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Degradation kinetic modelling of color, texture, polyphenols and antioxidant capacity of York cabbage after microwave processing

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ABSTRACT

Vegetables as an essential component of the human diet usually undergo some type of processing before being consumed. In the present study, impact of microwave (MW) processing on various physiochemical properties of York cabbage was studied. York cabbage was processed at 400, 560 and 800 W for 0 to 14 min with an increment of 2 min followed by a kinetic study for the degradation of polyphenols, flavonoids, antioxidant capacity, color and texture which was carried out. Results showed that MW processing leads to significant reductions in the texture, color, polyphenols and antioxidant capacity. For all the MW processing power studied total phenolic content reduced by up to 85–90% while total flavonoid content reduced by up to 60–73% after 14 min of MW processing. These results were further confirmed by HPLC-DAD analysis. Serious losses in the antioxidant capacity (83–98%) were also observed as a result of MW processing as compared to fresh counterparts and a similar trend was observed for firmness, which reduced by up to 58.8–61.6%, and color up to 15.2–36.9%. First-order reaction model showed a good fit for the different studied parameters, with coefficients of determination (R^2) ranging from 0.90 to 0.99, except for texture (firmness) and color (chroma), which followed zero-order (R^2 = 0.88–0.98).

1. Introduction

Fruits and vegetables are an essential component of the human diet. Evidences from epidemiological studies suggest that diets rich in fruit and vegetables are associated with a lower risk of several diseases like atherosclerosis, stroke, cancer, diabetes, arthritis and aging (Blasa, Gennari, & Angelina, 2010; Southon, 2000). *Brassica oleracea* species constitutes a number of common vegetables like cauliflower, broccoli, kohlrabi, kale, cabbage and Brussels sprouts. Among these vegetables, cabbage is an economically and nutritionally important vegetable and consumed widely around the globe. It is rich in a number of biologically active metabolites such as vitamins, phenolic acids, flavonoids and isothiocyanates, which are associated with antioxidant (AO), antibacterial and anticancer properties and contribute to health promotion.

Fruits are most commonly consumed raw; however, vegetables such as cabbage usually undergo some type of processing before being consumed. Among the various available processing methods such as boiling, microwave (MW) and steaming; MW processing has gained more interest both for domestic purposes in addition to industrial applications. MW heating has many advantages over conventional heating including precise timing, rapidity, and energy saving (El-Abassy, Donfack, & Materny, 2010). It is 3–5 times faster than conventional heating; therefore, it has the potential to improve product quality with reduced heating time.

Microwaving relies on the application of dielectric heating in order to heat food products. This is accomplished by using MW radiation to heat water and other polarized molecules within the food, which leads to heat generation in the entire volume due to internal thermal dissipation of the vibrations of the water molecules in the food (Decareau, 1985; Kamel & Stauffer, 1993). In contrast, conventional heating generates heat at the contact surface first, and then the heat diffuses inwards.

Thermal processing techniques emphasize the achievement of commercial sterility while minimizing changes in nutritional value and sensory properties. However, no matter how minimal the heating source is, thermal processing can promote reactions that could affect the overall quality of foods. Quality loss involves both subjective factors like taste that cannot be readily quantified, and quantifiable factors such as nutrient degradation (Awuah, Ramaswamy, & Economides, 2007). In recent years, many studies have been undertaken to investigate nutrient properties of various vegetables processed by MW heating such as ready to eat vegetables (Murcia et al., 2009), broccoli (Zhang & Hamauzu, 2004), potato, carrot, onion, broccoli, and white cabbage (Faller & Fialho, 2009), peas, carrot, spinach, cabbage, cauliflower, turnips (Sultana, Anwar, & Iqbal, 2008), broccoli, green beans and asparagus (Brewer & Begum, 2003). However, both positive and negative effects have been reported depending upon differences in process conditions and morphological characteristics of vegetables.

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Data on the effect of MW processing on kinetic modelling of physiochemical properties of vegetables are scarce (Ramesh, Wolf, Tevini, & Bognár, 2002). For the design of an optimized process that can lead to a maximized preservation of phytochemicals, kinetic modelling is necessary to derive basic kinetic information for a system in order to describe the reaction rate as a function of experimental variables and hence, to predict changes in a particular food during processing (Van Boekel, 2008; Yu, Wu, Hu, Cui, & Yu, 2011). A number of kinetic models such as zero-order, first-order and fractional conversion (FC) first-order have been used for phytochemical content, AO capacity, texture and color degradation for a range of fruit and vegetables (Gonçalves, Pinheiro, Abreu, Brandão, & Silva, 2010). Therefore, the purpose of our study was to find out effects of MW processing of York cabbage on the degradation kinetics of a number of physiochemical properties such as texture, color, polyphenols, and AO activity. These objectives are justified having in mind that the literature lacks some information on kinetic evaluation of phytochemicals, antioxidant capacity, physical characteristics such as color and texture together upon MW processing.

2. Materials and methods

2.1. Plant materials and their preparation

Fresh Irish York cabbage (*B. oleracea var. capitata alba subvar. conica*) was purchased from a local supermarket in Dublin in April 2010. Eighteen to twenty York cabbage heads (25–30 kg) were randomly selected and trimmed of their outer leaves and stem. The heads were then divided into four segments and the central core was removed. The segments were chopped into 0.5 × 5–6 cm pieces, using a vegetable cutting machine. A pooled batch of about 18 kg chopped cabbage was stored in a plastic bag under dark refrigerated conditions (4 °C ± 0.5) and was utilized as the raw material for all subsequent treatments. A 50 g sample was taken from the pooled batch (in duplicate) as reference for fresh, unprocessed cabbage.

2.2. MW processing

MW processing was carried out using a domestic oven (Sharp, Model R 244; Sharp Electronics (UK) Ltd, Manchester, Lancashire, M40 5BE) with a maximum output power of 800 W. Microwave heating was carried out at 400, 560 and 800 W which are 30, 50 and 100% of power output. The main reason behind specifying these power levels is to represent MW power typically applied in food processing applications. The procedure consisted of adding 50 g of chopped cabbage in 500 ml beaker filled with 100 ml deionized water and then was placed inside the MW oven. The microwaving time was noted as soon as the vegetables were placed inside the MW at the studied power. For all the power levels studied, samples were withdrawn every 2 min up to 14 min. The processed material was drained, cooled in ice water (1–4 °C) for 1 min and then allowed to drain for 30 s. The processed samples were kept in a plastic bag (20 × 25 cm) and color and texture analyses were carried out on the same day. In order to eliminate bias, treatments were completely randomized and were performed in duplicate. The processed samples were submerged in liquid nitrogen and ground to a coarse powder using mortar and pestle and stored in plastic bags at −20 °C until further analysis (10–15 days).

2.3. Preparation of extracts

A 5 g of crushed cabbage sample was extracted using 50 ml of 60% methanol. In order to prevent sample oxidation during the extraction process, a reduced environment was created using nitrogen flushing. Flasks were kept in a shaking incubator (Innova 42, Mason Technology, Dublin, Ireland) at 100 rpm and 40 °C for 2 h. The infusions were filtered with Whatman # 1 until a clear extract was obtained. The extracts were evaporated to dryness in a multi evaporator (Syncore Polyvap, Mason Technology, Dublin, Ireland) at 60 °C at their respective pressure and stored at −20 °C until used.

2.4. Phytochemical analysis

2.4.1. Determination of total phenolic and flavonoid content

Total phenolic content (TPC) and total flavonoid content (TFC) of samples were estimated according to our earlier report (Jaiswal, Rajauria, Abu-Ghannam, & Gupta, 2012a). Fresh and MW processed cabbage extracts were dissolved in deionized water (1 mg/ml) as samples were soluble in water. In brief, for the TPC estimation, 100 μl aliquots of sample in deionized water were mixed with 2 ml of 2% Na_2CO_3 and were allowed to stand for 2 min at room temperature. After incubation, 100 μl of 1N Folin–Ciocalteau's phenol reagent was added. Reaction mixture was allowed to stand for 30 min at room temperature in the dark. Absorbance of all the sample solutions was measured at 720 nm. Results were expressed as mg gallic acid (Sigma-Aldrich, Steinheim, Germany) equivalents per 100 g (mg GAE/100 g) fresh weight (fw) of cabbage.

For the TFC estimation, 250 μl of sample was mixed with 1.25 ml of deionized water and 75 μl of 5% $NaNO_2$ solution. After 6 min, 150 μl of 10% $AlCl_3 \cdot H_2O$ solution was added. Finally, 0.5 ml of NaOH (1 M) solution was added and the total volume was made up to 2.5 ml with deionized water. Absorbance against blank was taken at 510 nm. Results were expressed as mg quercetin (Sigma-Aldrich, Steinheim, Germany) equivalents per 100 g (mg QE/100 g) fresh weight of cabbage.

2.4.2. HPLC-DAD analysis of polyphenolic compounds

HPLC-DAD analysis of fresh and MW processed cabbage polyphenols was carried out according to Jaiswal, Rajauria, Abu-Ghannam, and Gupta (2011). In brief, the HPLC system consisted of a reversed-phase HPLC column on an Alliance HPLC (Waters, e2695 Separations modules) equipped with an auto sampler and controller with dual pump, a 2998 photodiode array detector (PDA) and the Empower software. An Atlantis C18 column (250 mm × 4.6 mm, 5 μm particle size) from Waters (Waters, Milford, MA) was used for polyphenolic separation at 25 °C. All the solvents used were similar to our earlier report (Jaiswal et al., 2011). The chromatogram was monitored at 280 nm and complete spectral data were recorded in the range of 220–600 nm.

2.5. Antioxidant capacity analysis

In the present study, four different methods namely 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity, ferric reducing AO potential (FRAP) assay, lipid peroxidation in a hemoglobin-induced linoleic acid system (LPO) and hydrogen peroxide (H_2O_2) scavenging assay were used for the estimation of total AO capacity of the fresh and processed York cabbage. All the methods were carried out according to the existing protocols in our laboratory (Rajauria, Jaiswal, Abu-Gannam, & Gupta, 2012). For the DPPH radical scavenging capacity and LPO inhibitory ability, ascorbic acid was used as a reference compound and the results were expressed as mg ascorbic acid equivalents per 100 g (mg AscE/100 g) (fw) of cabbage. Trolox was used as a standard for FRAP assay and the results were expressed as mg trolox equivalents per 100 g (mg TE/100 g) (fw) of cabbage; whereas BHT was used as a reference compound for H_2O_2 scavenging capacity and the results were expressed as mg BHT equivalents per 100 g (mg BHTE/100 g) (fw) of cabbage.

2.6. Instrumental texture analysis

The texture of the raw and MW processed samples was analyzed using an Instron texture analyzer (Instron 4302 Universal Testing Machine, Canton MA, USA) (Jaiswal, Gupta, & Abu-Ghannam, 2012b). The texturometer was mounted with a 500 N load cell and equipped with a Warner–Bratzler blade (V-notch blade) which cuts through the sample at a download speed of 50 mm/min. A 5 g sample was