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Potential of different mechanical and thermal treatments to control off-flavour generation in broccoli puree

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ABSTRACT

The aim of this study was scientifically investigate the impact of the sequence of different thermo-mechanical treatments on the volatile profile of differently processed broccoli puree, and to investigate if any relationship persists between detected off-flavour changes and microstructural changes as a function of selected process conditions. Comparison of the headspace GC–MS fingerprinting of the differently processed broccoli purees revealed that an adequate combination of processing steps allows to reduce the level of off-flavour volatiles. Moreover, applying mechanical processing before or after the thermal processing at 90 °C determines the pattern of broccoli tissue disruption, resulting into different microstructures and various enzymatic reactions inducing volatile generation.

These results may aid the identification of optimal process conditions generating a reduced level of off-flavour in processed broccoli. In this way, broccoli can be incorporated as a food ingredient into mixed food products with limited implications on sensorial consumer acceptance.

1. Introduction

Currently, food industry aims to manufacture healthier, tastier but authentic fruit- and vegetable based food products such as soups, smoothies and sauces (Blatt, Roe, & Rolls, 2011). For that, a major challenge is to (re)design the manufacturing processes of such food products (Lopez-Sanchez et al., 2015) in order to comply with the increasingly important requested quality criteria.

The health benefits of broccoli (*Brassica oleracea* L.) have been described to be linked with a decreased risk of cancer and prevention of chronic diseases (Cox, Melo, Zabaras, & Delahunty, 2012). Broccoli contains a high concentration of antioxidants (carotenoids, tocopherols and ascorbic acid), dietary fibres and considerable amounts of sulfur-containing glucosides such as glucosinolates. Besides their desired health benefit, the glucosinolate degradation products (e.g. isothiocyanates, thiocyanates, indoles and nitriles) also give rise to the formation of a wide range of (un)desirable odour-active compounds (Baik et al., 2003; Hennig et al., 2014). These are typically characterized as 'off-flavour notes' having bitter, sulfurous sensorial quality perceptions which are negatively affecting consumer acceptance.

Fresh broccoli is generally low in volatile aroma compounds. The formation of aroma volatiles generally occurs spontaneously upon tissue disruption, by enzymatic reaction and/or by thermal degradation during cooking (Whitfield & Last, 1991). Formation of off-flavour volatiles in raw broccoli upon storage under anaerobic or low-oxygen atmosphere has been well-described (Di

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Pentima, Rios, Clemente, & Olias, 1995; Forney, Mattheis, & Austin, 1991; Hansen, Buttery, Stern, Cantwell, & Ling, 1992). Also development of off-flavour in heat-processed broccoli has been studied too (Buttery, Guadagni, Ling, Seifert, & Lipton, 1976; Forney & Jordan, 1998; Hansen, Lausten, Olsen, Poll, & Sorensen, 1997; Jacobsson, Nielsen, & Sjöholm, 2004).

Broccoli flavour is mainly characterized by various sulfur compounds, aldehydes, alcohols and aromatic compounds (Buttery et al., 1976). In summary, the strong off-flavours in broccoli have mainly been linked to compounds such as β-ionone and sulfur compounds such as methanethiol (MT), hydrogen sulfide, dimethyl sulfide (DS), dimethyl disulfide (DMDS), dimethyl trisulfide (DMTS) (Forney et al., 1991; Hansen et al., 1992; Maruayama, 1970), mostly originating from the breakdown of alkyl-cysteine sulfoxides through enzymatic action (Marks, Hilson, Leichtweis, & Stoewsand, 1992). Other volatile compounds, such as Z-3-hexen-1-ol, β-ionone, hexanal and nonanal, have also been considered as some of the major contributors to the broccoli flavour due to their low-odour threshold values (Hansen et al., 1992; Jacobsson et al., 2004; Tulio, Yamanaka, Ueda, & Imahori, 2002). Heat treatment of broccoli further increased the content of these off-flavour volatiles (Jacobsson et al., 2004).

Generally, thermal processing is used to inactivate microorganisms and/or enzymes in foods, to a targeted level aiming to increase the product safety and stability to a particular level (Awuah, Ramaswamy, & Economides, 2007). In order to obtain homogenized food systems such as a vegetable puree, different combinations of unit operations like heating and blending/shear (i.e. thermo-mechanical process conditions) have been applied. As described in our previous study (Koutidou, Grauwet, & Acharya, 2016), application of the mechanical step before or after the thermal process step is termed as 'cold break' (CB) and 'hot break' (HB), respectively. The aim in CB process is to break the plant tissue under cold condition whereas in HB the aim is to break the tissue at high temperature. Such order of thermal and mechanical process steps (i.e. unit operations) has been previously described to affect microstructures with different flow properties in broccoli purees (Lopez-Sanchez et al., 2011), however without any insight on the impact of the sequence of these processing steps on the volatile profile.

Broccoli purees are used in food industry as food ingredients in soups etc. Due to their high fibre content they can also potentially be used as natural structuring materials in several food products thereby increasing simultaneously nutritional value. However, case should be taken not to negatively affect the odour and the flavour of the final product.

The general objective of this paper is to investigate the effect of changing the order (i.e. sequence) of unit operations such as thermal and mechanical processing on the volatile profile of broccoli purees. The effect of changing the sequence of these unit operations was studied at different temperature (70 and 90 °C) and time (20 and 60 min) combinations. The selected temperatures are commonly used in the food industry for pasteurization purposes. In addition, since the above-mentioned process conditions probably modulate the microstructure of the product as well, we aimed to better understand the inter-relationship between flavour volatiles formation and microstructure. An untargeted GC–MS based chemical fingerprinting approach along with multivariate data analysis has been applied in order to detect significant differences in volatile profiles (discriminative marker compounds) of broccoli purees prepared by different (sequences of) process conditions. Such understanding of processing-induced compositional changes in broccoli puree, described in this paper, not only demonstrates the impact of different process conditions but can also facilitate the use of specific thermo-mechanical process steps to reduce undesired off-flavour in processed broccoli. In addition, in this work, a sensory difference test has been performed to corroborate if the compositional differences detected instrumentally in the volatile profiles are perceivable by the human nose (sniffing test). The correlation of the human perception of the odour with the chemical constituents is undeniably not a simple task.

The current study constitutes a systematic approach to investigate the relationship between the microstructure, the flavour profile and the human perception of differently processed broccoli. The identification of the optimal process conditions which can generate a reduced level of off-flavour in processed broccoli is necessary for the food industry. This knowledge will help to incorporate broccoli as a food ingredient into mixed food products with limited implications on sensorial consumer acceptance.

2. Materials and methods

2.1. Raw materials

The same batch of frozen broccoli florets (*Brassica oleracea* L. *italica*) was used for the preparation of all samples. The florets were obtained in standardized small pieces (3–4 cm) from Ardo (Zundert, The Netherlands). They were stored at −20 °C and thawed overnight at +4 °C before processing.

2.2. Sample processing

The thermo-mechanical process conditions applied in the current study consists of varying the sequence of unit operations for thermal and shear process conditions. The term 'cold break' (CB) is used when thawed broccoli florets were first blended and then heated, whereas 'hot break' (HB) refers to broccoli florets that were first heated and then blended. More details about the exact parameters used for the 'blending' and 'heating' steps are discussed below. All process steps were performed in a closed Thermomix system (Vorwek, Wuppertal, Germany).

Before processing, deionized water (1:3 wt ratio) was added to the broccoli florets. The blending step consisted of shearing of the florets at high speed (8000 rpm) for 10 min with 1 min interval after each 1 min of blending to avoid heating of the system due to friction. The heating step was performed at different temperatures (70 °C and 90 °C) and for different holding times (20 min and 60 min starting from the moment when the broccoli reached the required holding heating temperature of 70 °C or 90 °C). In order to achieve uniform heat transfer, the samples were slowly stirred (40 rpm) during the heating step, while the temperature was recorded externally by a digital sensor. Eight broccoli purees were prepared with various combinations of processing conditions (Table 1).

Directly after the preparation, the samples were placed in aseptic polypropylene vials of 125 mL capacity (VWR International, Amsterdam, Netherlands), cooled for 10 min in ice water, frozen with liquid nitrogen and stored at −20 °C until analysis. On a single day, all eight different broccoli purees were prepared. Every set of eight puree samples was prepared two independent times (i.e. two different days) to include experimental error originating from the preparation of the puree in the results.

2.3. HS-SPME-GC–MS analysis

2 g of thawed broccoli puree were homogenized with 2 mL of saturated NaCl solution in a 10 mL amber glass vial with PTFE/silicon septum seal screw-caps (Supelco, Bellefonte, PA, USA) and placed to the cooling tray of the autosampler which was set up at 5 °C. GC–MS analysis was performed on an Agilent gas chromatograph model 7890A coupled to a mass selective detector