LWT - Food Science and Technology 43 (2010) 1253–1264

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Effects of refrigerated storage and processing technologies on the bioactive compounds and antioxidant capacities of 'Marion' and 'Evergreen' blackberries

Ruyi Wu [a], Balz Frei [b], James A. Kennedy [a,1], Yanyun Zhao [a,*]

[a] Department of Food Science & Technology, Oregon Sate University, Corvallis, OR 97331, USA
[b] Linus Pauling Institute, Oregon Sate University, Corvallis, OR 97331, USA

ARTICLE INFO

Article history:
Received 8 April 2009
Received in revised form
8 April 2010
Accepted 9 April 2010

Keywords:
Blackberries
Bioactive compounds
Antioxidant capacities
Refrigeration
Freezing
Drying
Canning
Jamming
Processing
Storage

ABSTRACT

The effects of refrigerated storage at 2 °C and 95% RH and processing treatments on the bioactive compounds and antioxidant capacities of 'Marion' and 'Evergreen' blackberries were investigated. During refrigerated storage, total phenolics (TPC), total monomeric anthocyanins (ACY), and radical scavenging activity (RSA) fluctuated in 'Marion', but TPC and ACY continuously declined in 'Evergreen'. Oxygen radical absorbance capacity (ORAC) and ferric reducing antioxidant power (FRAP) decreased by 20% and increased by 19% in 'Evergreen', respectively after 7-d refrigerated storage, while no changes ($P > 0.05$) in 'Marion' were observed. Compared with frozen samples, freeze-dried 'Evergreen' had higher TPC (21%), ACY (5.5%), and RSA (14%), while hot-air dried "Marion" had lower ACY (56%), ORAC (37%), and FRAP (27%) and hot-air dried 'Evergreen' had lower TPC (37%), ACY (84%), and RSA (13%). ORAC and FRAP in canned 'Marion' was 21–61% lower than that of frozen samples. Jam also had lower TPC and ACY (67–84%), RSA (80%), and ORAC and FRAP (65–77%) values than frozen ones in both varieties ($P < 0.05$). The 6-mo post-process room storage had little effect on the bioactive compounds of frozen and freeze dried samples, but reduced ACY in hot-air dried, canned, and jam samples, and antioxidant capacities of all samples ($P < 0.05$).

1. Introduction

Berry fruits have been widely recognized as an excellent source of bioactive phenolic compounds including flavonoids, phenolic acids, and tannins (Seeram, 2008a), that both individually and synergistically may help protect against cardiovascular disease, cancer, inflammation, obesity, diabetes, and other chronic diseases (Kraft et al., 2008; Liu, 2007; Liu et al., 2000; Prior et al., 2008; Seeram, 2008b; Shukitt-Hale, Lau, & Joseph, 2008).

Blackberries contain high concentrations of anthocyanins and ellagitannin and have high antioxidant activity and a desirable flavor (Hager, Howard, Liyanage, Lay, & Prior, 2008; Hager, Howard, & Prior, 2008; Siriwoharn & Wrolstad, 2004; Siriwoharn, Wrolstad, Finn, & Pereira, 2004). The production of blackberries in the United States was 35,099 tons in 2005, which accounted for the highest portion of the worldwide production of blackberries (Strik, 2007). Unfortunately, the fragility and high post-harvest respiration rate of blackberries contributes significantly to their nutritional and microbiological deterioration, resulting in limited shelf-life and diminished quality and health benefits (Bower, 2007). Refrigerated storage is the most common practice used for fresh blackberry preservation (Antunes, Duarte, & De Souza, 2003; Perkins-Veazie, Collins, & Clark, 1999; Perkins-Veazie & Kalt, 2002).

Most fresh blackberries are converted into frozen, dried, and canned products, or processed into jams, jellies, and juices for longer storage to satisfy various markets and consumer demands (Rickman, Barrett, & Bruhn, 2007). Freezing is generally considered to be the least destructive preservation technology for phenolic compounds in berries and is recommended as a pretreatment for manufacturing other berry products, although the physical and nutritional quality of frozen fruit can be affected by freezing method, packaging material, storage conditions, variety, and maturity stage (Zhao, 2007).

Drying is a traditional method used to preserve fresh berries by reducing fruit water activity. The quality of dried berries is determined by the type of drying method applied, water activity of the final product, packaging, and storage conditions. For 'Marion' blackberries, freeze drying has been shown to retain higher per fruit phenolic concentration than hot-air drying (Asami, Hong, Barrett, & Mitchell, 2003). Consistent with this, freeze drying has also been

* Corresponding author.
E-mail address: yanyun.zhao@oregonstate.edu (Y. Zhao).
[1] Present address: The Australian Wine Research Institute, PO Box 197, Glen Osmond, South Australia, Australia.

0023-6438/$ – see front matter
doi:10.1016/j.lwt.2010.04.002

shown to help preserve anthocyanins and antioxidant capacity of Saskatoon berries (Kwok, Hu, Durance, & Kitts, 2004) due to the minimum heat treatment applied to remove water from fruit tissue.

Canning uses high temperatures to destroy microorganisms (Ramaswamy & Meng, 2007). Previous work has shown that the canning of Oregon strawberries in syrup increases their total extractable phenolics and anthocyanins (Ngo, Wrolstad, & Zhao, 2007). A recent study concluded that canning increased percent polymeric color (a color change usually associated with anthocyanins degradation), but decreased anthocyanin content and antioxidant capacity of blackberries, while storage at 25 °C did not significantly change the antioxidant capacity, but led to the increase in polymeric color and loss in anthocyanins (Hager, Howard, & Prior, 2008).

Berry jams are an important dietary form of berry fruit (Figuerola, 2007). Previous studies have indicated that a small portion of flavonols were lost when producing strawberry jams (Häkkinen, Kärenlampi, Mykkänen, & Tőrrőnen, 2000), while total phenolics were preserved during blackberry jam processing (Amakura, Umino, Tsuji, & Tonogai, 2000).

The extent to which nutraceuticals are preserved in blackberry products depends heavily on the specific processing technology, blackberry variety, production location, maturity, time of harvest, and storage conditions (Rickman et al., 2007). To increase our understanding of these variables on nutraceutical preservation, more comprehensive studies are required. The information from these studies could be used by processors to develop novel procedures and by consumers to better understand potential health benefits of the various products. The objective of this study was to investigate the effect of processing on the change in total phenolics, total monomeric anthocyanins, and antioxidant capacity of two blackberry varieties, 'Marion' and 'Evergreen'. The specific processing technologies being investigated include refrigerated storage of fresh fruit, freezing, drying, canning, jamming, and subsequent storage under room conditions. Basic physicochemical properties of the fresh and processed berries were also investigated.

2. Materials and methods

2.1. Fruit

'Marion' and 'Evergreen', the two predominant blackberry varieties in the US Pacific Northwest, were selected for this study. 'Marion" blackberries were obtained from Scenic Fruit Co. (Gresham, OR) and 'Evergreen' from RainSweet, Inc. (Salem, OR) in early July and early September, 2007, respectively. Fresh fruit was shipped under refrigeration to the Department of Food Science & Technology at Oregon State University the day after harvest. For refrigerated storage, fresh fruit was packed in 300 g clam-shell containers and stored in the dark at 2.0 ± 0.5 °C and 95 ± 2% RH. For frozen samples, fresh fruit was washed with 20 mg/kg chlorinated water for 80 s, and then individually frozen on stainless steel trays in an air blast freezer at −23 °C. Frozen fruit was packed in 2 L wide-mouth glass jars with lids, stored at −23 ± 2 °C and 30 ± 2% RH, and sampled at 0, 3 and 6 months (Fig. 1). Additionally, frozen fruit was processed into various other products.

2.2. Fruit processing

Both freeze and hot-air drying were investigated. For freeze drying, whole fruit was loaded onto aluminum trays, placed in a freeze drier (Model 651 m-9WDF20, Hull Corp., Hatboro, PA), cooled at a condenser temperature of −45 °C for about 1 h till the fruit were fully frozen, and then vacuum dried at a maximum vacuum pressure of 30 Pa. It took ~72 h for the fruit to be fully dried at a shelf temperature of 35 °C and 50% RH. For hot-air drying, whole fruit was dried in an MP-2000 Enviro-Pak conventional drier (Division of Tech-Mark, Inc., Clackamas, OR) at a shelf temperature of 50 °C and 50% RH for ~48 h. Dried fruit was packaged and sealed in food-grade moisture-resistant plastic bags and stored in glass desiccators containing drierite (anhydrous calcium sulfate, W.A. Hammond Ltd., Xenia, OH).

Blackberry jams composed of 45% fruit and 55% sugar (including added sugar and sugar from berries. Sugar content of frozen 'Marion' and 'Evergreen' blackberries were about 11.5 and 12.6%, respectively) were prepared as follows. Frozen berries were thawed overnight at room temperature and then crushed in a stainless steel kettle. The pH of the fruit was adjusted to 3.2 by adding citric acid (1 g/L, Integra Chemical Company, Renton, WA). The fruit puree was transferred to a jacketed steam kettle, heated to ~49 °C, mixed with cane sugar and 150 grade rapid-set pectin (Pacific pectin Inc., Oakhurst, CA) (amount of pectin added to the jams was calculated as: total amount of sugar (sugar from fruit and added sugar)/150), and stirred to avoid clumping. Fruit mixtures were heated to boiling, and the Brix was checked until it reached ~68 °Brix. The

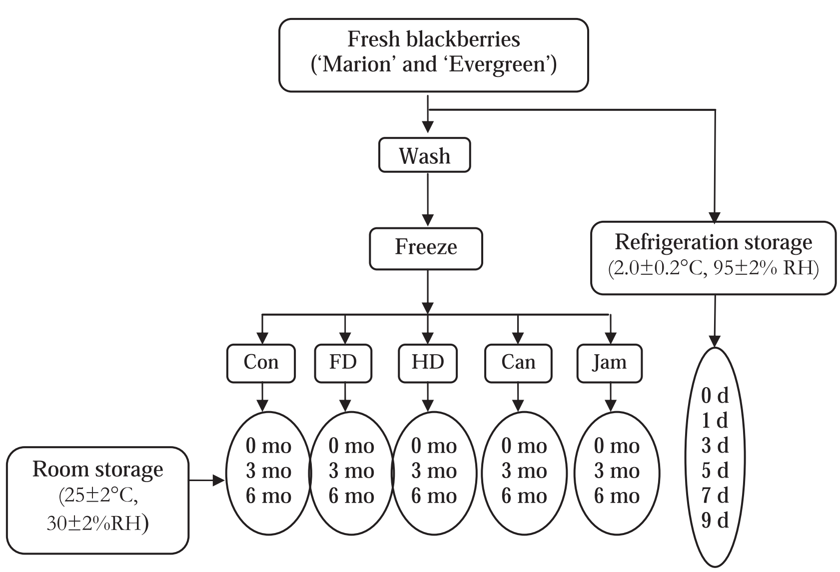

Fig. 1. Flow diagram of experimental design. Con: Control (frozen); FD: Freeze drying; HD: Hot-air drying; Can: Canning; Jam: Jam processing; RH: Relative humidity.