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Effects of gamma radiation on physicochemical, thermogravimetric, microstructural and microbiological properties during storage of apple pomace flour

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A B S T R A C T

The effects of gamma radiation on the physicochemical, thermogravimetric, microstructural and microbiological properties of apple pomace flour were evaluated for a period of nine months storage. Calcium levels were higher in the irradiated samples. The irradiated samples remained stable during storage regarding the contents of protein, lipids, total dietary fibre, total reducing sugars, potassium, zinc, iron and manganese. The chemometric approach enabled a better visualisation of the samples. The results were not influenced by the effect of gamma radiation during storage. The thermogravimetric curves showed four major mass losses in consecutive reactions. The photomicrographs showed a composite of organic and heterogeneous material, with agglomerated particles with irregular shapes and sizes. For the microbiological analysis at a dose of 1 kGy, the presence of moulds occurred at 9 months of storage, however, the levels were below the indicative tolerance and for 2 kGy there was no contamination of yeasts and moulds.

1. Introduction

It is estimated that 70% of apples are consumed in a fresh state, while 30% are used in the processing of juices, ciders, wines, vinegar, spirits and other products derived from this fruit (Alberti et al., 2016). With this industrialisation has resulted in a subsequent increase in production and marketing that produces an enormous volume of waste in many countries - about 12 million tonnes per year (USDA, 2015).

The composition of the nutrients of apple pomace is associated with the characteristics of the fruit processing and also the methodology used to extract the juice, contains high levels of carbohydrates, fibre and phenolic compounds (Ito, Avila, & Wosiacki, 2015). The high fibre content found in apple pomace can aid in the prevention and treatment of obesity, arteriosclerosis, cardiovascular disease, colon cancer and diabetes. The consumption of dietary fibre decreases insulin levels in the blood and brings benefits to the gastro-intestinal tract (Kosmala, Kolodziejczyk, Zduńczyk, Juśkiewicz, & Boros, 2011). These health-promoting properties have been the subject of research studies related to apples and their derivatives (Yan & Kerr, 2013). However, it is still rare to find thermal behaviour studies of these fibres using thermogravimetry and it is very important to reveal all the relevant details, such as the thermal stability and decomposition profile of the raw material.

Food irradiation is a technology that aims to improve food security. In recent decades it has been widely researched and its effects are known to preserve, reduce microbial load or sterilization, increase the shelf life of products and above all to maintain the quality of food (Tawema, Han, Vu, Salmieri, & Lacroix, 2016). It represents an effective and environmentally friendly technology (Pereira et al., 2014). Its efficacy and safety are proven (Food and Agricultural Organization (FAO); International Atomic Energy

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Agency (IAEA); World Health Organization (WHO)). However, the aim of this study was to evaluate the physicochemical, thermogravimetric, microstructural and microbiological properties of apple pomace flour irradiated with doses of 0, 1 and 2 kGy, during 0, 3, 6 and 9 months of storage.

2. Materials and methods

2.1. Materials

The Fuji apples used in the experiments were purchased in the local supermarket at commercial maturity in the city of Ponta Grossa (25° 05′ 42″ S 50° 09′ 43″ O), Paraná, Brazil, from the 2013 harvest.

2.2. Processing of apple pomace

The pomace was obtained according to the methodology used by Ito et al. (2016). The flour was separated and packed in samples of about 250 g in small non-toxic polyethylene bags with hermetic closure until the moment of the analysis.

2.3. Radiation of samples

All the samples of the apple pomace flour were subjected to gamma radiation at doses of 0, 1 and 2 kGy at 0.87 kGy/h dose rate. Harwell Amber 3042 dosimeters were used to measure the radiation dose and the uncertainty dose was less than 1%. The irradiation source was with Cobalt 60 (Gammacell Excell 220 - MDS Nordion) located in the Centre for Nuclear Energy in Agriculture (CENA/USP). The pomace was evaluated during 0, 3, 6 and 9 months after irradiation. The sample with 0 kGy dose (control), 1 and 2 kGy were subjected to the analysis (time 0), and the others samples were stored at room temperature until the end of each storage time (Ito et al., 2016).

2.4. Physicochemical analysis

The contents of moisture, protein, ash, lipids and total dietary fibre of the apple pomace flour (APF) samples were determined according to the official methods (AOAC, 2005). Total reducing sugars content was determined using the Somogyi Nelson method (Somogyi, 1952). The determination of pectin, was performed according to the methodology proposed by Fertonani et al. (2009). For the analysis of calcium (Ca), copper (Cu), cobalt (Co), iron (Fe), magnesium (Mg), potassium (K), sodium (Na), zinc (Zn) and manganese (Mn) the readings were taken using a flame atomic absorbtion spectrometer (Varian, model 240FS), using as an accessory an automatic SIPS diluter system equipped with deuterium lamp as background correction and multi-element hollow cathode lamps. The results were performed in triplicate and expressed in g.100 g^{-1} dry matter (DM). The water activity (A_w) was measured with a digital A_w meter (Aqualab®, USA).

2.5. Thermal properties: thermogravimetry (TG) and thermal differential analysis (DTA)

To obtain the TG and DTA results, TGA-50 (Shimadzu, Japan) equipment was used. Approximately 7.0 mg of each sample was placed in open micro alpha-alumina (α-Al_2O_3) pans that were pre-weighed on thermobalance equipment. Readings were performed in a synthetic air atmosphere at a flow rate of 100 ml min^{-1}, with a

Table 1
Effects of gamma irradiation on the physicochemical properties in APF during storage.

Analysis (g 100 g^{-1})	Doses (kGy)	Time (months)			
		0	3	6	9
Moisture	0	5.66 ± 0.04^{d}	7.87 ± 0.51^{ABc}	9.59 ± 0.38^{b}	11.52 ± 0.76^{a}
	1	5.53 ± 0.25^{d}	6.75 ± 0.44^{Bc}	8.52 ± 1.00^{b}	11.50 ± 0.17^{a}
	2	5.87 ± 0.05^{c}	8.46 ± 0.66^{Ab}	9.37 ± 0.73^{b}	11.82 ± 0.25^{a}
Protein	0	4.49 ± 0.05^{Aa}	3.05 ± 0.01^{Bb}	3.68 ± 0.55^{b}	3.42 ± 0.65^{b}
	1	3.90 ± 0.58^{AB}	4.00 ± 0.37^{A}	3.77 ± 0.31	3.54 ± 0.40
	2	3.42 ± 0.19^{B}	3.59 ± 0.06^{A}	4.15 ± 0.56	3.85 ± 0.49
Lipids	0	1.96 ± 0.15	1.95 ± 0.40	1.84 ± 0.47	1.73 ± 0.42
	1	1.75 ± 0.13	1.64 ± 0.48	1.63 ± 0.47	1.67 ± 0.19
	2	1.90 ± 0.12	1.97 ± 0.05	1.78 ± 0.26	1.75 ± 0.31
Total Reducing Sugars	0	37.60 ± 0.50^{AB}	37.54 ± 0.50	37.79 ± 0.17	37.53 ± 0.55
	1	37.23 ± 0.77^{B}	38.00 ± 0.79	38.06 ± 0.44	37.34 ± 0.51
	2	38.36 ± 0.04^{A}	37.66 ± 1.25	38.35 ± 0.27	37.96 ± 0.05
Reducing Sugars	0	27.36 ± 0.27^{a}	26.50 ± 0.47^{b}	26.80 ± 0.14^{ab}	26.56 ± 0.31^{b}
	1	26.61 ± 1.01	26.71 ± 0.57	26.62 ± 0.50	26.68 ± 0.48
	2	27.59 ± 0.42^{a}	26.65 ± 0.44^{b}	26.89 ± 0.62^{ab}	26.46 ± 0.40^{b}
Glucose − GOD	0	7.82 ± 0.22^{a}	6.73 ± 0.43^{ABb}	6.88 ± 0.41^{ABb}	6.56 ± 0.57^{Bb}
	1	7.86 ± 0.17^{a}	6.52 ± 0.05^{Bb}	6.47 ± 0.14^{Bb}	6.34 ± 0.29^{Bb}
	2	8.02 ± 0.00^{a}	7.16 ± 0.10^{Ac}	7.35 ± 0.09^{Abc}	7.42 ± 0.16^{Ab}
Sucrose	0	10.24 ± 0.61	11.04 ± 0.54	10.99 ± 0.24	10.97 ± 0.36
	1	10.61 ± 0.31	11.29 ± 1.36	11.44 ± 0.18	10.67 ± 0.59
	2	10.77 ± 0.41	11.01 ± 0.88	11.46 ± 0.57	11.50 ± 0.45
Fructose	0	19.54 ± 0.48	19.77 ± 0.82	19.92 ± 0.38	20.00 ± 0.87
	1	18.75 ± 1.18	20.19 ± 0.56	20.15 ± 0.64	20.34 ± 0.74
	2	19.57 ± 0.42	19.49 ± 0.35	19.55 ± 0.65	19.04 ± 0.54
Total Dietary Fibre	0	50.01 ± 1.47^{Aa}	49.30 ± 0.55^{a}	47.27 ± 1.18^{b}	47.27 ± 0.45^{b}
	1	46.05 ± 1.38^{B}	46.05 ± 1.61	46.65 ± 0.36	45.98 ± 0.56
	2	45.46 ± 1.15^{B}	45.46 ± 1.75	46.25 ± 0.24	46.26 ± 0.58
Pectin	0	14.15 ± 0.07^{a}	14.16 ± 1.17^{a}	12.27 ± 0.30^{b}	12.04 ± 0.21^{b}
	1	14.33 ± 1.02^{a}	14.47 ± 0.56^{a}	12.44 ± 0.29^{b}	12.13 ± 0.48^{b}
	2	14.59 ± 0.71^{a}	14.53 ± 0.81^{a}	11.84 ± 0.34^{b}	11.51 ± 0.58^{b}

Note - Results are expressed as mean ± standard deviation; Different capital letters in the same column indicate significant difference between the doses; Different small letters in the same line indicate significant differences during storage. The significant differences at a level of 5% were performed by Duncan's test.