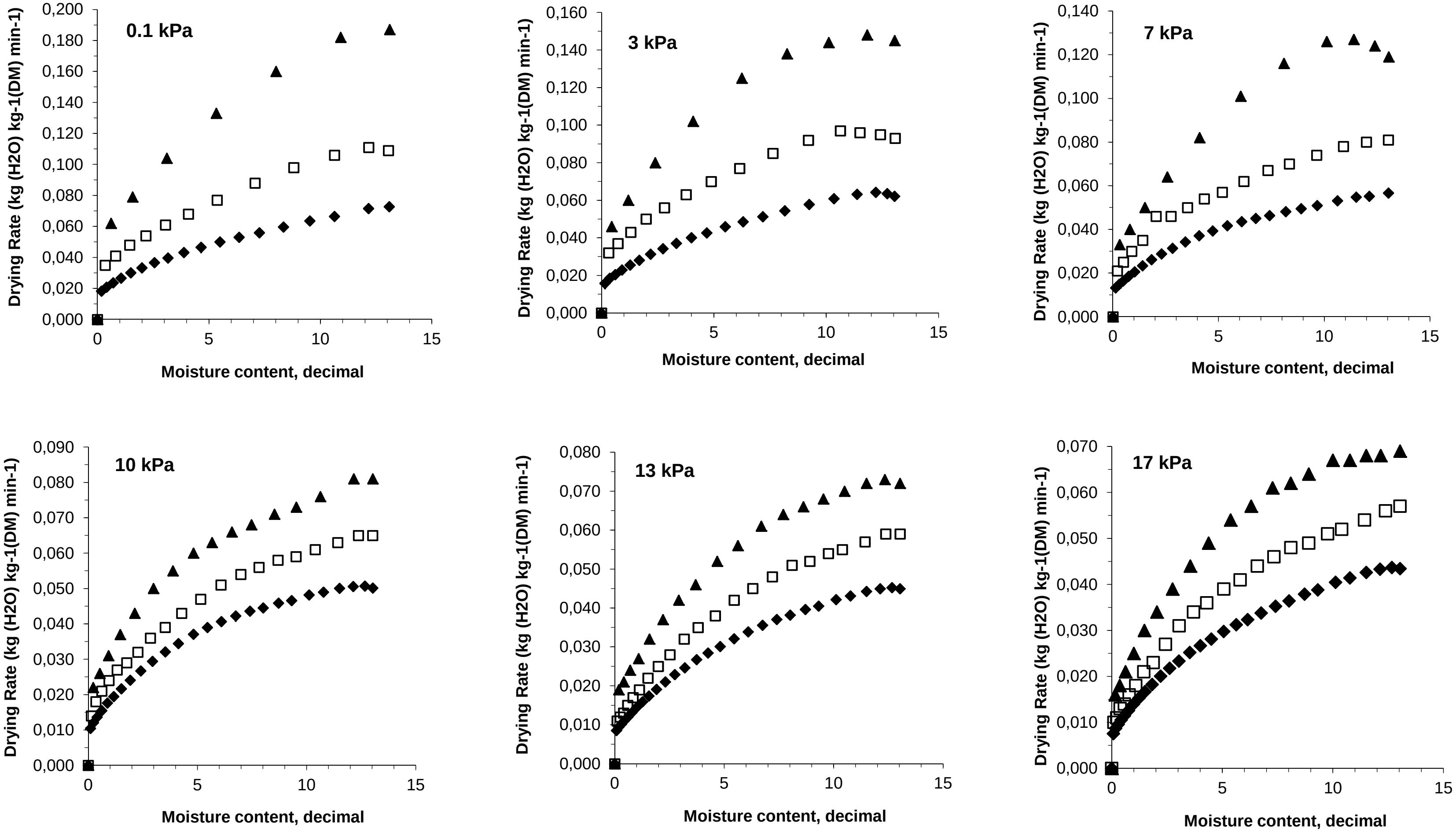

Figure 2. Vacuum drying rates of the celeriac slices at different pressure and temperatures; ▲, 75°C; □, 65°C; ♦, 55°C.

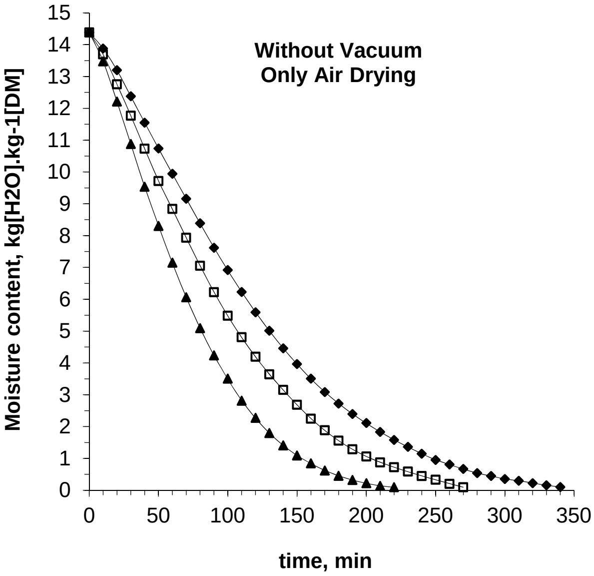

Figure 3. The air drying curve of celeriac slices on dry basis (kg[H2O].kg-1[DM]); ▲, 75°C; □, 65°C; ♦, 55°C.

The air drying rates (kg [H_2O] kg^{-1}[DM] min^{-1}) obtained under different temperatures are given in Fig 4. The drying rate increased with increasing temperature (Doymaz and Pala 2002, Demir *et al.,* 2004, Doymaz 2004, Alibas 2006, Alibas 2007, Alibas 2009, Alibas 2010). Depending on the air drying conditions, the average drying rates of celeriac slices ranged from 0.0260 to 0.1134 kg [H_2O] kg^{-1}[DM] min^{-1} between 55°C and 75°C, respectively.

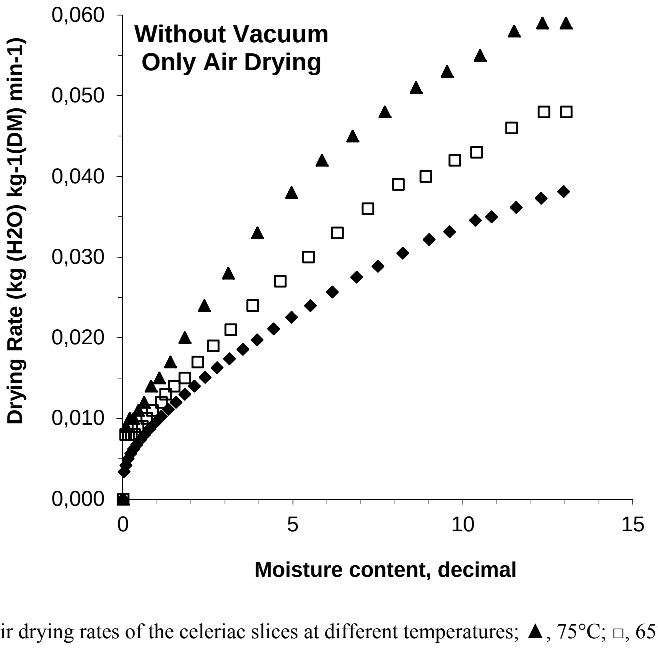

Figure 4. Air drying rates of the celeriac slices at different temperatures; ▲, 75°C; □, 65°C; ♦, 55°C.

Energy consumption and power requirement

The energy consumption and power requirement values obtained during vacuum and air drying of celeriac slices is given in Table 1. As shown in Table 1, there was a reduction in the energy consumption with increasing air temperature in the drying trials in which the same pressure was applied. Higher energy consumption was noted in the drying process at 55°C and 17 kPa, and the lowest energy consumption was recorded in the drying trials at 75°C and 0.1 kPa pressure. There is a reduction in the energy consumption with an increase in pressure because the drying period is shortened. The vacuum pump also uses nearly as much energy as the vacuum oven during operation. Therefore, the energy consumption in vacuum-drying trials is more than the energy consumption in the trials in which vacuum was not applied.

A reduction in the power requirement was seen with decreasing air temperature in the drying trials in which the same pressures were applied. The higher power requirement was noted in the drying process at 75°C temperature and 0.1 kPa pressure, and the lowest power requirement was recorded in the drying trials at 55°C.

There is a reduction in the energy consumption with an increase in pressure because the drying period is shortened (Alibas 2007, Alibas 2009, Alibas 2010).

Drying time is found out to decrease substantially in the drying processes at the high pressure and high temperature compared to those done at low pressure and low temperature. Also, energy consumption was observed to be less in the same situations (Alibas 2007, Alibas 2009, Alibas 2010).

The energy consumption values obtained from drying experiments could provide only a rough approximation. The drying systems used in this study were designed for experimental purpose. Energy consumption values in commercial drying systems are higher than laboratory type drying systems. Energy consumption values will be increased with increased of the quantity of the product.

Table 1. Energy consumption, trying time and power during the vacuum drying of celeriac slices.

	Drying Time (min)**	***Energy Consumption (kWh) *****	***Power (kW)*****
Air Drying			
55°C	340^{q}	1.07^{d}	0.19^{a}
65°C	270^{n}	0.97^{b}	0.22^{b}
75°C	220^{k}	0.84^{a}	0.23^{c}
Vacuum Drying			
0.1 kPa – 55°C	180^{g}	1.27^{f}	0.42^{f}
0.1 kPa – 65°C	120^{d}	1.14^{e}	0.57^{n}
0.1 kPa – 75°C	70^{a}	1.01^{c}	0.87^{r}
3 kPa – 55°C	210^{j}	1.54^{k}	0.44^{g}
3 kPa – 65°C	140^{e}	1.38^{h}	0.59^{o}
3 kPa – 75°C	90^{b}	1.29^{f}	0.86^{q}
7 kPa – 55°C	230^{l}	1.62^{l}	0.42^{f}
7 kPa – 65°C	160^{f}	1.41^{i}	0.53^{l}
7 kPa – 75°C	110^{c}	1.33^{g}	0.73^{p}
10 kPa – 55°C	260^{m}	1.73^{m}	0.40^{e}
10 kPa – 65°C	200^{i}	1.52^{k}	0.46^{h}
10 kPa – 75°C	160^{f}	1.44^{j}	0.54^{m}
13 kPa – 55°C	290^{o}	1.88^{n}	0.39^{d}
13 kPa – 65°C	220^{k}	1.62^{l}	0.44^{g}
13 kPa – 75°C	180^{g}	1.52^{k}	0.51^{j}
17 kPa – 55°C	300^{p}	2.00^{o}	0.40^{e}
17 kPa – 65°C	230^{l}	1.88^{n}	0.49^{i}
17 kPa – 75°C	190^{h}	1.64^{l}	0.52^{k}

**P<0.01. Column mean values with different superscripts are significantly different

Modelling drying data

The parameters "*k*" and n of the semi-empirical Page's thin layer drying equation [Eqn (1)] for a given vacuum and air drying condition were estimated using a non-linear regression technique (Table 2) and the fitness is illustrated in Fig 5 for vacuum drying and Fig 6 for air drying.

The model gave an excellent fit for all experimental data points with values for the coefficient of determination greater than 0.9995.

Table 2. Non-linear regression analysis results of semi-empirical page's equation [eqn (1)] for vacuum drying of celeriac slices under various vacuum values and temperatures; *SEE*, standard error of estimate; *R^2*, coefficients of determination.

	Drying rate constant (k) min^{-1}	***Exponent (n)*** **	***SEE (±)***	***R^2***
Air Drying				
55°C	0.0012	1.39486	0.00563	0.9997
65°C	0.0019	1.35643	0.00745	0.9995
75°C	0.0026	1.37103	0.00610	0.9997
Vacuum Drying				
0.1 kPa – 55°C	0.0156	1.06887	0.00471	0.9998
0.1 kPa – 65°C	0.0317	1.01372	0.00726	0.9995
0.1 kPa – 75°C	0.434	1.07569	0.00654	0.9997
3 kPa – 55°C	0.0136	1.07713	0.00467	0.9998
3 kPa – 65°C	0.0274	1.03379	0.00369	0.9999
3 kPa – 75°C	0.0322	1.10985	0.00406	0.9999
7 kPa – 55°C	0.0101	1.11683	0.00454	0.9998
7 kPa – 65°C	0.0176	1.08616	0.00568	0.9997
7 kPa – 75°C	0.0200	1.16896	0.00693	0.9996
10 kPa – 55°C	0.0075	1.16007	0.00454	0.9998
10 kPa – 65°C	0.0120	1.11353	0.00362	0.9999
10 kPa – 75°C	0.0179	1.09202	0.00481	0.9997
13 kPa – 55°C	0.0048	1.20213	0.00562	0.9997
13 kPa – 65°C	0.0052	1.25014	0.00732	0.9995
13 kPa – 75°C	0.0132	1.12532	0.00469	0.9998
17 kPa – 55°C	0.0043	1.21784	0.00363	0.9999
17 kPa – 65°C	0.0050	1.25049	0.00645	0.9996
17 kPa – 75°C	0.0102	1.17461	0.00574	0.9997

$^{**}P<0.01$, Column mean values with different superscripts are significantly different

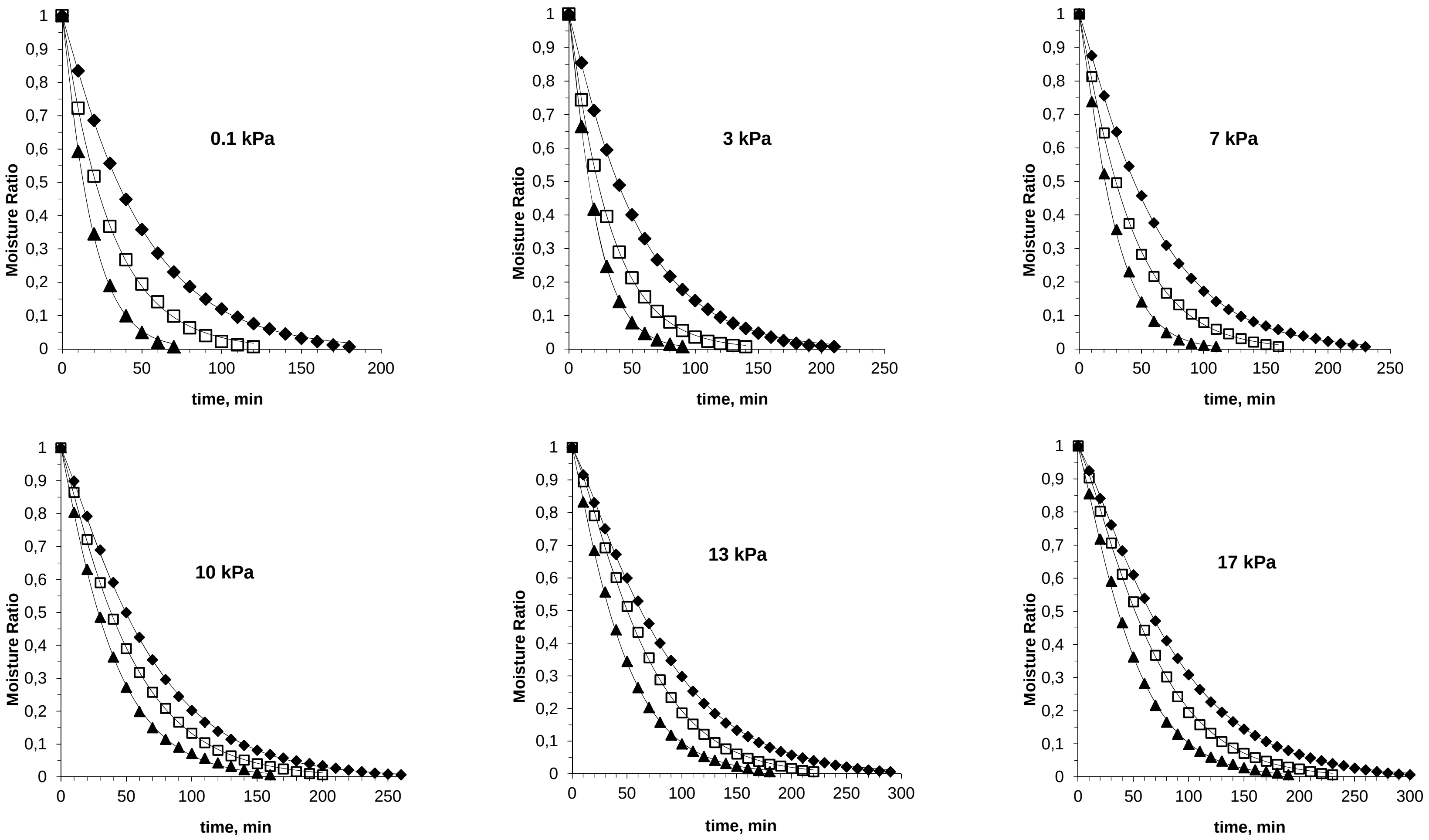

Figure 5. Moisture ratio versus time, comparing experimental curve with the predicted one (-) through semi-empirical Page's equation [Eqn(1)] for celeriac slices; ▲, 75°C; □, 65°C; ♦, 55°C.

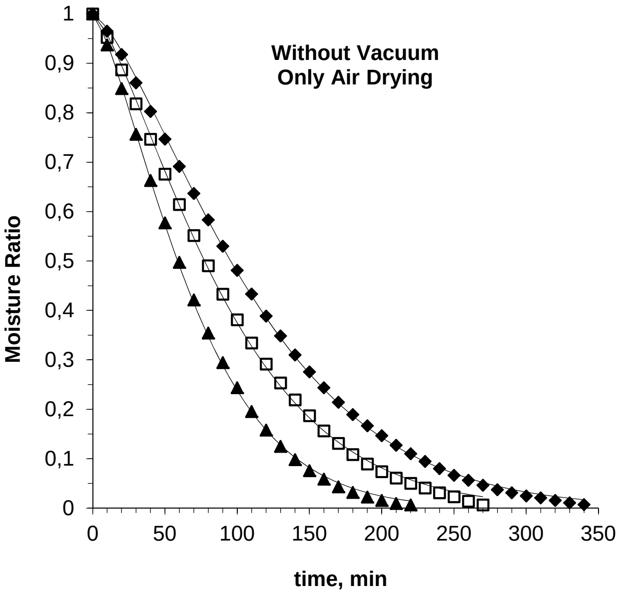

Figure 6. Moisture ratio versus time, comparing experimental curve with the predicted one (-) through semi-empirical Page's equation [Eqn(1)] for celeriac slices during air drying; ▲, 75°C; □, 65°C; ♦, 55°C.

Colour parameters

The colour criteria obtained from the vacuum drying trials carried out using 55, 65, and 75°C temperatures at 0.1, 3, 7, 10, 13, and 17 kPa pressure and air drying experiments carried out using 55, 65, and 75°C temperatures are given in Table 3. The mutual effect of the same pressures and the same temperatures are also given in Table 3. According to this, the colour closest to the fresh product was obtained in the vacuum drying process carried out at 75°C and under 0.1 kPa pressure. Colour criteria become worse, compared with the fresh produce, with increasing pressures. The worst colour criteria were recorded in the air drying process carried out at 55°C. The best colour values for the same pressure were obtained in the drying processes at 75°C and the worst were obtained in the drying processes at 55°C.

Colour value is found out to be closer to the fresh production in the drying processes at the high pressure and high temperature compared to those done at low pressure and low temperature (Methakhup *et al.*, 2005, Alibas 2007, Alibas 2009, Alibas 2010).

Table 3. Colour parameters of celeriac slices during vacuum drying (L: brightness (+100)/darkness (+0), a: redness (+50) / greenness (-50) coordinate, b: yellowness (+50) / blueness (-50) coordinate, C: chroma, α°: hue angle).

	L* *	***a* ****	***b* ****	***C* ****	**α^{0} ****
Fresh Product					
	80.34^{a} (±0.341)	-1.85^{a} (±0.48)	12.19^{a} (±0.033)	12.33^{a} (±0.026)	98.61^{J} (±0.244)
Air Drying					
55°C	74.26^{o} (±0.111)	-2.34^{i} (±0.031)	10.37^{i} (±0.029)	10.63^{j} (±0.033)	102.71^{a} (±0.140)
65°C	74.86^{n} (±0.066)	-2.29^{hi} (±0.025)	10.72^{hi} (±0.158)	10.96^{ij} (±0.151)	102.06^{ab} (±0.260)
75°C	74.95^{n} (±0.45)	-2.26^{ghi} (±0.40)	11.01^{gh} (±0.104)	11.24^{ghi} (±0.095)	101.60^{bc} (±0.300)
Vacuum Drying					
0.1 kPa – 55°C	77.94^{de} (±0.47)	-1.97^{abc} (±0.038)	11.80^{abcd} (±0.107)	11.97^{abcde} (±0.110)	99.48^{ghi} (±0.099)
0.1 kPa – 65°C	78.09^{d} (±0.116)	-1.91^{ab} (±0.053)	11.87^{abc} (±0.087)	12.02^{abcd} (±0.093)	99.14^{hij} (±0.181)
0.1 kPa – 75°C	79.24^{b} (±0.170)	-1.89^{ab} (±0.006)	12.09^{a} (±0.40)	12.24^{a} (±0.039)	98.88^{ij} (±0.055)
3 kPa – 55°C	77.37^{fgh} (±0.131)	-2.01^{bcd} (±0.059)	11.58^{cde} (±0.202)	11.76^{cdef} (±0.190)	99.84^{fgh} (±0.447)
3 kPa – 65°C	77.77^{def} (±0.117)	-1.96^{abc} (±0.018)	11.79^{abcd} (±0.148)	11.95^{abcde} (±0.148)	99.46^{ghi} (±0.036)
3 kPa – 75°C	78.65^{c} (±0.066)	-1.93^{ab} (±0.017)	12.03^{ab} (±0.023)	12.19^{ab} (±0.020)	99.11^{hij} (±0.093)
7 kPa – 55°C	77.08^{hi} (±0.026)	-2.10^{def} (±0.46)	11.38^{efg} (±0.137)	11.58^{efgh} (±0.130)	100.44^{ef} (±0.330)
7 kPa – 65°C	77.56^{efg} (±0.066)	-2.06^{cde} (±0.43)	11.64^{bcde} (±0.174)	11.82^{bcdef} (±0.164)	100.4^{fg} (±0.370)
7 kPa – 75°C	78.11^{d} (±0.069)	-2.00^{bcd} (±0.050)	11.92^{abc} (±0.055)	12.08^{abc} (±0.057)	99.51^{ghi} (±0.208)
10 kPa – 55°C	76.99^{hi} (±0.030)	-2.18^{efgh} (±0.020)	11.30^{efg} (±0.092)	11.51^{fgh} (±0.092)	100.94^{cde} (±0.060)
10 kPa – 65°C	77.33^{gh} (±0.069)	-2.12^{def} (±0.012)	11.56^{cde} (±0.171)	11.75^{cdef} (±0.169)	100.40^{ef} (±0.120)
10 kPa – 75°C	78.02^{d} (±0.41)	-2.08^{cde} (±0.018)	11.80^{abcd} (±0.069)	11.98^{abcd} (±0.064)	99.98^{fg} (±0.125)
13 kPa – 55°C	76.19^{kl} (±0.114)	-2.21^{fgh} (±0.019)	11.03^{gh} (±0.026)	11.24^{ghi} (±0.026)	101.32^{bcd} (±0.090)
13 kPa – 65°C	76.34^{jk} (±0.41)	-2.16^{efg} (±0.015)	11.32^{efg} (±0.139)	11.53^{fgh} (±0.140)	100.82^{de} (±0.090)
13 kPa – 75°C	76.67^{ij} (±0.032)	-2.11^{def} (±0.009)	11.44^{def} (±0.052)	11.63^{defg} (±0.052)	100.43^{ef} (±0.030)
17 kPa – 55°C	75.56^{m} (±0.47)	-2.28^{ghi} (±0.024)	10.73^{hi} (±0.052)	10.97^{ij} (±0.050)	102.02^{ab} (±0140)
17 kPa – 65°C	75.77^{m} (±0.102)	-2.22^{fghi} (±0.41)	11.01^{gh} (±0.009)	11.23^{hi} (±0.017)	101.39^{bcd} (±0.200)
17 kPa – 75°C	75.92^{lm} (±0.021)	-2.18^{efgh} (±0.021)	11.14^{fg} (±0.090)	11.35^{ghi} (±0.084)	101.07^{cde} (±0.190)

** $P<0.01$, Column mean values with different superscripts are significantly different

CONCLUSIONS

The parameters of drying period, average drying rate, energy consumption, and colour criteria were investigated during the vacuum drying of celeriac slices at 55, 65, and 75°C under 0.1, 3, 7, 10, 13, 17 kPa pressures and air drying at 55, 65, and 75°C. It was determined that the best results with respect to drying period, average drying rate, and colour criteria were obtained at 75°C temperature and 0.1 kPa pressure, however the energy consumption in the vacuum drying processes were high.

Drying using a combination of 75°C temperature and 0.1 kPa pressures lasted 70 minutes and the energy consumption during this period was measured to be 1.01 kWh. Colour criteria at these values (L: 77.94, a:-1.97, b: 11.80, C: 11.97 and α°:99.48) were the closest to fresh product's colour values. The increase in pressure and decrease in temperature increased drying time and decreased the product's quality. The worst results in terms of drying quality were obtained by a combination of the highest pressure (17 kPa) and lowest temperature (55°C), which are the lowest values used for this study. In 17 kPa – 55°C vacuum drying, the drying time was 340 minutes and energy consumption is 2.00 kWh. The dried product's colour values for this drying method were L: 75.56, a:-2.34, b: 10.37, C: 10.63, and α°:102.71. In terms of darkening after the drying, the best method was found to be 0.1 kPa-75°C, and the worst was 17 kPa-55°C, comparing all attempts where pressure was effective. We can understand this from the value in colour criteria. When the product was dried only by air, the drying time and energy consumption values decreased as temperature increased. We can understand that pressure increases the darkening in dry product from colour parameter a. In other words, as pressure decreased and temperature increased, and the value of an approached 0, the darkening in the dry product decreased.

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