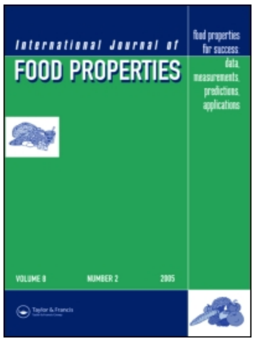

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Degradation kinetics of β-carotene in carrot slices during convective drying

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ABSTRACT
The β-carotene degradation was investigated in carrot (*Daucus carota* L. cv Nantes) slices during convective drying at three temperatures (45, 55, and 65°C) at an airflow rate of 0.2 m s^{-1}. Degradation kinetics of β-carotene in carrot slices during convective drying followed a first-order reaction. Drying temperature showed a significant effect on the degradation of β-carotene in carrot slices. The range of the reaction rate constants for β-carotene loses were 0.23 ± 0.08 –0.48 ± 0.04 h^{-1}. The activation energy of β-carotene degradation is found 33.33 ± 0.05 kJ mol^{-1}. Half-life time was calculated as 3.02 ± 0.04 h at 45°C, which dropped to 1.43 ± 0.03 h at 65°C.

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Carrot; drying; β-carotene; kinetics

Introduction

Carrots are the most common and popular vegetable in the world.[1] They are good source of natural antioxidants, especially carotenoids, which are a group of fat-soluble pigments characterized by a linear, long-chain polyene structure.[2,3] The presence of high concentration of antioxidants, carotenoids, especially β-carotene, may account for the biological and medicinal properties of carrots but the loss of β-carotene during processing and storage is well-established.[4]

Drying is one of the oldest methods of food preservation. It is a simultaneous heat and mass transfer operation in which moisture is removed from food material and carried away by hot air.[5] Longer shelf-life, product diversity, and volume reduction are the reasons for the popularity of dried fruits and vegetables.[6] Several degradation reactions affect the color, nutrient properties, texture, and flavor of fruits and vegetables during drying.[7,8] Degradation of β-carotene not only affects the color of carrot but also its nutritive value and flavor. The stability of β-carotene during carrot drying is a very important objective to make the final product acceptable. Kinetic parameters including reaction order, rate constant, Q_{10} value, half-life time, and activation energy are significant predict the quality of foods when they are processed. The effect of drying on carrot quality has been studied by several researchers.[9–16] However, the literature contains few references on the degradation kinetics of β-carotene in carrot during drying.[8,17,18] The objective of this study was to investigate the kinetics of β-carotene degradation in carrot slices during convective drying.

Materials and methods

Materials

Fresh carrots (*Daucus carota* L. cv Nantes) were purchased from a local market in Denizli. The carrots in polyethylene packages were kept refrigerated until drying. The moisture content of

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ljfp fresh carrots was determined by drying the samples at 70°C for 24 h in a vacuum oven (Model EV 018, Nuve Laboratory and Sterilization Tech.). β-Carotene standard was obtained from Sigma (St. Louis, MO, USA). The high-performance liquid chromatography (HPLC)-grade solvents, including ethanol, *n*-hexane, methanol, acetonitrile, and dichloromethane were from Merck (Darmstadt, Germany). A C_{18} column (250 × 4.6 mm ID, 5 μm) was from ACE (Aberdeen, Scotland).

Methods

Drying process

Carrot slices were dried in a convective dryer at 45, 55, and 65°C. Air flow rate was 0.2 m s^{-1} in through flow. The carrots were washed prior to each drying experiment. The washed carrots were sliced into circular discs (7 ± 1 mm thickness) using a stainless steel knife. The sliced carrots were placed on tray as a single layer. Five hundred grams of carrot slices were used to monitor the time dependent weight loss. The drying was carried out to final moisture content of around 10% from initial moisture content of about 90% (wb). Dried samples were wrapped in aluminum foil in polyethylene packages and stored at –20°C for further β-carotene analyses. All experiments were carried out in triplicates. The moisture content of (kg water/kg dry matter) carrot samples during convective drying was measured by the oven method. The drying curves were obtained by plotting instant moisture contents (on dry basis) versus drying time.

β-carotene content

The β-carotene content was measured on both fresh and dried carrot samples. Seven grams of fresh or dried carrot samples were homogenized with 70 mL of ethanol-hexane solution (4:3 v/v) containing 1% butylated hydroxytoluene (w/v). After homogenization, the mixture was transferred into a polypropylene centrifuge tube. The samples were centrifuged (Universal 30RF, Hettich Zentrifugen, Tuttlingen, Germany) at 11,000 × *g* at 5°C for 15 min. Then, supernatants were transferred into amber bottles by using Pasteur pipettes. Supernatants were filtered through 0.45 μm membrane filters (Minisart, Sartorius, Germany) prior to their injection into the HPLC system.

The HPLC system consisted of a pump and a controller (Shimadzu LC-20AD, Shimadzu Corporation, Kyoto, Japan) a photodiode array detector (SPD-M20A), a degasser (DGU-20A), and a column oven (CTO-20A). A mixture of acetonitrile:methanol:dichloromethane:hexane (40:20:20:20, v/v/v/v) was used as the mobile phase, and its flow rate was set at 0.45 mL min^{-1} at 25°C. Injection volume was 20 μL while detection wavelength was 445 nm. The concentration of β-carotene was calculated from the relative peak area of the β-carotene standard curve. All standard curves showed good linearity (R^2 > 0.99). Recovery rates were found higher than 90%.

Calculation of kinetic parameters

The evaluation of β-carotene change during convective drying was based on the assumption follows first-order kinetics, as given in Eq. (2):

$$C/C_0 = \exp(-kt)$$

The rate of β-carotene change can be determined by the Arrhenius equation (Eq. [3]),

$$k = k_0 e^{E_a/RT}$$

where k is the reaction rate constant (h^{-1}), k_0 is the pre-exponential constant (h^{-1}), E_a is the activation energy (kJ mol^{-1}), R is the universal gas constant (kJ molK^{-1}), and T is the absolute temperature (K). The coefficient Q_{10} is another way to characterize the effect of the temperature on the rate of a reaction and it was calculated by Eq. (4).

$$Q_{10} = (k_2/k_1)^{10/(T_2-T_1)}$$

where k_1 and k_2 are reaction rate constants at temperatures T_1 and T_2, respectively (h^{-1}). The half-life time value ($t_{1/2}$) is the time required for the β-carotene to lose half of its concentration in dried carrots. It was calculated by Eq. (5).

$$t_{1/2} = -\ln(0.5) \text{ x } k^{-1}$$

where k is the reaction rate constant.

Results and discussion

Effect of drying temperature on moisture content

The carrot slices were dried as a single layer with thickness of 7 mm at the drying temperatures of 45, 55, and 65°C in a convective dryer. The carrot slices of initial moisture content of around 8.98 ± 0.06 kg water per kg dry matter were dried to a final moisture of about 0.34 ± 0.04 kg water per kg dry matter. Figure 1 presents the variations in the moisture content at different drying temperatures. It can be seen that moisture content decreases with drying time. The drying temperature had a significant effect on the moisture content of the carrot slices as expected.

Degradation kinetics of β-carotene

The average β-carotene content of fresh carrot samples was 173.2 ± 0.50 mg 100 g dry matter^{-1}. A large range of β-carotene contents of fresh carrots were reported in the literature, depending on the variety, maturity, and extraction procedure, as well as instruments used for analysis. Some studies results are given in Table 1. Drying carrot slices at 45°C resulted in a low degradation rate of β-carotene. The degradation rate of β-carotene increased with temperature. In this study, the β-carotene content of carrots dried at 45°C changed from 173.2 ± 0.50 to 36.2 ± 0.40 mg 100 g dm^{-1} at the end of drying. But at 65°C, it dropped to 27.6 ± 0.60 mg 100 g dm^{-1}. In a previous study by Suvarnakuta et al.,[19] carrots (*Daucus carota* var. sativa) were dried by using hot air drying methods at 60, 70, and 80°C to obtain a product with 10% initial moisture content. β-carotene content of carrot samples dried at 60°C for 420

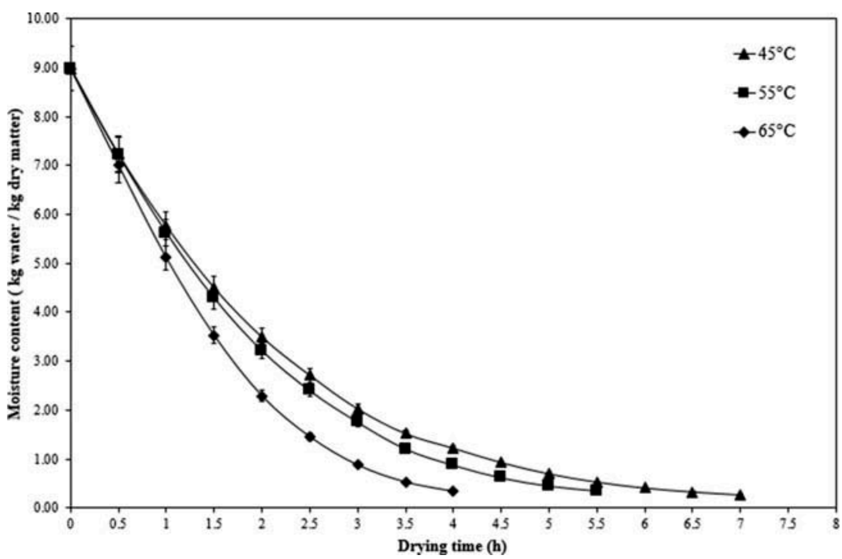

Figure 1. Effect of drying temperature on moisture content for carrot slices.

Table 1. The β-carotene content of some carrot varieties.

Carrot variety	β-carotene content (mg/100 g dm)	References
Daucus carota L.	115.3	[9]
Daucus carota L. cv Nantes	31.99	[21]
Daucus carota L.	76.37	[20]
Daucus carota var. Pusa Kesar	158	[6]
Daucus carota var. sativa	51.11	[19]
Daucus carota L.	30.3-100.5	[22]
Daucus carota var. sativa	68-76	[17]
Daucus carota L. cv Nantes	216	[23]
Daucus carota var. sativa	63-77	[18]
Daucus carota L. cv Macon F1	117.29	[1]
Daucus carota L. super Red Core F1	43.47	[24]

min were 21.46 mg 100 g dm^{-1}. However, this value was reported as 22.05 mg 100 g dm^{-1} for carrot samples dried at 80°C for 240 min. The authors concluded that lipoxygenase and peroxidase are activated at the temperature around 60°C.

The kinetics of β-carotene degradation in dried carrots followed a first-order reaction. This first-order kinetic model was in good agreement with Hiranvarachat et al.[17] and Koca et al.[8] The reaction rate constants for β-carotene in dried carrots were determined by plotting the natural logarithm of β-carotene concentration (mg 100g dm^{-1}) against time for each drying temperature (Fig. 2). The plots were approximately linear (R^2 = 0.957–0.997) confirming that the reaction of β-carotene degradation is a first order. The kinetic parameters are given in Table 2 for different drying temperatures. The calculated rate constant for the β-carotene degradation in carrot slices during convective drying were in the range of 0.23 ± 0.08–0.48 ± 0.04 h^{-1} and significantly affected by

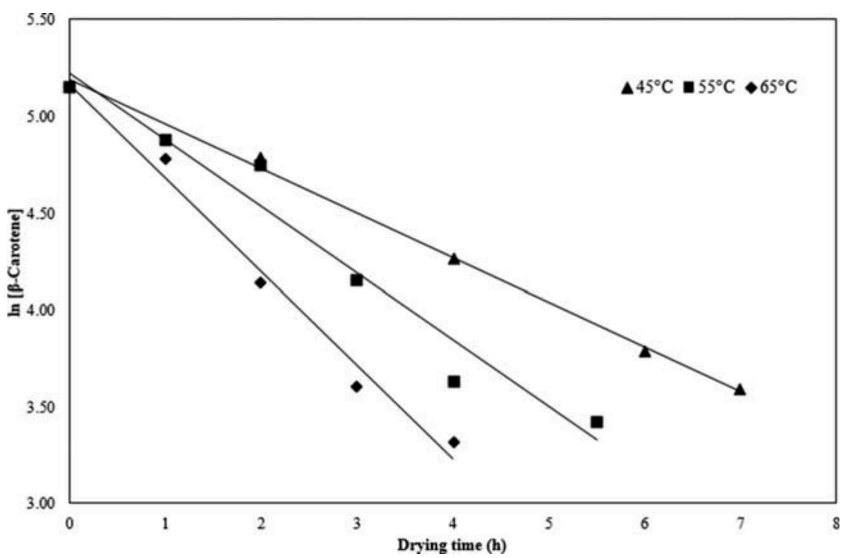

Figure 2. The degradation kinetics of β-carotene in carrots dried at different temperatures.

Table 2. The kinetic parameters[a] for β-carotene losses in carrots during drying at three different temperatures.

Temperature (ºC)	Q_{10} value	k (h^{-1})	$t_{1/2}$ (h)	E_a ($kJmol^{-1}$)
45	1.5 ± 0.3	0.23 ± 0.08	3.02 ± 0.04	33.33 ± 0.05
55	1.4 ± 0.2	0.34 ± 0.04	2.01 ± 0.02	
65		0.48 ± 0.04	1.43 ± 0.03	

[a] Q_{10}, k, $t_{1/2}$, and E_a: temperature coefficient, reaction rate constant, reaction half life time and activation energy, respectively.

drying temperature. When drying temperature increased, the β-carotene degradation rate also increased. The highest Q_{10} value was determined in β-carotene degradation in dried carrots when drying temperature was increased from 45 to 55°C. Half-life time of β-carotene in dried carrots was 3.02 ± 0.04 h at 45°C, but it decreased to 1.43 ± 0.03 h at 65°C. The activation energy for β-carotene changes of dried carrots obtained from the Arrhenius equation was 33.33 ± 0.05 kJ mol^{-1}.

Conclusion

In this study, the degradation kinetics of β-carotene in carrot slices during convective drying was investigated. The first-order reaction was best fitted to the degradation of β-carotene. The reaction rate was greatly influenced by the temperature during drying. The activation energy value for β-carotene was 33.33 ± 0.05 kJ mol^{-1}. The highest Q_{10} value for β-carotene was calculated at increasing drying temperature from 45 to 55°C. Kinetic models which can be applied to predict the quality changes in carrots during drying as a function of time, temperature, and moisture content were developed. Under the conditions studied, carrots should be dried at temperature range of 45–55°C in order to obtained better retention of β-carotene in final products.

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