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Effect of gamma irradiation on some physicochemical properties and bioactive compounds of jujube (*Ziziphus jujuba* var *vulgaris*) fruit

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HIGHLIGHTS

- The effects of gamma irradiation on bioactive compounds of jujube fruit were studied.
- Total phenolic and anthocyanin contents increased by irradiation.
- A considerable decrease of organic acids contents was observed at high doses.
- Irradiation affected significantly the water-soluble vitamins contents.
- Irradiation protected the main bioactive compounds of jujube fruit up to 2.5 kGy.

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ABSTRACT

Interest in the protection of bioactive compounds and a safe alternative method for preservation of processed fruits and fruit juices has recently increased significantly throughout the world. There is a distinct lack of information on the profile of bioactive compounds in jujube fruit (e.g. organic acids, anthocyanins, and water-soluble vitamins) and their changes during processing (e.g. gamma irradiation). Therefore, in this study, the effect of gamma irradiation at different doses (0.0, 0.5, 1.0, 2.5 and 5.0 kGy) on some physicochemical properties and the bioactive compounds of jujube fruit was investigated. The total soluble solids (TSSs) values remained unaffected at various doses, while the level of total acidity (TA) showed a slight increase at doses $\geq$2.5 kGy ($p \leq 0.05$). Irradiation up to 2.5 kGy caused a significant increase in the total monomeric anthocyanin and the total phenolic content (about 12% and 6%, respectively), but a significant decrease was observed in both parameters immediately after irradiation at 5 kGy. Moreover, irradiation treatment caused a significant decrease in L* value and a significant increase in a* and b* values ($P \leq 0.05$); however, changes of color were slight until the dose of 5 kGy. Gamma irradiation up to 2.5 kGy had no significant effect on the concentration of malic, citric and succinic acids, while the level of ascorbic acid decreased significantly at all irradiation doses (0–5 kGy). Cyanidin-3, 5-diglucoside was determined as the major anthocyanin in the jujube fruit studied (about 68%), which was reduced significantly when 5 kGy of irradiation was applied (degradation percentage: 27%). The results demonstrated that vitamins C, B_2 and B_1 are the most water-soluble vitamins in jujube fruit, respectively. Vitamins C and B_1 content significantly decreased at all applied doses (0–5 kGy), whereas B_2 content at doses $\leq$2.5 kGy was not significantly affected. The results of this study indicate that gamma irradiation at doses below 2.5 kGy can be successfully used for improving the quality the jujube fruit.

1. Introduction

Jujube (Ziziphus spp.) belongs to the Rhamnaceae family, and is one of the oldest known medicinal plants. Jujube extensively is grown in tropical and subtropical regions of the world (San and Yildirim, 2010). Iran is one of the main producers of jujube with an annual production of 3000 ton and the extent of its cultivation is 1350 ha (Golmohammadi, 2013). Jujube, enjoying an exquisite taste and attractive color, is widely used in functional foods such as beverages, jams, loaf, cakes, jelly, etc (Nazni and Mythili, 2013; San and Yildirim, 2010; Sun et al., 2011). However, its functional properties are not known for many people in the world. Kamiloğlu et al. (2009) reported the total phenolic content (TPC) for jujube (*Zizyphus jujube* Mill.) genotypes selected from Turkey to be

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between 42 and 40 mg of gallic acid equivalents per 100 g dry weight (mg GAE/g DW). This is while Xue et al. (2009) reported a range of 42.2–55.4 for mg GAE/g DW Chinese jujube fruits. Zhang et al. (2010) explained that the total anthocyanin content of pulps (1.38–10.59 mg cy-3-g/100 g DW) was significantly lower than that of peels (29.79–42.91 mg cy-3-g/100 g DW) for *Ziziphus jujuba* Mill from China.

Thermal technique significantly inactivates enzyme and microorganisms, ensuring food safety and improving the shelf life of the product; however, it also results in degradation of bioactive compounds and their antioxidant activity (Nazni and Mythili, 2013). To avoid quality degradation of fruit juice by thermal processing, non-thermal preservation methods such as gamma irradiation have been studied during the last decade (Naresh et al., 2015). Additionally, new trials for increasing biological activities of foods by gamma irradiation showed advantage in increasing total phenolic content, improving color, and antioxidant activity of various juices (Naresh et al., 2015; Mali et al., 2011; Arjeh et al., 2015).

As described above, due to nutritional and technological effects of the bioactive compounds, in the present research, we studied the profiles of organic acids, anthocyanins, and water-soluble vitamins of Iranian native jujube fruit and their changes during of gamma irradiation at different doses (0.0, 0.5, 1.0, 2.5 and 5.0 kGy). It should be noted that there were no reported data about the profile of organic acids, anthocyanins, and water-soluble vitamins of jujube fruit varieties and their changes during of processing such as gamma irradiation before.

2. Materials and methods

2.1. Sample preparation

Fully ripened jujube fruits (*Ziziphus jujuba* var *vulgaris*) were originally obtained from South Khorasan Agricultural and Natural Resources Research and Training Center, Iran (more than 30 trees). The overall weight of fruits was about 10 kg. The fruits were cleaned; then their stones were removed by hand, and dried by hot air oven (Memmert, Germany) at 45 °C for 8 h. The initial moisture content of jujube fruit was found to be 47.51% that was reduced to 3.46% on drying. Then a fine powder was obtained using a mill (Moulinex, Type DPA1, CMMF 800 W, France), and was passed through a 30-mesh sieve. Then the samples were classified into five groups by irradiation doses (0, 0.5, 1.0, 2.5, and 5.0 kGy) in high density polyethylene (HDPE) self sealed pouches (thickness 0.1 mm) until used for further analysis. All samples were freezed at −18 °C during the study.

2.2. Irradiation treatment

Three pouches each containing 25 g of dried jujube fruit powder were irradiated at various doses (0, 0.5, 1.0, 2.5 and 5.0 kGy) using a gamma cell-220 irradiator (Nordion, Canada). The source strength was approximately 12,470 Ci at the dose rate of 3.63 Gy/s. Dosimetry was performed using Red-Perspex dosimeter (Harwell Dosimeters, UK) at the outer side of the pouches. The actual doses were within ±2% of the target dose. The temperature during irradiation was 40 °C ± 2 °C. The irradiated samples were immediately stored at 4 °C (relative humidity 40%) along with the control (0 kGy) for one month.

2.3. Extraction studies

Solvent extraction studies were performed using a modified method (Chew et al., 2011; Chirinos et al., 2007) for maximal extraction of total phenolic content and recovery of the bioactive compounds of jujube fruit powder. Both the control and irradiated jujube powder samples were extracted with 20 ml of water-ethanol solvent (80:20 v/v), and sample to solvent ratio of 1:20 (w/v). Then they were put on rotary shaker (IKA®, KS 4000i control, India) at a speed of 180 rpm for 1 h at 37 °C ± 2 °C. The extracts were centrifuged (Sigma, 3–30 K, Germany) for 2 min at 10,000 rpm at 4 °C, and filtered through Whatman filter no.1. The clear extracts were divided into small colored vials, and kept frozen at −18 °C for one day upon analysis.

2.4. Determination of total acidity (TA) and total soluble solids (TSSs)

The total acidity of the aqueous-ethanolic extract was assessed by titrating with 0.1 N NaOH to an endpoint of pH 8.1, and the results were expressed as percentage of citric acid. TSSs in the extract were measured with a digital refractometer (DR-AlATAGO, Japan) at 20 °C. The instrument was calibrated with distilled water before the analysis. TSS values were expressed as °Brix (AOAC (Association of Office Analytical Chemists), 1996).

2.5. Color measurement

The color of aqueous-ethanolic extract was measured using a Hunterlab Color Flex (Hunterlab, Reston, Virgina, USA). The instrument was calibrated each time against black and white (L=92.23, a=−1.29, b=1.19) ceramic plates. The Hunter color L* (Lightness), a* (redness) and b* (yellowness) values evaluated and the total color difference, ($\Delta E=\sqrt{(\Delta L)^2+(\Delta a)^2+(\Delta b)^2}$) calculated from them (Timmermans et al., 2011).

2.6. Determination of total phenolic content (TPC) and total monomeric anthocyanin content (TMAC)

Total phenolic content (TPC) was determined using spectrophotometer (carry 60, Agilent, Us) by Folin–Ciocalteu colorimetric method (Yang et al., 2010). Briefly, 20 µl of aqueous-ethanolic extract was mixed first with 1.58 ml distilled water and then 100 µl Folin–Ciocalteu reagent, and 300 µl of saturated Na_2CO_3 (20%) was added. After the mixture has been allowed to stand for 30 min at 40 °C, the absorbance was measured at 765 nm. The standard curve of the absorbance of gallic acid was used, and the results were reported as mg gallic-acid equivalents per g dry weight of the extract (mg GAE/g DW).

Total monomeric anthocyanin content (TMAC) was estimated by the pH-differential method (Lee et al., 2005). Two buffer systems were used: 0.025 M potassium chloride buffer (pH 1.0) and 0.4 M sodium acetate buffer (pH 4.5). 200 µl of the aqueous-ethanolic extract were mixed with 1.8 ml of either potassium chloride or sodium acetate buffer and the absorbance of samples was recorded at 510 and 700 nm according to the following equation:

$$A = (A_{510\ nm} - A_{700\ nm})\ pH_{1.0} - (A_{510\ nm} - A_{700\ nm})\ pH_{4.5} \quad (1)$$

The results were reported as mg of cyaniding-3- glucoside equivalents per 100 g dry weight of extract (mg cy-3-g/100 g DW) using a molar absorptive coefficient (ε) of 26,900 L $mol^{-1}cm^{-1}$, molecular weight (MW) of 449.2 g mol^{-1}, dilution factor (DF), absorption value (A), and L is the cell path length (1 cm) according to the following equation:

$$\text{Monomeric anthocyanin pigment (mg/l)} = A \times MW \times DF \times 1000/(\varepsilon \times L) \quad (2)$$