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Novel high-humidity hot air impingement blanching (HHAIB) pretreatment enhances drying kinetics and color attributes of seedless grapes

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ABSTRACT

Seedless grapes blanched by high-humidity hot air impingement blanching (HHAIB) at different temperatures (90, 100, 110, and 120 °C) and several durations (30, 60, 90, and 120 s) were air-dried at temperatures ranging from 55 to 70 °C. The PPO activity, drying kinetics, and the product color parameters were investigated to evaluate the effect of HHAIB on drying kinetics and color of seedless grapes. The results clearly show that HHAIB not only extensively decreases the drying time but also effectively inhibits enzymatic browning and results in desirable green–yellow or green raisins. In view of the PPO residual activity, drying kinetics and color attributes, HHAIB at 110 °C for 90 s followed by air drying at 60 °C are proposed as the most favorable conditions for drying grapes. These findings indicate a new pretreatment method to try to enhance both the drying kinetics and quality of seedless grapes.

Industrial relevance: Drying grapes into raisins is a major processing method in almost all grape-growing countries. Drying grapes is more difficult than some other biological materials, since a thin-layer of wax covers on its surface peel. Currently, chemical pre-treatment methods are used frequently to dissolve the wax layer and accelerate dry rate. However, the chemical additive residue in the raisins may cause food safety problems and how to deal with larger quantities of corrosive chemicals is a serious problem. HHAIB is a new and effective thermal treatment technology with advantages such as minimum solids loss, uniform, rapid and energy-efficient blanching process. The current work indicates that HHAIB may be a useful non-chemical pretreatment technology for seedless grape drying, which can not only accelerate drying kinetics but also improve color parameters of seedless grape.

1. Introduction

According to Food and Agriculture Organization (FAO) data for 2011, grape production in the world was over 6.08×10^7 tons while China produced about 9.17×10^6 tons (FAO, 2011). China, Italy (about 7.12×10^6 tons), United States of America (about 6.69×10^6 tons), France (about 6.59×10^6 tons), Spain (about 6.10×10^6 tons), and Turkey (about 4.30×10^6 tons) are the six leading countries in grape production (FAO, 2011). Grapes as a seasonal fruit, having relatively high sugar content and moisture content, are very sensitive to microbial spoilage during storage. Therefore, after harvest grapes must be consumed or processed into various products in a few weeks in order to reduce economic losses. Drying grapes into raisins is a major processing method in almost all grape-growing countries (Pangavhane, Sawhney, & Sarsavadia, 1999).

Grapes have a peculiar structure of a peel covered with a thin-layer of wax. For this reason, drying grapes is more difficult than some other biological materials. A number of chemical pre-treatment methods are used to ameliorate the permeability of the grape skin to increase drying rate (Bingol, Roberts, Balaban, & Devres, 2012; Carranza-Concha, Camacho, & Martinez-Navarrete, 2011; Doymaz, 2006; Doymaz & Pala, 2002; Esmaiili, Sotudeh-Gharebagh, Mousavi, & Rezazadeh, 2007). Chemical pre-treatment consists of dipping grapes into an alkaline emulsion (generally containing ethyl oleate and K_2CO_3) for several minutes, by which the wax is dissolved, thus reducing the resistance to water diffusion through the skin. However, the chemical additive residue in the raisins may cause food safety problems and how to deal with larger quantities of corrosive chemicals is a serious problem. As organic foods becoming more and more popular, using of chemical additives in foods is being discouraged (Dev, Padmini, Adedeji, Gariépy, & Raghavan, 2008). Beside chemical pre-treatment, some physical pre-treatments have also been developed for drying grapes. For examples, Matteo, Cinquanta, Galiero, and Crescitelli (2000) treated the grapes with some abrasion of the peel prior to drying. They found that drying rate in this case was almost the same as that with the traditional ethyl oleate dipping treatment, but the final products were darker than those obtained from chemically treated samples. Feasibility of this process

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Nomenclature

a^*	redness/greenness
b^*	yellowness/blueness
C	Chroma
D_0	pre-exponential factor of Arrhenius equation (m^2)
d.b.	dry basis (kg water)/(kg dry solids)
D_{eff}	moisture effective diffusivity (m^2/s)
E_a	activation energy (kJ/mol)
ΔE	total color difference
H°	hue angle (°)
L^*	lightness
M_0	initial moisture content (kg water/kg dry matter)
Me	equilibrium moisture content (kg water/kg dry matter)
MR	moisture ratio (dimensionless)
M_t	moisture content at time t (kg water/kg dry matter)
n	positive integer
r	volume equivalent radius (m)
R	the universal gas constant (kJ/mol K)
R^2	coefficient of determination
t	drying time (s)
T	drying temperature (°C)
w.b.	wet basis (%)

on an industrial scale has not been considered. Therefore safer and more effective pretreatment methods should be explored to accelerate the drying behavior and yet keep good quality of raisins.

Among all the pre-treatment methods for drying fruits and vegetables, hot-water blanching is one of the most frequently used methods as it can accelerate drying rate and prevent quality deterioration by expelling intercellular air from the tissues, softening the texture, denaturing the enzymes and destroying microorganisms (Jayaraman & Gupta, 2007; Neves, Vieira, & Silva, 2012; Xiao et al., 2012). However, grape drying with hot-water pretreatment has not been reported in the literatures. The reason for this may be the special structure of grapes. Grape belongs to a class of berries rich in juice, so the sugars and other soluble components will be lost in hot-water once the peel of the grapes is cracked. Hence, hot-water blanching is not suitable for pre-treatment of grapes. Therefore, a new blanching technology is very desirable for grape drying.

High-humidity hot air impingement blanching (HHAIB) is a new and effective thermal treatment technology which combines the advantages of steam blanching and impingement technologies, resulting in minimum solids loss, a uniform, rapid and energy-efficient blanching process. In HHAIB jets of high-humidity hot air impinge on the product surface at high velocity to achieve a high rate of heat transfer. It has been observed that the heat transfer coefficient of HHAIB at the initial stage is about 1400 W/(m^2·K) at 14.4 m/s, 135 °C, and 35% as its velocity, temperature, and relative humidity, respectively, which is about 12 times of that of pure hot air impingement at the same temperature and velocity (Du, Gao, & Zhang, 2006). Furthermore, the materials are heated by steam or high humidity hot air, not dipped in water, which avoids loss of water-soluble nutrients during blanching. Xiao et al. (2012) found that appropriately HHAIB pretreatment can accelerate drying and improve the whiteness index of yam slices probably because of absence of oxygen. Bai, Gao, Xiao, Wang, and Zhang (2013) reported that HHAIB pretreatment is an effective pretreatment for Fuji apple quarters to inactivate PPO and meanwhile to maintain produce quality.

Color is one of the most important criteria determining quality and consumer preference of raisins (Jairaj, Singh, & Srikant, 2009). Raisins of green or gray–green color are acceptable in the international market and fetch better price. Browning reactions occurring in the drying process are caused mainly by enzymatic browning. The main step of enzymatic browning is the oxidation of phenolic compounds by polyphenol oxidase (PPO) in the presence of oxygen (Rapeanu, Loey, Smout, & Hendrickx, 2006). Besides, the presence of PPO is also generally considered detrimental to food quality from both sensory and nutritional points of view (Waliszewski, Márquez, & Pardio, 2009). The inactivation of PPO is very helpful to prevent grapes from browning and obtain good quality. Therefore, the analysis of the PPO activity of grape samples under different HHAIB pre-treatment is essential to understand and control the color changes of grapes during drying process.

The main objectives of the current work are: 1) to analyze the PPO activity in grape samples under different HHAIB conditions, 2) to evaluate the effect of HHAIB temperature and blanching time on drying kinetics of seedless grapes by drawing drying curves, determining the moisture effective diffusivity and activation energy, and 3) to examine the product color attributes in terms of lightness (L^*), Chroma value (C), hue angle (H°), and the total color difference (ΔE).

2. Materials and methods

2.1. Raw material

Fresh Thompson seedless grapes were purchased from a local market in Beijing, China. To ensure uniformity of physical characteristics of the experimental materials, the grape samples were carefully selected with the same size (average berry length, width, and weight are 18.4 mm, 12.3 mm and 3.34 g, respectively). The initial moisture content of samples was determined by vacuum drying at 70 °C for 24 h following the standard method (AOAC, 1990). The initial moisture content of the samples was found as 3.95 kg/kg in dry basis (d.b.) or 79.78% in wet basis (w.b.). All the grapes were stored in a refrigerator at 4 ± 1 °C and 90% relative humidity before the experiments were carried out.

2.2. HHAIB and impingement drying equipment

A schematic diagram of the equipment used for HHAIB treatment and impingement drying is shown in Fig. 1; it is located in the College of Engineering of China Agricultural University, Beijing, China. This equipment has previously been described in detail by Xiao et al. (2012) and hence this information is not repeated here. To apply HHAIB pretreatment the steam generator was turned on, and when the impingement drying experiments were carried out it was turned off.

2.3. HHAIB treatment and impingement drying experiments

The grapes were separated from the bunch and rinsed with distilled water to prepare samples free from dust and foreign material. The samples were dried and warmed up to the room temperature with a fan. To investigate the effect of HHAIB treatment and drying temperature on drying kinetics and products color of seedless grapes, experiments were carried out according to the list in Table 1. The sample weight was kept at 250.0 ± 0.5 g for all runs. After the drying chamber had reached steady state conditions for the set points (temperature 90, 100, 110 or 120 °C; relative humidity 40–45%), the samples were spread in a single layer on stainless steel wire grid in the drying chamber of impingement dryer. Then they were treated by the HHAIB for 30, 60, 90 or 120 s. The blanched grapes were cooled under ambient conditions at about 25 °C.

After HHAIB treatment, the samples were dried in the air impingement dryer described previously at temperatures of 55, 60, 65 and 70 °C according to Table 1. When the dryer was under steady state conditions for the set temperature, the samples were spread into a single layer onto a stainless steel wire mesh in the drying chamber. The weight loss was recorded on an electronic balance (SP402, Ohaus Co., New Jersey, USA) within the accuracy of ±0.01 g at 1 hour intervals during drying. Drying was stopped when the moisture content of the samples reached the final moisture content of 0.25 kg/kg (d.b.). The dried product was