

Drying of chilli pepper in various conditions

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RESEARCH ARTICLE

Abstract

Fresh red pepper was blanched with water (at 90 °C for 3 min), 5% potassium carbonate and 2% ethyl oleate (both at 20 °C for 1 min) and then dried either with forced hot air (at 55, 65 and 75 °C) or solar energy. Then the effects of different variables on the kinetics and quality parameters of dehydrated red chilli pepper were studied. The peppers blanched with boiling water or ethyl oleate and dried at 75 °C had the lowest drying time and their quality indicators (vitamin C, colour values, shrinkage percentage, and rehydration rate) were not significantly different. However, peppers blanched with potassium carbonate and dried at 55 °C had the highest content of this vitamin and also colour scores among different treatments. While the untreated samples (blank) dehydrated either with hot air at 55 °C or solar energy had the lowest shrinkage (%), they did not have significant difference ($P < 0.01$) with the water-blanched samples dried at 65 °C.

Keywords: blanching, drying kinetics, hot air drying, quality parameters, red pepper, sun drying

1. Introduction

Red chilli (RC) pepper is one of the broadly used varieties of pepper with scientific name of *Capsicum frutescens*. Red chilli pepper is a good source of vitamins A and C, β -carotene and minerals such as potassium (Akintunde, 2010). While it used as a spice and flavour in various foods (Isiduro *et al.*, 1995), it can be converted to medicinal and therapeutic substances to increase appetite, relieve pain (due to arthritis) and prevent some cardiovascular disorders (Bosland, 1994; Marinelli, 1998). Although this product is consumed in fresh or cooked form, most of the times it is dried to extend its shelf life and processed to make pastes or sauces (Akintunde, 2010). Since traditional sun drying of red pepper is very slow (usually takes 7-10 days depending on the weather conditions) and is not easy to control its final moisture content, a relatively low quality product is obtained after drying. In this method, red chilli pepper is contaminated with dust, dirt, rainfall, animals, birds, rodents, insects and microorganisms (Hossain and Bala, 2007). Under these conditions, losses will reach up to 40-60% of total quantity (Mangaraj *et al.*, 2001). This is the main reason that different pretreatments and drying techniques have been adopted to eliminate any

contamination and protect the nutritional properties of fresh vegetables by using appropriate temperature and reduced drying times. Various blanching and colour fixing treatments (hot water and steam, potassium metabisulphate, potassium and sodium hydroxide, potassium carbonate, methyl and ethyl ester, citric acid and ascorbic acid) and drying techniques (osmotic solution and hot air movement) have been practised in food dehydration.

Blanching is used to stop various physiological processes of fruits and vegetables before drying process (Doymaz, 2010). The treatment inactivates the browning and off-flavours producing enzymes, increases drying rate and yields a final product with desirable qualities. Doymaz and Pala (2002) showed that pre-treated peppers dry faster and have a higher colour quality in comparison with untreated samples. In another case, white mulberry blanched with ethyl oleate and dehydrated with sunlight, had a much lower drying time than the un-blanched products dried with similar conditions (Doymaz, 2004). Overall, proper blanching will reduce the surface resistance of fruits and vegetables and improve their water transfer during dehydration.

The type of blanching solution before dehydration has an effect on the quality of final vegetable products. Zhao *et al.* (2013) blanched pepper in three different solutions (10% NaCl, or 50% sucrose or their combination) and used a hot air/microwave drier for dehydration. They reported that the quality indicators of samples blanched in a binary solution was much better than the ones treated in single solution of NaCl or sucrose. Akintunde (2010) examined various blanching methods along with an osmotic solution (with 60-70 °Brix sucrose concentrations) and concluded that the blanched pepper dried faster than the untreated samples. Ayub Hossain *et al.* (2007) showed that the increasing temperature along with decreasing relative humidity of the drying air, had significant effects on improving the drying rate of chilli pepper. Scala and Crapiste (2008) measured the degradation kinetics of ascorbic acid and carotenoids of pepper in range of 50-70 °C drying temperatures and modelled them as first order reactions. They stated that the average activation energies of carotenoid and vitamin C degradation were 50.1 and 26.9 kJ/mol, respectively.

It was our main objective to study the effects of various blanching methods and air drying temperatures on the quality criteria of RC pepper and compare them with the un-blanched samples dehydrated in traditional sun drying.

2. Materials and methods

Raw material preparation

RC pepper (*Capsicum annum*) was purchased from a local market and placed in a refrigerator at ~5.0 °C to reduce the biological and respiratory activities until required for testing. The initial moisture content of the fresh produce was measured by AOAC method No. 931.04 (AOAC, 1990) in an oven at 105 °C was 80-90% (wet basis). The cooled red chilli pepper were washed, cut into uniform pieces (approximately 2.5×2.5 cm) and selected (with weight of 30 g for each sample) for further processing

Blanching treatments

The following blanching solutions and processing conditions were used for chilli pepper before drying:

- Water blanching: pepper samples soaked in a hot water bath at 90 °C for 3 min and then drained on a metal mesh to remove excess water.
- Ethyl oleate blanching: pepper samples were dipped in a solution containing 2% ethyl oleate at ambient temperature for 1 min followed by draining on a similar mesh.
- Potassium carbonate blanching: pepper samples were dipped in a solution containing 5% potassium carbonate at ambient temperature for 1 min followed by draining on a similar mesh.

Drying treatments

The treated and untreated (blank) samples were dried at three temperatures, 55, 65 and 75 °C in a conventional air drier (Groom Company, Tehran, Iran) until their weights remained constant. The drier was equipped with an electrical heater and fan to circulate air for at least 30 min and reached the desired airflow and temperature before each test. The weight control of peppers was checked during dehydration using a digital balance (model FX-300CT; A&D Co., Limited, Tokyo, Japan) at 15 min time intervals. After drying, the samples were cooled and packaged in polyethylene bags. For sun drying, the treated and untreated samples were placed on a clean cloth and exposed to direct sunlight for several days until their weight became constant. The weight control of samples was carried out during daylight (9 am to 5 pm) at 1 h time intervals, due to the fact that significant moisture loss took place during these hours.

Figure 1 shows the average temperature and relative humidity of the ambient air for the sun drying experiments in Nishapur City (northeast of Iran) during the day times of October 2013. According to the data obtained from the local weather station, the average wind speed during this month was ~7 m/s.

Data fitting

For selecting the best blanching (drying pre-treatments) and fitting of the drying curves for red chilli pepper, Equation 1 from the model of Midli-kucuk (Zhu *et al.*, 2015) was used. This model was chosen to provide a good fit of the drying curve of chilli pepper, as confirmed by many researcher using agriculture materials (Arslan and Ozcan, 2011; Darvishi *et al.*, 2014; Kavak Akpinar and Bicer, 2008). Equation 2 was used to determine the moisture ratio during drying process.

$$MR = a \exp(-kt^n) + bt \quad (1)$$

Where MR, t, k, a, b, and n are moisture ratio, drying time (min), drying rate constant (min⁻¹) and the parameters of the model, respectively.

$$MR = \frac{X_t - X_e}{X_o - X_e} \quad (2)$$

Where, X_t is moisture content at a given time (d.b.), X_e is equilibrium moisture content (d.b.) and X_o is initial moisture content (d.b.) of the pepper samples. According to previous results (Tavakolipour *et al.*, 2014), Equations of 3, 4, 5 and 6 were used to evaluate the best fitting model for drying red chilli pepper.

$$R^2 = 1 - \frac{\sum_{i=1}^N (U_{p,i} - U_{e,i})^2}{\sum_{i=1}^N (\bar{U}_{p,i} - U_{p,i})^2} \quad (3)$$

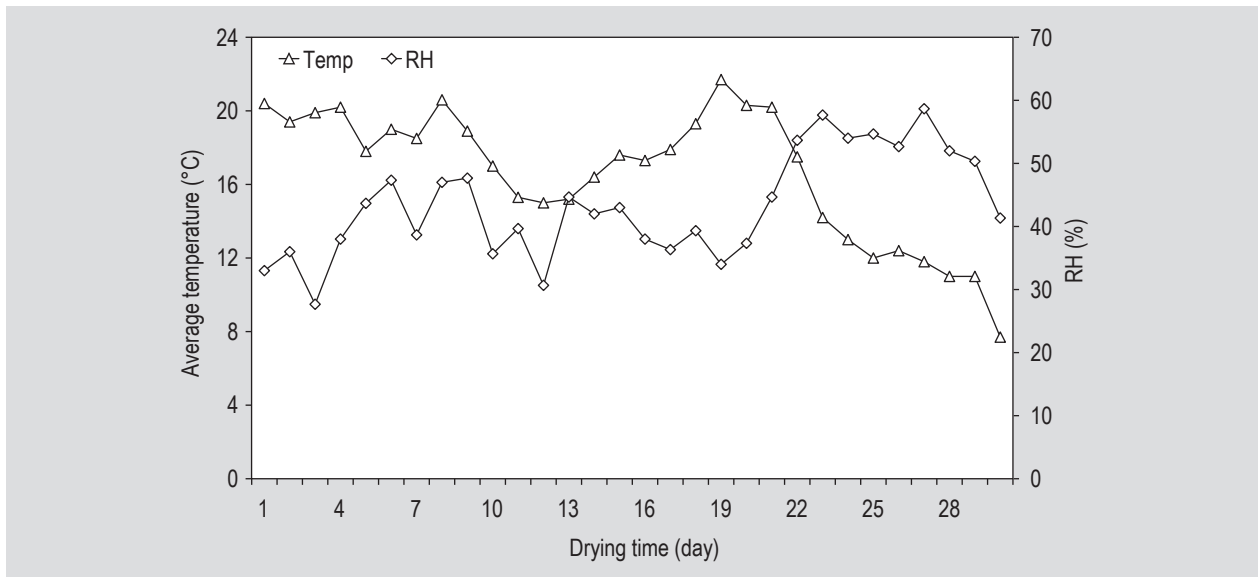


Figure 1. Average temperature and relative humidity during the sun drying process of red chilli in Neishapour, Iran in October 2013.

$$\text{RMSE} = \left(\frac{1}{N} \sum_{i=1}^N (U_{p,i} - U_{e,i})^2 \right)^{0.5} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^N (U_{e,i} - U_{p,i})^2}{N - z} \quad (5)$$

$$P(\%) = \frac{100}{N} \sum_{i=1}^n |U_{p,i} - U_{e,i}| \quad (6)$$

Where R^2 is the coefficient of determination, RMSE the root mean square error, χ^2 the reduced chi-square, $P(\%)$ the mean relative deviation modulus, $U_{e,i}$ the i^{th} experimental data, $U_{p,i}$ the i^{th} predicted data, $\bar{U}_{p,i}$ the average predicted data, N the number of observations and z the number of model's constant (Tavakolipour and Mokhtarian, 2012; Tavakolipour *et al.*, 2014). Data fitting was carried out by SigmaPlot software (version 11; Systat Software Inc, London, UK).

Physical and chemical tests

In this study, the vitamin C content was measured according to AOAC standard method No. 967.21 (AOAC, 1990). The colour of chilli pepper was calculated according to the American Spice Trade Association method (ASTA; Vega-Gálvez *et al.*, 2009). Between 70–100 mg of chilli pepper was mixed with 100 ml acetone and kept in darkened storage for 16 h at ambient temperature. The absorbance of an aliquot of the pure acetone (as a blank) and the prepared samples were measured using a Shimadzu spectrophotometer (model UV-120-02; Genzo Shimadzu Co., Kyoto, Japan) at 460 nm. The ASTA colour value, the shrinkage and rehydration ratios of the dried samples were computed using Equations 7, 8 and 9 obtained from Vega-Gálvez *et al.*

(2009), Devahastin *et al.* (2004), and Doymaz and Ismail (2011), respectively.

$$\text{ASTA colour value} = \frac{\text{Absorbance of acetone extracts} \times 16.4 \times I_f}{\text{Sample weight (gr)}} \quad (7)$$

$$\% \text{ Shrinkage} = \left(\frac{V_i - V_f}{V_i} \right) \times 100 \quad (8)$$

$$RR = \frac{W_t - W_d}{W_t} \quad (9)$$

In these equations, I_f is the correction coefficient of the instrument in the range of 0.4–0.6 and is considered to be an average equal to 0.5, V_i is the initial sample volume before drying and V_f the volume after drying. RR, W_d and W_t are the rehydration ratio, sample weight before and after rehydration, respectively.

Statistical analysis

The statistical program Statistix (version 8; Analytical Software, Tallahassee, FL, USA) was used to carry out ANOVA (analysis of variances) for the recorded data (obtained from the three replicates of each treatments) and compared the mean values by using least significant difference test at a confidence level of 99%.

3. Results and discussion

Drying kinetics

The variation of moisture content versus drying time showed a downward trend, so that, the slope of drying curve is faster in samples blanched with ethyl oleate (Figure 2). This is due to the ability of ethyl oleate to dissolve the waxy skin and cell wall structure of pepper which improves moisture transfer in the produce during the drying time.

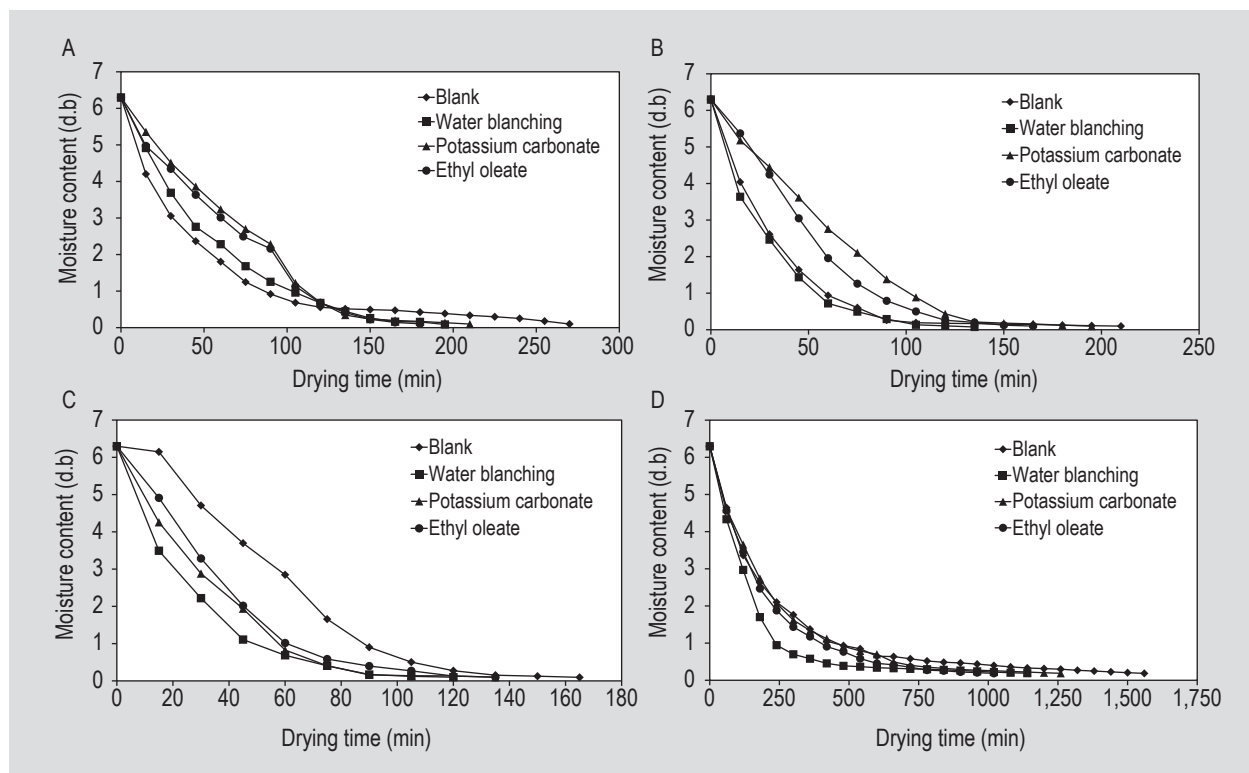


Figure 2. Drying curves of chilli pepper dehydrated at convective air temperatures (A) 55 °C; (B) 65 °C; (C) 75 °C; and (D) sun drying.

When Doymaz and Pala (2002) dried pepper with 2% ethyl oleate, they could reduce the drying time considerably due to the acceleration of drying rate. Red chilli pepper did not show a constant drying rate period under the experimental conditions but exhibited a falling rate period like most vegetables. Kaymak-Ertekin (2002) measured rehydrating kinetics of dried green and red peppers blanched with ethyl oleate and obtained similar results.

Quality properties

The ANOVA results (Table 1) showed that blanching treatments and drying air temperature had pronounced effects on the colour of dried chilli pepper at 99% probability level. The results illustrated that red chilli pepper blanched with potassium carbonate and dried at 65 °C gave the highest colour values among the dried samples blanched with different methods. Vega-Gálvez et al. (2009) reported similar results when they showed that the increasing of drying air temperature was the cause of red pepper colour changes. They stated that, ASTA colour was more dependent on the carotenoid properties of red pepper (such as capxantine, capsorubin and β -carotene) rather than the drying air temperature. Most probably the high colour value of ASTA is related to more carotenoid compounds in red pepper. According to Guiné and Barroca (2012), the discoloration of chilli pepper during the drying process is due to oxidation (enzymatic and non-enzymatic) of the carotenoid compounds. Different pre-treatments have

been suggested for preventing pigment degradation during dehydration. Ergunes and Tarhan (2006) indicated that chilli pepper blanched with 2% ethyl oleate + 2% NaCl + 4% potassium carbonate solution at 60 °C maintained its original red colour during the drying process. While this solution inhibits enzyme activity and protects the red colour (mainly due to its low alkaline pH), immersion of this product in saline solution caused pigment degradation (Ergunes and Tarhan, 2006). On the other hand blanching with ethyl oleate has positive effects on the drying conditions of chilli pepper. Doymaz and Pala (2002) showed that immersing fresh pepper in 2% ethyl oleate protects its original attractive colour after drying. The ANOVA results showed that different blanching treatments and drying air temperatures had pronounced and significant effects ($P < 0.01$) on both the shrinkage and vitamin C content of red chilli pepper (Table 1). Furthermore, the red chilli pepper blanched with water and dried at 75 °C or solar light had respectively the highest and lowest values of shrinkage.

A high shrinkage value was observed at 75 °C most probably due to the difference between the sample temperature (very close to the drying temperature) and its glass transition temperature. As the moisture content of a product diminishes during dehydration process, its solid mobility reduces and water behaves as a plasticising agent in shapeless (amorphous) vegetable products. Since the critical moisture content of the dried product is beyond this plastic or rubbery state, a change from the rubbery to a glassy state

Table 1. Quality parameters of chilli pepper in different drying conditions.¹

Treatments	Vitamin C (%)	Colour (ASTA unit)	Shrinkage (%)	Rehydration ratio (g/g)
Blank + 55 °C drying	8.70±1.08 ^{cde}	157.9±1.69 ^{bc}	4.167±1.44 ^{bcd}	0.679±0.33 ^a
Blank + 65 °C drying	5.80±1.25 ^e	158.6±0.90 ^{abc}	3.333±1.44 ^{cd}	0.674±0.33 ^a
Blank + 75 °C drying	6.89±0.62 ^{cde}	160.0±0.98 ^{ab}	3.333±1.44 ^{cd}	0.635±0.31 ^b
Blank + sun drying	6.16±0.62 ^{de}	159.1±0.59 ^{ab}	1.667±1.44 ^d	0.601±0.30 ^{cd}
Ethyl oleate + 55 °C drying	13.05±2.17 ^a	160.1±0.02 ^{ab}	5.556±0.95 ^{abcd}	0.640±0.31 ^b
Ethyl oleate + 65 °C drying	9.06±0.62 ^{bcd}	160.6±0.49 ^{ab}	5.000±0.00 ^{bcd}	0.601±0.30 ^{cd}
Ethyl oleate + 75 °C drying	9.06±1.66 ^{bcd}	161.0±0.78 ^{ab}	6.667±2.88 ^{abc}	0.621±0.30 ^{bc}
Ethyl oleate + sun drying	11.96±1.08 ^{ab}	160.0±0.27 ^{ab}	7.222±2.54 ^{abc}	0.587±0.29 ^d
5% potassium carbonate + 55 °C drying	14.86±1.25 ^a	161.1±0.75 ^{ab}	6.111±0.95 ^{abcd}	0.616±0.30 ^{bc}
5% potassium carbonate + 65 °C drying	7.25±1.66 ^{cde}	161.6±0.404 ^a	6.111±0.95 ^{abcd}	0.637±0.31 ^b
5% potassium carbonate + 75 °C drying	7.97±0.62 ^{cde}	160.9±0.58 ^{ab}	7.222±2.54 ^{abc}	0.597±0.29 ^{cd}
5% potassium carbonate + sun drying	11.96±0.00 ^{ab}	158.8±1.25 ^{abc}	6.333±3.21 ^{abc}	0.624±0.31 ^{bc}
Water blanching + 55 °C drying	11.96±1.88 ^{ab}	159.8±0.64 ^{ab}	6.667±2.88 ^{abc}	0.635±0.31 ^b
Water blanching + 65 °C drying	9.792±1.08 ^{bc}	158.0±2.06 ^{bc}	8.333±2.88 ^{ab}	0.678±0.33 ^a
Water blanching + 75 °C drying	9.429±1.66 ^{bc}	158.0±0.76 ^{bc}	10.00±0.00 ^a	0.606±0.30 ^{cd}
Water blanching + sun drying	13.05±2.17 ^a	155.7±4.34 ^c	6.667±2.88 ^{abc}	0.639±0.31 ^b

¹ In each column, means with the same superscript letters are not significantly different ($P < 0.01$).

will also occur and the dried material would become rigid and volume reduction is greatly restricted (Katekawa and Silva, 2007). In other words, the physical mobility of the product matrix during drying was not powerful enough to support the structure of the solid material during water vaporisation and more collapse and shrinkage occurred (Champion *et al.*, 2000; Mayor and Sereno, 2004).

The vitamin C content of samples treated with potassium carbonate or ethyl oleate and then dried at 55 °C, was significantly higher than in the sun dried untreated (blank) sample. Additionally, the lowest vitamin C content was noted for untreated (blank) samples when dried in sunlight or at 65 and 75 °C. Vega-Gálvez *et al.* (2009) showed that increasing the drying air temperature of chilli pepper up to 90 °C caused a 98.2% reduction of vitamin C in comparison with the fresh product. They stated that, this was due to the irreversible oxidative processes of water-soluble vitamin C during drying. Mota *et al.* (2010) made a similar statement when they studied the vitamin C oxidation during the drying process. The ANOVA results of this study also showed that the blanching treatment and drying air temperature had meaningful effects on the rehydration ratio of dried chilli pepper at the 99% probability level ($P < 0.01$) (Table 1). While the highest rehydration ratio was observed with the untreated sample (blank) dried at 55 °C, its difference with untreated or water blanched samples dried at 65 °C was insignificant. The high rehydration ratio of red chilli pepper is quite exceptional in comparison with the drying of other vegetables and fruits. Doymaz (2007) showed that increasing the drying temperature of tomatoes (pre-treated

with 2% ethyl oleate + 4% potassium carbonate) reduced the rehydration rate. Similar results were observed when Doymaz and Ismail (2011) dried sweet cherry pre-treated with 2% ethyl oleate + 4% potassium carbonate.

Mathematical modelling

The drying model of Midli-kucuk (Zhu *et al.*, 2015) was used to evaluate the fitness of our dehydration data and estimate the moisture ratio as a function of drying time. The drying constants (a, b, and n) and k value of this model are given in Table 2. Additionally, the statistical parameters including R^2 , χ^2 , mean relative deviation modulus, P(%) and RMSE were prepared for the data in Table 2 to evaluate the Midli-kucuk model for different drying conditions. The following treatments had high values of R^2 , along with low amounts of χ^2 , P(%) and RMSE:

- blanching of red chilli pepper with 2% ethyl oleate followed by hot air drying at 55 °C;
- blanching of red chilli pepper with 2% ethyl oleate followed by sun drying;
- blanching of red chilli pepper with hot water followed by sun drying gave the highest value of R^2 and lowest values of other parameters.

4. Conclusions

The following outcomes were obtained from this study for the different pre-treatments and drying of chilli pepper:

- Hot air drying of chilli pepper reduced the drying time and increased drying efficiency in comparison with sun

Table 2. The results of statistical analysis and constants of Midli-kucuk's model on thin layer drying of red chilli pepper.

Treatments	Constants				Statistical parameters ¹			
	k (min ⁻¹)	n	a	b	R ²	χ ²	P(%)	RMSE
Blank + 55 °C drying	0.0367	0.8827	0.9985	5.81×10 ⁻⁵	0.9977	0.00018	1.0607	0.0122
Blank + 65 °C drying	0.0219	1.0993	0.9969	-4.4×10 ⁻⁷	0.9992	8.8×10 ⁻⁵	0.6005	0.0080
Blank + 75 °C drying	0.0004	1.8387	1.0103	-5.0×10 ⁻⁵	0.9970	0.00060	1.4393	0.0200
Blank + sun drying	0.0107	0.8546	1.0062	6.65×10 ⁻⁶	0.9985	0.00010	0.7946	0.0092
Ethyl oleate + 55 °C drying	0.0080	1.0810	0.9788	-0.000822	0.9899	0.00149	2.772	0.0321
Ethyl oleate + 65 °C drying	0.0022	1.5255	0.9945	-3.0×10 ⁻⁵	0.9997	5.45×10 ⁻⁵	0.4814	0.0060
Ethyl oleate + 75 °C drying	0.0049	1.4409	0.9987	1.38×10 ⁻⁵	0.9995	8.75×10 ⁻⁵	0.6152	0.0072
Ethyl oleate + sun drying	0.0067	0.9521	1.0013	-4.9×10 ⁻⁶	0.9996	3.91×10 ⁻⁵	0.4172	0.0055
5% potassium carbonate + 55 °C drying	-0.0078	0.9423	0.9933	-0.015765	0.9937	0.00094	2.190	0.0263
5% potassium carbonate + 65 °C drying	-0.0049	1.0347	0.9918	-0.016074	0.9975	0.00038	1.4135	0.0164
5% potassium carbonate + 75 °C drying	0.0128	1.2198	0.9921	-0.000145	0.9958	0.00074	1.8213	0.0211
5% potassium carbonate + sun drying	0.0072	0.9229	1.0002	-3.2×10 ⁻⁶	0.9993	6.12×10 ⁻⁵	0.4935	0.0070
Water blanching + 55 °C drying	0.0167	1.0113	1.0010	-0.000201	0.9992	0.00010	0.7241	0.0086
Water blanching + 65 °C drying	0.0369	0.9756	0.9972	-0.000148	0.9981	0.00030	1.0181	0.0135
Water blanching + 75 °C drying	0.0404	0.9798	0.9984	-0.000166	0.9987	0.00023	0.8139	0.0114
Water blanching + sun drying	0.0031	1.1715	0.9998	1.35×10 ⁻⁵	0.9976	0.00019	1.0583	0.0126

¹ R² = coefficient of determination; χ² = chi-square; P(%) = mean relative deviation modulus; RMSE = root mean square error).

drying. Also the secondary infection of dried product was decreased considerably due the shorter drying time.

- By increasing the drying air temperature the vitamin C content and shrinkage of chilli pepper decreased and increased, respectively.
- The maximum value of vitamin C content was observed in chilli pepper pre-treated with potassium carbonate and dried at 55 °C. Similarly, the highest shrinkage (10%) was measured in water blanched samples dried at high temperature at 75 °C.
- The best colour score was observed in the samples pre-treated with potassium carbonate and dried at 65 °C.
- The maximum rehydration ratio was observed in untreated samples (blank) dried at 55 °C which did not have significant difference ($P>0.01$) with the water blanched samples dried at 65 °C.

Most probably blanching of the red chilli pepper with 1% potassium carbonate (instead of 5%) followed by drying at 60 °C will produce a dehydrated product with the highest vitamin C, best colour score, lowest shrinkage and maximum rehydration ratio.

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