Advanced Powder Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Advanced Powder Technology

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

Original Research Paper

Functional relationships between phytochemicals and drying conditions during the processing of blackcurrant pomace into powders

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ARTICLE INFO

Article history:
Received 13 June 2016
Received in revised form 23 November 2016
Accepted 5 March 2017
Available online xxxx

Keywords:
Ribes
By-products
Convective drying and microwave vacuum drying
Bioactive compounds
Functional relations

ABSTRACT

The effect of convective drying, microwave-vacuum drying and their combination applied to blackcurrant by-product on the quality being measured in terms of the content of phytochemicals in the powders was examined. Convective drying, along with the increase in the temperature, linearly reduced the content of anthocyanins, flavonols and chlorogenic acids. Microwave vacuum drying significantly shortened the drying time, and resulted in higher retention of bioactive compounds at higher temperatures in comparison to convection. No functional relationship was observed between bioactive compounds and the power of magnetrons thus between the processing temperature and the content of individual groups of polyphenols, apart from delphinidin-3-*O*-rutinoside and delphinidin-3-*O*-glucoside. During the dehydration of blackcurrant pomace the exponential formation of hydroxymethylfurfural was noticed. The antioxidant capacity decreased along with the increase in drying temperature and in parallel with the decrease in anthocyanins content, thus suggesting that those polyphenols considerably influence the antioxidant potential of final products.

1. Introduction

Blackcurrant (*Ribes nigrum* L.) is a deciduous shrub naturally growing in Northern and Central Europe and in some regions of Asia. According to FAO, the Russian Federation is the world's biggest producer of blackcurrant with production of about 373 thousand tones in 2013 [1]. The second largest producer is Poland with an output of 197 thousand tones. Poland is also the export leader for both fresh and processed blackcurrant; its exports account for about 80% of global exports of frozen blackcurrant and 90% of global exports of blackcurrant juice concentrate. Blackcurrant is rich in many substances that are beneficial to human health. They include notably polysaccharides, unsaturated fatty acids, vitamins, organic acids, anthocyanins and flavonoids [2]. In recent years, polysaccharides contained in currants have drawn scientific attention due to their anticarcinogenic and immunostimulatory (antioxidant, anti-inflammatory, antimicrobial) activity [3]. Strathearn et al. [4] compared the effectiveness of extracts from six plant species rich in bioactive compounds in preventing the Parkinson's disease and found that blackcurrant extract, containing high levels of anthocyanins and proanthocyanidins had a much better neuroprotective effect than extracts from other plants.

Also pomace, a by-product of blackcurrant juice production, is a valuable source of polyphenolic compounds with proved excellent antiradical properties [5]. Using processed pomace as an additive in food products may be an excellent method to compensate for a short period of supply of fresh blackcurrant. From the industrial point of view, the most practical and convenient way of applying processed blackcurrant pomace is the form of powders obtained by drying the fruit material. Drying, which reduces water activity in the products, thus hindering the development of microorganisms, is one of the oldest, and therefore the best known, methods to preserve fruit and vegetables [6], and fruit powders can be very easily added to various food products [7].

Drying involves a number of physical and chemical changes in the processed material [8–10], the most important chemical reactions being enzyme activity deactivation or acceleration, color or

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http://dx.doi.org/10.1016/j.apt.2017.03.002
0921-8831/

Please cite this article in press as: A. Michalska et al., Functional relationships between phytochemicals and drying conditions during the processing of blackcurrant pomace into powders, Advanced Powder Technology (2017), http://dx.doi.org/10.1016/j.apt.2017.03.002

vitamin oxidation and cell membrane denaturation [11] and the Maillard reactions [12]. Thus, developing an understanding of how drying induces the changes in the chemical composition of fruit material, especially the content of biologically active compounds, could help in choosing the best drying method.

Convective drying (CD) is considered the most popular drying method applied to plant material [13] owing to a favorable cost-efficiency ratio it allows to achieve for large quantities of dried product [14]. However, convective drying involves long processing times, which leads to the aeration and, consequently, strong oxidation of valuable bioactive components [15], as well as to the loss of aromatic compounds and color [16]. The drying time can be shortened by reducing air pressure, and thus by increasing the vaporization of water in fruit material [9], as is the case in vacuum drying (VD) or microwave vacuum drying (MVD). Both methods are recommended to avoid the disintegration of biologically active compounds [11].

Freeze drying (FD) is based on sublimation, i.e. the transformation from ice to vapor without passing through the liquid phase. FD enables to better preserve total bioactive compounds in fruits as compared with air drying [17], and therefore is generally recommended for the drying of foodstuffs containing heat-sensitive antioxidant components, such as plant phenolics [18].

Microwave drying is a new addition to the existing drying techniques, and is used as an alternative to convective air-drying (cabinet, flat bed, tunnel), spray, vacuum, foam mat and freeze-drying [19]. During microwave drying, microwave energy is converted into heat by the agency of water present in food. This enables to significantly reduce the drying time and to ensure high quality of the finished product [20].

Microwave-vacuum drying (MVD) has been investigated as a potential method for obtaining high quality dehydrated food products including fruits, vegetables and grains. MVD combines the advantages of both microwave heating and vacuum drying. During MVD drying, the energy of microwaves is absorbed by water located in the whole volume of the material being dried. This creates high vapor pressure in the center of the material, allowing rapid transfer of moisture to the surrounding vacuum and preventing structural collapse. This process, well known as the puffing phenomenon, creates a porous texture of the food and in this way reduces its density [21].

The quality of dried fruit evaluated in terms of the content of bioactive compounds, such as anthocyanins [22], flavonoids [23], hydroxymethylfurfural [24,25] and the total antioxidant capacity [26] is an important criterion used in the evaluation and optimization of novel drying technologies [27] as well as the functional properties of the products [23]. The latest trends in food science are focused on dried fruit-based functional products as dewatering of fruits ensure their availability with health benefits all over the year time [23]. The production of functional fruit powders required the thorough knowledge of the processes and the material subjected to the drying as numerous relationships between the biologically active components and process parameters may occurred during drying that might influence the quality of the final products as well as the costs of their production. Gaining the knowledge about the content of biologically active components and their alterations caused by different drying technologies has an influence on the design of the functional products. Thus, the aim of the study was to measure the levels of anthocyanins, flavonols and phenolic acids and the antioxidant capacity of blackcurrant pomace powders obtained using convective drying (CD), microwave vacuum drying (MVD) and combined drying (CD-MVD) as well as applying different drying parameters (such as temperature and wattage), and to compare those levels with the levels found in non-processed material. Another goal of the research was to identify, and to measure the level of, hydroxymethylfurfural, which a potentially harmful compound, and thus also a possible quality indicator in pomace processing. Further, a functional relationship was examined between the content of selected blackcurrant pomace constituents and processing temperature.

2. Material and methods

2.1. Reagents

Hydroxymethylfurfural, Trolox®, 2,4,6-tris(2-pyridyl)-s-triazine were purchased from Sigma–Aldrich (Switzerland). Delphinidin-3-*O*-glucoside, malvidin-3-*O*-galactoside, cyanidin-3-*O*-glucoside and quercetin-3-*O*-glucoside, quercetin-3-*O*-rutinoside, myricetin-3-*O*-galactoside, kaempherol-3-*O*-glucoside were from Extrasynthese (Lyon, France). Chlorogenic and neochlorogenic acids were obtained from TRANS MIT GmbH (Giessen, Germany). Acetonitrile for UPLC (Gradient Grade) was from Merck (Darmstadt, Germany). UPLC grade water prepared using the HLP SMART 1000 s system (Hydrolab, Gdansk, Poland) was additionally filtrated through a 0.22 μm membrane filter.

2.2. Material

Frozen blackcurrants were purchased from a local market; their initial moisture content was 2.3 kg kg^{-1} db. The fruit was ground by a Thermomix (Wuppertal, Vorwerk, Germany) and pressed in a laboratory hydraulic press (SRSE, Warsaw, Poland). Pomace obtained after pressing was thoroughly mixed and directly subjected to different drying methods.

2.3. Drying methods

Blackcurrant pomace (≈500 g) was dehydrated by freeze-drying (FD) (OE-950, Hungary) for 24 h at 65 Pa. Afterwards, the samples were vacuum packed and submitted to analyses.

Convective drying (CD) was carried out in a pilot-scale laboratory dryer designed at the Institute of Agricultural Engineering (Wrocław University of Environmental and Life Sciences, Poland). Portions of blackcurrant pomace (≈100 g) were placed in a tray (of diameter 100 mm) and dried at air temperatures: 50 °C, 60 °C, 70 °C, 80 °C and 90 °C with a constant air velocity of 0.8 m s^{-1}. The dehydration process was performed until the pomace reached the moisture content below 0.065 kg kg^{-1}. This moisture content is acceptable in terms of microbiological safety and enables a grinding process that was confirmed by preliminary tests.

Microwave vacuum drying (MVD) was done in a Plazmatronika SM 200 dryer (Wrocław, Poland) [28] at constant power: 120 W, 240 W, 360 W and 480 W. Samples (≈100 g) were located in a cylindrical container of organic glass (18 cm of diameter and 27 cm of length) and the temperature of samples was measured with an infrared camera Flir i50 (Flir Systems AB, Sweden) immediately after taking them out of the dryer. The external temperature of the most heated samples was recorded. It was assumed that the temperature measured with this method reflected the changes in mean temperature during MVD. The direct measurement of the temperature of samples under microwave radiation at vacuum conditions is problematic [28]. For this reason a care should be taken when comparing the values of temperature recorded using an infrared camera with the values of temperature chosen for CD. Combined drying (CPD-MVFD) consisted of convective pre-drying (CPD) of 100 g of blackcurrant pomace at temperatures 50 °C, 60 °C, 70 °C, 80 °C and 90 °C until achieving the pre-established moisture content of ca. 0.25 kg kg^{-1} db, followed by MV finish-drying (MVFD) with microwave wattage adjusted to