Journal of Food Engineering 172 (2016) 9–18

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Drying characteristics and quality of grape under physical pretreatment

G. Adiletta [a], P. Russo [b,*], W. Senadeera [c], M. Di Matteo [a]

[a] Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II 132, 84084 Fisciano, SA, Italy
[b] Department of Chemical Engineering Materials Environment, University of Rome "La Sapienza", Via Eudossiana 18, 00184 Roma, Italy
[c] School of Chemistry Physics and Mechanical Engineering, Faculty of Science and Engineering, Queensland University of Technology, 2 George Street, Brisbane, QLD 4001, Australia

A R T I C L E I N F O

Article history:
Received 7 October 2014
Received in revised form
29 May 2015
Accepted 23 June 2015
Available online 27 June 2015

Keywords:
Grape
Drying
Abrasive pretreatment
Antioxidant activity
Shrinkage
Empirical models

A B S T R A C T

Grape drying is a slow and energy intensive process because the waxy peel has low permeability to moisture. Therefore, peel chemical and physical pretreatments are considered before drying in order to facilitate water diffusion. However, they cause heterogeneity in the waxes removal and problems during shelf-life.

In this paper an alternative abrasive pretreatment of grape peel, for enhancing the drying rate and preserving the samples, was applied to Red Globe grapes. Convective drying experiments were carried out at 40–70 °C and at 2.3 ms^{-1} air velocity. The effect of wax abrasive pretreatment on the drying kinetics and quality parameters of raisins was investigated. The results were compared with those of samples pretreated by dipping in alkaline ethyl oleate solution and untreated grapes. All the dried samples are darker than fresh one and shrunked. The samples pretreated by peel abrasion and dried at 50 °C showed the lowest color changes, less shrinkage and the best rehydration capacity. The drying kinetics and shrinkage curves were also analyzed using some commonly available empirical models.

1. Introduction

Grape is a non-climacteric fruit that grows on the perennial and deciduous woody vines of the genus *Vitis*. It contains large amounts of phytochemicals including phenolics, flavonoids, anthocyanins and resveratrol, which offer health benefits. Antioxidant compounds include vitamins, phenols, carotenoids, and flavonoids. Among the last group, flavones, isoflavones, flavanones, flavonols, anthocyanins and catechins are the most important, and exhibit substantial antioxidant activity (Wang et al., 1997). The high content of grapes in phenolics, flavonoids, and anthocyanins have been suggested to be responsible for their health benefits (Yang et al., 2009).

Grapes are one of the major dietary sources of anthocyanins, which are responsible for the coloring of black, red and purple grapes. Anthocyanins are reported to have antioxidant activity, anti-inflammatory activity, anticancer activity, apoptotic induction effect, α-glucosidase inhibition activity, vision benefits and effects on collagen, blood platelet aggregation and capillary permeability and fragility (Hou, 2003).

Grapes have relatively high sugar content and moisture content, are very sensitive to microbial spoilage during storage. Therefore, after harvest they 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. Traditionally raisins are obtained by sun drying of the fruit for 8–10 days, which substantially reduces water content. This drying method is cheap, but there is a risk of damage due to dust and insect infection (Pangavhane and Sawhney, 2002). An alternative to it is hot air drying. In general, the dehydration causes damages in texture, color, taste and nutritional value of food due to the high temperatures (60–75 °C) and long drying times required in the process (2–3 days) (Singh et al., 2012). According to Carranza-Concha et al. (2012), the dehydration of grapes affects their content of polyphenols, ascorbic acid and antioxidant activity. That is why efforts should be made to reduce drying times but also to decrease the temperatures used in the drying processes in order to obtain better quality products.

Drying of grape is difficult because grapes contain a wax outer peel layer which acts as a barrier to moisture movement across the

* Corresponding author.
E-mail address: paola.russo@uniroma1.it (P. Russo).

http://dx.doi.org/10.1016/j.jfoodeng.2015.06.031
0260-8774/

membrane. Therefore, various drying methods and pretreatments were investigated as reviewed by Esmaiili et al. (2007a).

Currently, chemical pretreatment methods are used frequently to dissolve the wax layer and accelerate drying rate (Bingol et al., 2012; Doymaz, 2006; Doymaz and Pala, 2002; Esmaiili et al., 2007b). Chemical pretreatment consists of dipping grapes into an alkaline solution, i.e. NaOH (Berna et al., 1991; Femenia et al., 1998; Carranza-Concha et al., 2012), or in oil emulsion: ethyl oleate and K_2CO_3 (Cinquanta et al., 2002; Doymaz, 2004) for several minutes. By this way, the wax is dissolved, thus reducing the resistance to water diffusion through the peel.

Doymaz and Pala (2002) studied the influence of dipping solutions such as ethyl oleate and potassium carbonate on drying time and color quality of dried untreated and pretreated grapes. They found that grapes dipped into alkaline emulsion of ethyl oleate showed shorter drying times than those untreated, or pretreated with potassium carbonate solution. About color analysis, the best results were obtained for grapes which were pretreated with ethyl oleate and dried at 60 °C.

Esmaiili et al. (2007b) studied the effect of different pretreatments (i.e. dipping in alkaline emulsion of ethyl oleate or in hot water) on moisture diffusivity of seedless grapes. They showed that both pretreatments activated the diffusion process by reducing the skin resistance to water transfer at the beginning of the process. The ethyl oleate pretreatment was found much more efficient by maintaining higher internal diffusivities at the end of the drying process. Moreover, the increase in mass transfer coefficients at different temperatures for the ethyl oletate pretreated samples was two times that for the hot water pretreated samples during the drying.

Vazquez et al. (1997), pretreating the grape peel by potassium carbonate solution, found the presence of micro-fissures in the grape peel.

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.

Beside chemical pretreatment, some physical pre-treatments have also been developed for drying grapes. An alternative physical pre-treatment, consisting of abrasion of the peel of grapes, was proposed by Di Matteo et al. (2000). They found that the pattern of the drying curves was quite similar for both chemical (alkaline ethyl oleate solution) and physical treated samples. Therefore, abrasion was found to be as effective as the traditional chemical method. The calculated mass transport coefficient for physical treated samples was about 4 times greater than that determined for untreated samples.

The same pretreatment was performed on plums, before drying at 60 °C, without significantly altering the qualitative characteristics of the plums, reducing drying time and causing a smaller loss of sugars (Cinquanta et al., 2002; Di Matteo et al., 2002).

The main purpose of this study was to investigate the effects of abrasive pre-treatment and of air drying conditions (i.e. temperature) on the quality properties of raisins, with the aim of produce minimally processed high quality raisins. We then compared the results with those relevant to raisins obtained by grape pretreated with alkaline ethyl oleate solution and untreated raisins.

Moreover, in order to represent the observed change in moisture during drying experiments, data of moisture ratio were fitted using empirical models available in the literature.

Since shrinkage influences drying and consequently rehydration, it has to be taken into account in mathematical modeling of such processes. Several types of models predicting volume changes are also available in the literature (Brasiello et al., 2013; Khalloufi et al., 2009; Mayor and Sereno, 2004). Some empirical models were here tested to verify their ability to represent experimental data of shrinkage volume during drying.

2. Materials and methods

2.1. Sample preparation

Red grapes (*Vitis Vinifera)* cv. *Red Globe* with an initial moisture content of 6.43 ± 0.02 kg water/kg db and average diameter of 24.4 ± 1.95 mm were used for the experiments. The fresh grape berries with uniform size and color and without surface damage or diseases were selected for the experiments and stored at 4 ± 0.1 °C before handling (up to 12 h).

Three kinds of samples were compared in this study: untreated grape (UTR), abraded grape (TR-Abr) and dipped grape in chemical solution (TR-EtOl).

Before drying, TR-Abr samples were submitted to a physical abrasive pretreatment. The abrasion of the grape peel was carried out in a motorized rotating drum ($D = 240$ mm, $L = 250$ mm) made of plexiglass, lined inside with sandpaper (US CAMI grit 400). The rotation speed of drum was 10 rpm, the pretreatment time was 15 min and the mass of grapes was 4 kg.

TR-EtOl samples were dipped in an aqueous solution of 2% (v/v) ethyl oleate and 2.5% (v/v) Na_2CO_3 at 40 °C for 3 min.

2.2. Drying experiments and empirical models

Drying of grapes was carried out in a convective dryer (*Zanussi FCV/E6L3*) at constant temperature at 40, 50, 60 and 70 °C and at air velocity of 2.3 m/s until the water content plateau was reached (about 0.30 kg water/kg db). During drying at regular intervals the samples were weighted by means of a digital balance (mod. Gibertini E42, Italia).

The results were reported in terms of M_t/M_0 vs time (min), where M_t was the moisture content (kg water/kg db) at a given drying time and M_0 was its initial value. They are reported as average of three sets of experiments.

All the raisins obtained by different pretreatment and at different drying temperatures were then characterized.

Empirical models that are commonly applied for vegetable food materials were here adopted (Table 1). The empirical constants for the drying models were determined experimentally from normalized drying curves (moisture ratio $M_R = M_t/M_0$ vs time) at each drying temperature. Non-linear least square regression analysis was used to evaluate the parameters of the selected model with the Levenberg–Marquardt procedure. The goodness of fit for each model was evaluated based on the statistical parameters R^2, and χ^2, RMSE calculated as follows:

$$\chi 2 = \frac{\sum_{i=1}^{N}\left(M_{R_{\exp,i}} - M_{R_{\mathrm{pre},i}}\right)^2}{N - z} \tag{1}$$

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(M_{R_{\mathrm{pre},i}} - M_{R_{\exp,i}}\right)^2\right]^{1/2} \tag{2}$$

The reduced χ-square is the mean square of the deviations between the experimental and calculated values for the models. The lower the values of the reduced χ-square, the better the goodness of the fit. The RMSE, root mean square error, gives the deviation between the predicted and experimental values and it is required to reach zero.

2.3. Color

For all samples, color was obtained through a colorimeter Minolta Chroma Meter II Reflectance CR-300 (triple flash mode