LWT - Food Science and Technology 80 (2017) 178–184

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Effect of hybrid drying methods on physicochemical, nutritional and antioxidant properties of dried black mulberry

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A R T I C L E I N F O

Article history:
Received 15 October 2016
Received in revised form
7 February 2017
Accepted 10 February 2017
Available online 17 February 2017

Keywords:
Explosion puffing drying
Colour
Texture
Antioxidant activity
Anthocyanin content

A B S T R A C T

The effect of hot air drying (HAD), freeze drying (FD), hot air-explosion puffing drying (HA-EPD) and freeze-explosion puffing drying (F-EPD) on the physicochemical, nutritional and antioxidant properties of black mulberries were investigated. F-EPD products showed the best texture attributes (hardness *29.46 N*, crispness *30*, rehydration ratio *1.65 g/g*), better colour (hue angle of 0.03) and the highest overall score of sensory evaluation. Although the highest retention of anthocyanin contents and antioxidant activities were found in FD samples, the products had the lowest crispness (*3*). Compared to HA-EPD and HAD, higher content of anthocyanin (*12.38 mg/g*), cyanidin-3-glucoside (*8.60 mg/g*) and cyanidin-3-rutinoside (*2.62 mg/g*) remained in F-EPD products, as well as DPPH scavenging ability and ferric reducing power (*91.53* and *120.59* mg trolox equivalent/g, respectively). Hence, F-EPD could be a more promising technique to develop the dried products of black mulberries. Correlation analysis results showed that cyanidin-3-glucoside content had significant positive correlation with antioxidant capacity.

1. Introduction

Black mulberries (*Morus nigra* L.) are a kind of juicy fruit with extraordinary colour and special acidic flavour which have been cultivated and grown over thousands of years throughout Asia, Africa, North America, and southern Europe. Black mulberries have commonly been used in traditional Chinese medicine to treat diabetes, hypertension, anaemia and arthritis (Özgen, Serçe, & Kaya, 2009). Thanks to their bioactive contents of polyphenolic and anthocyanins (Aramwit, Bang, & Srichana, 2010; Liang et al., 2012), the functional activities of black mulberries have been extensively reported in the literature, including antioxidant (Song et al., 2009), anticancer (Wang & Stoner, 2008), neuroprotective (Kim et al., 2010), hypolipidemic (Yang, Yang, & Zheng, 2010), anti-atherosclerosis (Chen et al., 2005) and anti-obesity (Wu et al., 2013). However, owing to their short harvesting season, high moisture content and sensitivity to storage, fresh black mulberries can only be kept for several days in a fridge.

Drying is one of the most used methods for processing and preserving black mulberries. Single drying methods including solar drying, air drying, vacuum drying and spray drying for the black mulberries were reported in the literature (Akbulut and Durmuş, 2009, 2010; Doymaz & Pala, 2003; Fazaeli, Emam-Djomeh, Ashtari, & Omid, 2012). Recently, more attention is paid to the hybrid drying method, a combined drying approach which utilises one or more drying techniques to compensate for the disadvantages of using only a certain drying method (Yi et al., 2016a). Chemical, mechanical and blanching pre-treatments were used in hybrid drying. These results showed that hybrid drying is a more economical and promising method for drying agro-products owing to its advantages in energy saving and product quality improvement (Chottamom, Kongmanee, Manklang, & Soponronnarit, 2012; Esmaeili Adabi, Motevali, Nikbakht, & Khoshtaghaza, 2013a; Esmaeili Adabi, Nikbakht, Motevali, & Seyedi, 2013b).

Explosion puffing drying (EPD) is a relatively new drying technique which involves the release or expansion of vapour or gas that could create products with porous structure (Zou, Teng, Huang, Dai, & Wei, 2013). EPD is performed at an intermediate stage in the drying process, often in conjunction with the other drying methods like hot air and freeze drying. Fruits including apple, raspberry, mango and jackfruit dried by EPD were investigated in the literature (Yi et al., 2016a; Si et al., 2016; Zou et al., 2013; Yi, Zhou, Bi, Wang, Liu, & Wu, 2016b), but there is little about the study of EPD on black mulberries. Hence, the objective of this present study is to investigate the effect of hybrid drying methods (hot air -

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http://dx.doi.org/10.1016/j.lwt.2017.02.017

Nomenclature

HAD	hot air drying
FD	freeze drying
HA-EPD	hot air and explosion puffing drying
F-EPD	freeze and explosion puffing drying
d.b.	dry basis moisture content (g/100 g)
w.b.	wet basis moisture content (g/100 g)
RR	rehydration ratio
TAC	total anthocyanins content (mg/100 g d.b.)
GAE	gallic acid equivalent
TPC	total phenolic content ((mg GAE/g db)
TE	trolox equivalent
C-3-G	cyanidin-3 -glucoside content (mg/100 g d.b.)
C-3-R	cyanidin-3-rutinoside content (mg/100 g d.b.)

explosion puffing drying (HA-EPD), freeze - explosion puffing drying (F-EPD)) on the physicochemical, nutritional and antioxidant properties of dried black mulberries. Hot air drying and freeze drying are included in this paper for comparative study.

2. Materials and methods

2.1. Samples preparation

Fresh black mulberries were picked from a local farm (Beijing, China) with an initial moisture content of 85.6 ± 0.1 g/100 g (wet basis, w.b.), determined by the method of AOAC (1984). Fresh black mulberries were then quick-frozen using liquid nitrogen and stored at −40 °C for further use.

2.2. Reagents

Sodium acetate, potassium chloride, HCl, $FeCl_3 \cdot 6H_2O$, methanol and Folin-Ciocalteu reagent were of analytical grade and purchased from Sinopharm Chemical Reagent Co. Ltd. Beijing, China. Formic acid (HPLC grade), acetonitrile (HPLC grade), gallic acid (purity ≥ 97.5%), 1,1-diphenyl-2-picrylhydrazyl radical (DPPH, purity ≥ 99.0%), 6-hydroxy-2,5,7,8 -tetramethylchromane -2-carboxylic acid (Trolox, purity ≥ 99.0%) and 2,4,6-tripyridyl-1,3,5-triazine (TPTZ, purity ≥ 99.0%) were obtained from Sigma-Aldrich Co. LLC (Shanghai, China). Cyanidin-3-glucoside and cyanidin-3-rutinoside were obtained from ChromaDex company (CA, USA).

2.3. Equipment and drying methods

Frozen black mulberry fruits were first thawed at room temperature for 30 min, and then dried using four different drying process: hot air drying (HAD) (DHG-9123A, Jing Hong Laboratory Instrument Co. Ltd, Shanghai, China); freeze drying (FD) (Alpha 1-4LD plus, Marin Christ, Osterode, Germany); hot air and explosion puffing drying (HA-EPD) (QDPH10-1, De le New Material Technology Co. Ltd. Tianjin, China.) and freeze and explosion puffing drying (F-EPD). The drying conditions for four different drying methods are presented in Table 1. The moisture contents of dried black mulberry fruits were all around 7% (w. b.). All the dried black mulberry fruits were packaged in aluminium foil bags and stored in a fridge at 4 °C.

2.4. Sample extraction

Methanol-water extraction method was used according to the method reported by Si et al. (2016). Initially, fresh black mulberry fruit (5 g) or dried black mulberry fruit (2 g) were crushed by a pulverizer (JYL B060, Joyoung Co. Ltd, Shandong, China) for 5 min. The black mulberry pulp or powder were mixed with 30 ml of methanol—water solution (80:20, mL: mL) in a test tube which was then placed in the dark at room temperature for 16 h. Ultrasonic extraction was then used at a frequency of 40 kHz for 30min, followed by centrifugation at 9408×g for 10 min. The supernatants were collected (25 ml) and filtered through a 0.45 μm filter for further analysis of anthocyanin and phenolic content and antioxidant capacity.

2.5. Colour

Colour change was measured before and after drying of mulberry fruit with a colorimeter (D25L, Hunterlab Co. Ltd, Reston, USA). The fresh and dried black mulberry fruits were first crushed by a pulverizer for 5 min, the black mulberry pulp or powders (20 g) were then used for colour determination. Colour was expressed as L^* (lightness/darkness), a^* (redness/greenness), b^* (yellowness/blueness), h° (hue angle) and C^* (chroma). h° and C^* were calculated using the following expressions (Si et al., 2016):

$$h^\circ = \arctan(b*/a*) \tag{1}$$

$$C* = \sqrt{a*^2 + b*^2} \tag{2}$$

Where L^*, a^*, and b^* are the values of dehydrated mulberry fruits. The measurements were performed in triplicate.

2.6. Hardness and crispness

The hardness and crispness of dehydrated black mulberry fruit were measured using the TA-XT2i/50 texture analyser (Stable Micro Systems Ltd, Vienna Court, Surrey, UK) according to the method of Si, Chen, Bi, Yi, Zhou, & Wu (2015). The maximum force (N) and the numbers of peaks (n) were used to express the values of hardness and crispness. The experiments were done in ten replications and the average values were calculated.

2.7. Rehydration ratio and bulk density

5 g of dried black mulberry fruit were rehydrated in 100 ml of distilled water at 70 °C for 10 min and the rehydrated ratio (RR) was calculated using Eq. (3).

$$RR = \frac{M_r}{M_d} \tag{3}$$

Where, M_d is the weight of dehydrated mulberry (g) and M_r is the weight of rehydrated mulberry (g).

Bulk density (ρ) of dried black mulberry was measured and calculated by the means of quartz sand replacement (Pei et al., 2014) using the following expression:

$$\rho = \frac{m}{v} \tag{4}$$

Where, m is the weight of dried black mulberry (g) and v is the volume of dehydrated mulberry (cm^3).