Innovative Food Science and Emerging Technologies 37 (2016) 115–124

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

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

Evaluation of ball-milling time on the physicochemical and antioxidant properties of persimmon by-products powder

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ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form 4 August 2016
Accepted 4 August 2016
Available online 5 August 2016

Keywords:
Persimmon
By-products
Ball-mill
Physicochemical
Antioxidant
Food

ABSTRACT

Persimmon by-products are known to contain higher bioactive constituents and biological activities than several other plant by-products. The present study investigated the effect of ball-milling time on the physico-chemical and antioxidant properties of persimmon seed, peel and calyx powders. The by-products were ball-milled using a planetary ball-mill for different periods of time. Increasing ball-milling time from 12 to 24 h improved the specific surface area, solubility, and DPPH radical scavenging activities of all by-products. The variable milling time also did not have any deleterious effect on bioactive constituents, reducing power and iron chelating abilities of seed powder. Ball-milling reduced the water holding capacity of all by-products but did not affect the oil holding capacity. Based on FTIR spectroscopy, increasing milling time did not alter the major constituents of all the by-products. Thus, longer ball-milling time (24 h) at relatively higher rpm (500 rpm) has the potential to produce superfine powders with improved physicochemical and antioxidant activities, thereby adding value to various applications including food.

Industrial relevance: Cost effectiveness and eco friendliness are major consideration in the processing of materials. Planetary ball-mill treatment offers an alternative processing method for the utilization of fruit and vegetable industrial wastes. Owing to the nature of some materials, understanding processing time can help in the prediction and regulation of physicochemical, technological and antioxidant properties of materials.

1. Introduction

Plant by-products offer increased value to food and pharmaceutical products through a variety of phytochemicals (Guendez, Kallithraka, Makris, & Kefalas, 2005). Plant by-products including fruit and vegetable industrial wastes such as seeds, peels, pips, skins, stems, and cores can be untapped sources of bioactives (O'Shea et al., 2012). Persimmon (*Diospyros kaki*) peel contains greater quantities of polyphenols and carotenoids than those in the pulp (Gorinstein et al., 1994). Persimmon peel extracts possess medicinal value (anti-tumor and multidrug resistance reversing activities) and cosmetic value (whitening effect due to tyrosinase inhibition) (Fukai et al., 2009; Kawase et al., 2003). It has been reported that persimmon seed extracts have higher radical scavenging activities and higher total tannin concentration than those of other seed extracts such as grape seed extracts (Ahn et al., 2002). Persimmon calyx is effective for treating intractable hiccups, particularly centric hiccups rather than peripheral hiccups (Saito, Uno, Honda, & Watanabe, 2001). Lignin present in persimmon calyces contains high polyphenols content (Matsuura and Iinuma, 1985). However, these active compounds are not effectively absorbed due to their large and complex structures or decreased solubility (Ma et al., 2009). Furthermore, extraction of phyto-chemicals through physical (e.g., ultrasound) and chemical methods (e.g., solvent extraction) have major disadvantages such as low extractability, remnants of hazardous chemicals, and inability of some solvents to penetrate deeply into tissues (Huang, Xie, Chen, Lu, & Tong, 2008; Puri, Sharma, & Barrow, 2012). In addition, disposing of plant by-products to landfills or by incineration is not only expensive, but also detrimental to the environment (Angulo et al., 2012; Leroy, Bommele, Reheul, Moens, & De Neve, 2007).

Ball-milling is an efficient cost-effective grinding method that is not detrimental to the environment (Liu, Ma, Yu, Shi, & Xue, 2011). A schematic depiction of the principle of ball-milling operation is shown in Fig. 1A. The container with the sample rotates on its axis (angular velocity ω) while the supporting main disk revolves in the opposite direction (angular velocity Ω), thus creating a centrifugal force. This causes the balls to move in a certain direction and hit the wall of the container and with each other, leading to impact effect and attrition effect (Loh, Samanta, & Heng, 2015). Ball-milled samples contain reduced particles size, resulting in increased surface area with improved bioavailability, absorption, and distribution (Huang et al., 2007; Zhao, Yang, Gai, &

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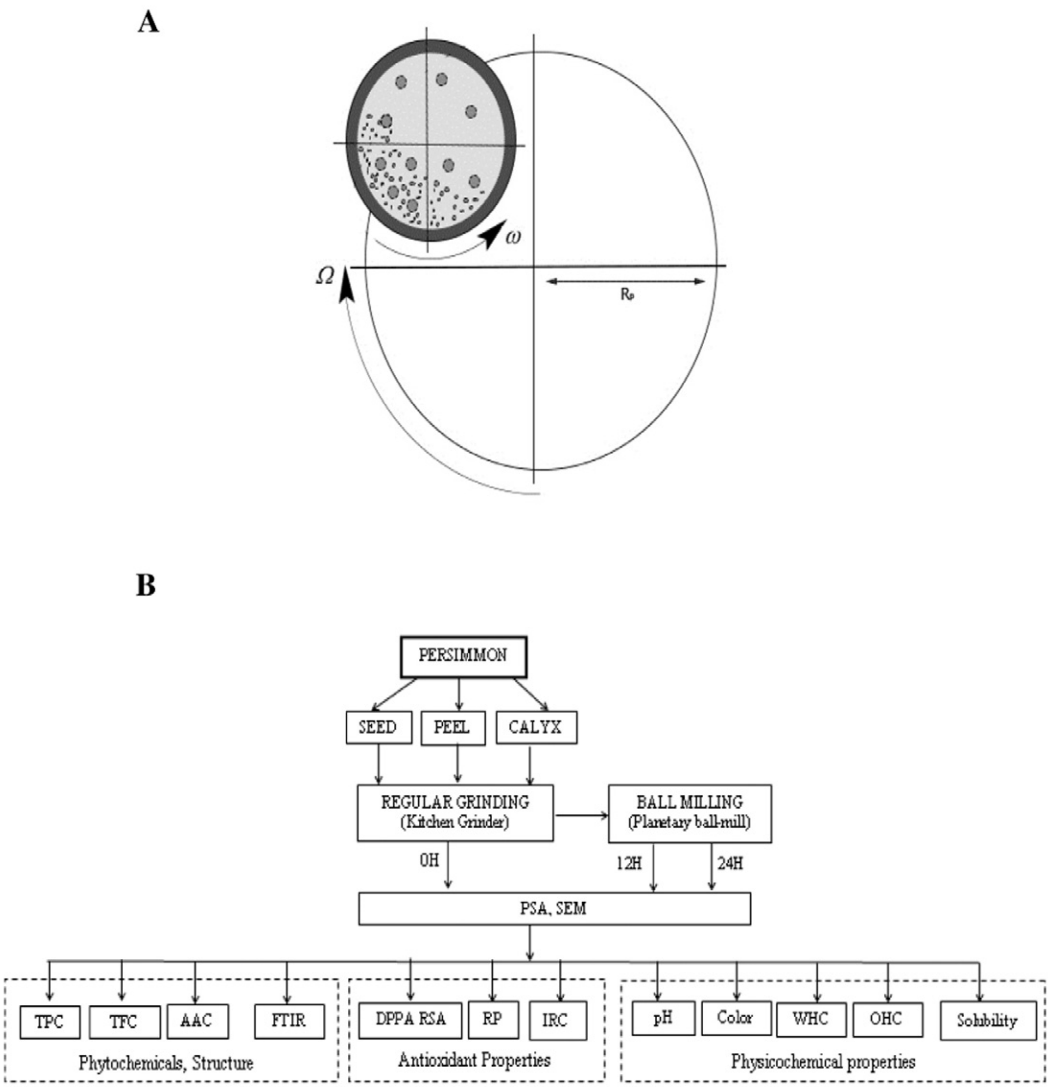

Fig. 1. (A) Schematic depiction of a ball mill; (B) procedural flow chart illustrating particle size reduction of persimmon by-products and its effect on physicochemical, technological and antioxidant properties.

Yang, 2009). Several operational variables influence the ball milling process including milling speed, time, ball to powder ratio and volume of the milling media (Rizlan & Mamat, 2014). Among these variables, milling time needs to be optimized so as to save production time, energy and costs. Although contingent upon material type, prolonged milling causes steady state particle size reinforcement and extending milling time is often undesirable (Basu & Balani, 2011). It is reported that longer milling time can lead to formation of defects in some drug materials that in turn may alter the structure of such materials (Loh et al., 2015). Therefore, ball-milling time can cause changes in structure and physico-chemical properties of materials. Some examples with reduced particle size have improved physicochemical properties, such as ginger

Table 1
Particle size distribution of persimmon by-products as affected by ball-milling time.

	Ball-milling time (h)	Dv 10 (μm)	Dv 50 (μm)	Dv 90 (μm)	Span	Surface area (m^2/g)
Seed	0	12.73 ± 0.02^a	82.60 ± 0.56^a	280.61 ± 6.87^a	3.20 ± 0.06^b	0.234 ± 0.03^c
	12	3.79 ± 0.04^b	21.14 ± 0.37^b	64.00 ± 0.17^c	2.86 ± 0.02^c	0.698 ± 0.07^b
	24	2.87 ± 0.05^c	18.46 ± 0.38^c	74.02 ± 3.00^b	4.03 ± 0.01^a	0.805 ± 0.01^a
Peel	0	15.57 ± 0.14^a	60.82 ± 0.40^a	157.75 ± 1.58^b	2.36 ± 0.01^c	0.249 ± 0.01^c
	12	6.29 ± 0.08^b	42.73 ± 1.75^b	181.10 ± 6.47^a	4.75 ± 0.03^a	0.387 ± 0.05^b
	24	3.38 ± 0.05^c	18.26 ± 0.74^c	72.74 ± 3.80^c	3.53 ± 0.02^b	0.739 ± 0.04^a
Calyx	0	10.42 ± 0.12^a	79.74 ± 3.51^a	482.46 ± 45.34^a	6.41 ± 0.17^a	0.276 ± 0.04^c
	12	2.50 ± 0.01^b	17.01 ± 0.12^b	61.69 ± 1.69^b	3.38 ± 0.01^b	0.920 ± 0.03^b
	24	2.33 ± 0.01^c	17.13 ± 0.03^b	63.13 ± 0.84^b	3.45 ± 0.04^b	0.952 ± 0.01^a

Dv 10, Equivalent volume diameter at 10% cumulative volume; Dv 50, Equivalent volume diameter at 50% cumulative volume; Dv 90, Equivalent volume diameter at 90% cumulative volume; Span, width of the particle size distribution.

$^{a–c}$Means with different superscripts in the same column are different ($p < 0.05$).