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Impacts of hot air and vacuum drying on the quality attributes of kiwifruit slices

Takahiro Orikasa [a,*], Shoji Koide [a], Shintaro Okamoto [b], Teppei Imaizumi [c], Yoshiki Muramatsu [d], Jun-ichi Takeda [a], Takeo Shiina [e], Akio Tagawa [f]

[a] Faculty of Agriculture, Iwate University, 3-18-8 Ueda, Morioka, Iwate 020-8550, Japan
[b] Graduate School of Food, Agriculture and Environmental Science, Miyagi University, 2-2-1 Hatatate, Taihaku, Sendai, Miyagi 982-0215, Japan
[c] Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University 6-10-1, Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan
[d] Faculty of Bioindustry, Tokyo University of Agriculture, 196 Yasaka, Abashiri, Hokkaido 099-2493, Japan
[e] National Food Research Institute, NARO, 2-1-12, Kannondai, Tsukuba, Ibaraki 305-8642, Japan
[f] Graduate School of Horticulture, Chiba University, 648 Matsudo, Matsudo, Chiba 271-8510, Japan

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ABSTRACT

Hot air and vacuum drying were performed to investigate changes in the moisture content, hardness, L-ascorbic acid content, antioxidant activity, and surface color of kiwifruit samples over the course of the drying process at temperatures of 50, 60, and 70 °C and a vacuum drying pressure of 3.00 kPa. The residual ratio of AsA and the antioxidant activity in the dried kiwifruit samples was 0.75–0.99 and 4.3–5.5, respectively. The L-ascorbic acid changes in the kiwifruit samples during the hot air drying process followed first order reaction kinetics. Changes in the sample hardness and antioxidant activity were represented by zero-order reaction kinetics. The sample surface color changes after drying were also measured, and the total color change (ΔE) of the samples at all temperatures and for each drying process was greater than 12. The sample color changes (Δa^*) after vacuum drying at each temperature level were significantly ($P < 0.01$) lower than those associated with hot air drying.

1. Introduction

Kiwifruit (*Actinidia deliciosa*) originated in China and was later improved and cultivated in New Zealand. This fruit contains a significant amount of L-ascorbic acid and has a limited shelf life after the fruit is fully ripened. In Japan, the kiwifruit crop yield and shipped quantity in 2011 were 26,100 t and 21,900 t, respectively (MAFF, 2013). These data show that approximately 16% of the kiwifruit were discarded as "food loss". Drying operations may not only help reduce this food loss but also renew interest in high-quality dried products.

Drying is a process in which water is removed to halt or slow down the growth of spoilage microorganisms and the occurrence of chemical reactions. Dehydration plays an important role in extending the shelf life of fleshy agricultural products. In addition to preservation, drying is used to reduce the cost or difficulty of packaging, handling, storage, and transport by converting raw food into a dry solid. This action reduces the weight and sometimes the volume of a food (Barbosa-Cánovas and Vega-Mercado, 1996). Hot air drying is a simple, common method for drying vegetables and fruits (Leonid et al., 2006; Ogura, 1993). Numerous investigators have examined the hot air drying characteristics in fruits and vegetables with a high moisture content, such as tomatoes (Orikasa et al., 2005), apples (Sjoholm and Gekas, 1995), garden beets, carrots (Pabis and Jaros, 2002), and sweet potatoes (Orikasa et al., 2010). The disadvantages of hot air drying include its low energy efficiency and lengthy drying time during the falling rate period. Hot air also causes substantial color and nutrient degradation (Drouzas et al., 1999; Leonid et al., 2006; Maskan, 2000). Vacuum drying is a process in which moist material is dried under subatmospheric pressure (Arevalo-Pinedo and Murr, 2006). Vacuum drying has some distinctive characteristics compared with conventional atmospheric drying. For example, oxidization is prevented because the sample has no contact with air during the drying process. Therefore, the sensory and nutritive qualities of foodstuffs are effectively maintained as a result of the comparatively short drying time and low drying temperature (Wu et al., 2007).

Chen et al. (2001) and Orikasa et al. (2008) designed a mathematical model to describe the moisture content changes during the hot air drying of sliced kiwifruit. Orikasa et al. (2012) also reported the vacuum drying characteristics and kiwifruit shrinkage. However, few quality change investigations in kiwifruit during hot air drying and vacuum drying have been reported. These

* Corresponding author. Tel./fax: +81 19 621 6179.
E-mail address: orikasa@iwate-u.ac.jp (T. Orikasa).

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characteristics may help us establish an optimal drying condition for a more nutritious and high-quality dried product.

In this paper, changes in sliced kiwifruit sample hardness, L-ascorbic acid, antioxidant activity, and surface color during hot air and vacuum drying were investigated by reaction rate theory. The objectives of this study were as follows: (1) obtain quantitative measurements of the quality changes of kiwifruit sample during hot air and vacuum drying, (2) model changes in the hardness, L-ascorbic acid, and antioxidant activity using reaction rate kinetics, and (3) discuss the different quality changes in kiwifruit samples between hot air and vacuum drying.

2. Materials and methods

2.1. Materials

Kiwifruits (Hayward, *Actinidia deliciosa*; New Zealand) were purchased from a local market and stored in a refrigerator at approximately 5 °C prior to the experiment. The initial moisture content of the kiwifruit was measured by using film with diatomite (Japan Food Research Laboratories, 1973). This method can dry completely high moisture content sample by using a diatomite as dehydrate additive, which prevent hardening of the sample surface and accelerate moving moisture in the dried sample (Tsutsumi, 1996). The kiwifruit was mashed up in a juice mixer, and the slurry was dried with dehydrated diatomite at 70 °C and at ambient atmospheric pressure. The weight was measured when the sample reached an equilibrium moisture content at which its weight reading remained the same for 1 h, and this number was converted to a dry basis moisture content (kg water/kg dry matter [d.b. decimal]). The initial moisture content was estimated to be 4.91 ± 1.296 (d.b. decimal) (number of replication = 15). The fruits were cut into approximately 10 mm slices (approximately 20 g) and then used for the drying tests.

2.2. Hot air drying

The hot air drying experiments were conducted at temperatures of 50, 60, and 70 °C in a hot air drying chamber (WFO-400, EYELA, Japan) with a volume of 400 L. The air velocity during drying was 0.3 m s^{-1}. Four samples were dried during each experiment. Each sample was weighed with a digital balance at 2.0 h intervals and dried from 4.91 to 0.20 (d.b. decimal). The temperature at the center of each kiwifruit sample was measured using 0.3 mm diameter T-type thermocouples that were inserted into the center of the sample and attached vertically along the sample surface. The experiments were replicated two times at each temperature, and the mean value was used in the analyses.

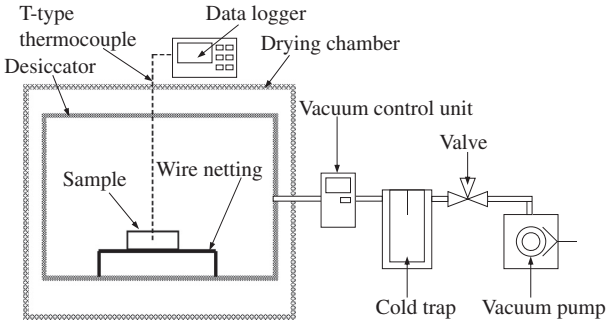

Fig. 1. Schematic diagram of the vacuum-drying apparatus.

2.3. Vacuum drying

Fig. 1 shows a schematic diagram of the vacuum drying apparatus used in this test. It consisted of a vacuum pump, a vacuum control unit, a cold trap, a dryer (which was also used as a temperature controller), and a desiccator. The desiccator, which functioned as a vacuum drying chamber, was placed inside the dryer (WFO-400, EYELA, Japan) to maintain the desired drying temperature. The vacuum pressure in the desiccator was maintained at 3.00 kPa by a vacuum pump (TSW-300, SATO SHINKU, Japan), a cold trap (UT-50, EYELA, Japan), and a vacuum control unit (NVC-2100, EYELA, Japan). The vacuum pressure level was determined from the literature (Bazyma et al., 2006; Cui et al., 2004). The vacuum drying chamber was preheated for 12 h before the start of each test to obtain a stable drying temperature. Sample drying tests were performed at temperatures of 50, 60, and 70 °C, and the moisture content was reduced from 4.91 to 0.20 (d.b. decimal). Four samples were dried during each experiment. The drying tests were repeated two times at each predetermined temperature, and the mean value was used for the analyses.

2.4. Hardness

Penetration tests were performed to evaluate changes in the sample hardness during the drying process. The tests were performed using a food hardness meter (RE2-3305S, YAMADEN, Japan) with a 20 N load cell and a 3 mm diameter flat-ended cylindrical probe. The deformation speed was 2 mm/s. The moving distance of the probe was 2 mm. The average maximum load at four different edge spots on the surface of the samples was defined as the hardness of the samples in this study. The hardness at six to eight moisture content levels was measured during drying at each temperature. The hardening ratio x_h was defined by the following Eq. (1) ($x_h > 0$ indicates hardening, $x_h < 0$ indicates softening):

$$x_h = \frac{y_0 - y}{y_0 - y_e} \tag{1}$$

where y_0 is the initial hardness of the sample [N], y is the measured hardness during drying [N], and y_e is the equilibrium hardness of the sample [N]. The equilibrium hardness y_e during hot air and vacuum drying represented the maximum actual hardness values, which were 6.98 N and 5.95 N, respectively.

2.5. L-ascorbic acid (AsA)

The AsA content [mg/100 g fresh weight] was determined by using a reflectometer (RQ-flex-plus, Merck, Japan) as described by Orikasa et al. (2008). A 5 g portion of the sample was placed in a beaker, and approximately 100 mL of 1% metaphosphoric acid solution was added. The mixture was homogenized for 1 min and then centrifuged at 8000 rpm for 10 min. The supernatant solution was used to analyze the ascorbic acid concentration. The total quantity of AsA [mg] in the test sample was calculated by multiplying the measured content [mg/100 g fresh weight] by the initial sample weight [g]. There were distinct differences in the total AsA quantities between the samples. Therefore, the AsA content changes were evaluated by using the residual AsA content ratio, which was defined as the value obtained by dividing the total quantity of AsA in the dried sample by that of the initial sample before drying. The measurements of each sample at each temperature were repeated four to twelve times.

2.6. Antioxidant activity

The antioxidant activity of each sample was determined as described by Suda (2000). The diluted sample was pipetted into