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Effect of cooking on the contents of glucosinolates and their degradation products in selected *Brassica* vegetables

Joanna Kapusta-Duch [a,*], *Barbara Kusznierewicz* [b], *Teresa Leszczyńska* [a], *Barbara Borczak* [a]

[a] *Department of Human Nutrition, Agricultural University of Cracow, Balicka 122, 30-149 Cracow, Poland*
[b] *Department of Food Chemistry, Technology and Biotechnology, Gdańsk University of Technology, 11/12 G. Narutowicza St., 80-233 Gdańsk, Poland*

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ABSTRACT

Changes in the levels of glucosinolates and their degradation products in selected *Brassica* vegetables due to the cooking process were investigated. The purple cauliflower was found to be the best source of aliphatic and indole glucosinolates, and it was also abundant in compounds such as sinigrin, glucoraphanin and glucobrassicin. As a result of cooking rutabaga, green cauliflower and purple cauliflower, a significant decrease was noted in total glucosinolates (6.6, 68.9 and 69.2%, respectively) compared to raw vegetables. The hydrothermal processing applied led to a decline in the sum of indoles and isothiocyanates of 48.5 and 11.0%, respectively, in green cauliflower; and of 75.8 and 42.4%, respectively, in purple cauliflower; whereas, in rutabaga it led to an increase of 142.9 and 329.4%, respectively, compared with raw vegetables.

1. Introduction

Nowadays, there is increasing interest in natural, safe and functional foods. A food is said to be 'functional' if it provides a preventive, protective and/or curative function against one or more diseases, in addition to its adequate nutritional benefits (Kazeem & Davies, 2016).

Over the last two decades crops from the *Brassicaceae* (formerly Cruciferae) have been the focus of intense research based on their human health benefits (Traka & Mithen, 2009). Numerous epidemiological and pharmacological studies have revealed that a diet rich in *Brassica* vegetables may play an important role in the protection against many chronic diseases, including cardiovascular disease, type II diabetes, dementia, age-related macular degeneration, immune dysfunction, obesity and some cancers (Dos Reis et al., 2015; Shahidi & Ambigaipalan, 2015). The *Brassicaceae* is a plant family of huge economic importance, containing about 340 genera and 3700 species (Pedras & Yaya, 2010). These vegetables are among the most important vegetables consumed in Europe and all over the world owing to their availability at local markets throughout

* *Corresponding author.* Department of Human Nutrition, Agricultural University of Cracow, Balicka 122, 30-149 Cracow, Poland. Tel.: +48 12 662 48 16; fax: +48 12 662 48 12.
E-mail address: joannakapustaduch@interia.pl (J. Kapusta-Duch).
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the whole year, affordable cost and consumer preference (Herr & Büchler, 2010; Hounsome, Hounsome, Tomos, & Edwards-Jones, 2009). Although horticultural *Brassicaceae* plants are excellent sources of nutrients, such as vitamins, minerals and fibre, the majority of the research has concentrated on the content of secondary metabolites, e.g. glucosinolates, polyphenols and others (Kapusta-Duch, Kopeć, Piątkowska, Borczak, & Leszczyńska, 2012; Manchali, Murthy, & Patil, 2012). An extensive body of literature strongly suggests that all these compounds exert physiological actions contributing to beneficial effects on human nutrition. Therefore, *Brassica* vegetables are classified as functional foods.

The glucosinolates (GLS) are a large group of sulphur-containing compounds that occur in all economically important varieties of *Brassica* vegetables. Their common structure comprises a β-D-thioglucose group, a sulphonated oxime moiety and a variable side-chain derived from methionine, tryptophan or phenylalanine and some branched-chain amino acids. The glucosinolates are themselves not biologically active, only their enzymatic derivatives are. When the plant tissue is damaged, the glucosinolates are hydrolysed by the endogenous enzyme 'myrosinase' (thioglucoside glucohydrolase EC 3:2:3:1) to release a range of breakdown products. Depending on the chemical structure of glucosinolates such as aliphatic, aromatic, or indole glucosinolates, coexisting factors in vegetables such as epithiospecifier proteins (ESP), ascorbic acid or Fe^{2+}, as well as environmental conditions such as pH value, and end products of hydrolysed glucosinolates are different, including isothiocyanates, indoles, nitriles, oxazolidines and thiocyanates (Girgin & El, 2015; Mithen, Dekker, Verkerk, Rabot, & Johnson, 2000; Tang, Paonessa, Zhang, Ambrosone, & McCann, 2013; Verkerk et al., 2009). Actually, more than 200 different naturally occurring glucosinolates that occur in relatively high levels have been identified in *Brassica* vegetables. The content of glucosinolates depends on many factors, such as plant variety, growing condition, climate, the tissue-specific distribution in a plant parts (seeds, stems, leaves and roots), and both storage conditions (type and duration) and culinary treatment (Fuentes, Paredes-Gonzalez, & Kong, 2015; Korus, Słupski, Gębczyński, & Banaś, 2014).

The protection provided by phytochemicals present in *Brassica* vegetables containing glucosinolates is of great interest, because they may provide a safe and cost-effective strategy for combating several chronic diseases. However, according to some scientists, not only breakdown products of glucosinolates, but also intact glucosinolates are responsible for their health-promoting effect (Abdull Razis, Bagatta, De Nicola, Iori, & Ioannides, 2010; Avato & Argentieri, 2015). Bioactivity or biological effects due to intact glucosinolates present in food or in forage of monogastric animals result from the glucosinolates and/or transformation products, which in turn occur in non-enzymatic and/or myrosinase-catalysed processes (Avato & Argentieri, 2015). In *Brassica* vegetables, glucoraphanin and glucobrassicin are the most desirable glucosinolates, while indole-3-carbinol is one of the most valuable glucosinolate breakdown products. Its chemopreventive action, as in the case of sulforaphane, is widely known and documented. It is responsible for, among others, the induction of phase I and II detoxification enzymes (Higdon, Delage, Williams, & Dashwood, 2007; Kim & Milner, 2005; Murray, 2006), the inhibition of DNA adducts as well as inhibition of cell proliferation (Nachshon-Kedmi, Yannai, Haj, & Fares, 2003), cell cycle arrest (Moiseeva, Heukers, & Manson, 2007; Pappa et al., 2006), the inhibition of invasive growth and angiogenesis (Wu, Lin, & Chen, 2005), the induction of apoptosis (Souli, Machluf, Morgenstern, Sabo, & Yannai, 2008), and anti-estrogenic activity (Rahman, Li, Wang, Sarkar, & Sarkar, 2006). The compound 3,3′-diindolylmethane shows similar activity to indole-3-carbinol, and in addition exhibits the ability to repair DNA (Kim & Milner, 2005). Isothiocyanates, including the one most widely known in the literature, i.e. 4-methylsulphinylbutyl isothiocyanate (sulforaphane), have a similar protective effect against cancer as the aforementioned indole compounds. The isothiocyanates, however, inhibit the activity of certain enzymes involved in the activation of xenobiotics (phase I) and they induce phase II enzymes, thereby reducing the amount of any active carcinogen (Śmiechowska, Bartoszek, & Namieśnik, 2008). Sulforaphane also has anti-inflammatory and antimicrobial activities against *Helicobacter pylori* (Fimognari & Hrelia, 2007). In contrast to isothiocyanates, the indole compounds induce enzymes of both phases I and II of detoxification (Nho & Jeffery, 2001). Knowledge about the bioavailability, transport and metabolism of glucosinolates after consumption of *Brassica* vegetables is an essential prerequisite to understand the mechanisms of their protective effects observed in humans (Moreno, Carvajal, López-Berenguer, & García-Viguera, 2006). The occurrence of such compounds in food determines its functional and health-promoting nature (Manchali et al., 2012; Volden, Bengtsson, & Wicklund, 2009). Therefore, their consumption should be highly promoted.

In most cases *Brassicas* are not eaten immediately after being harvested; hence, storage and cooking impact upon health beneficial components. Processing of *Brassica* vegetables has complex influences on the food matrix affecting the level of glucosinolates: enzymatic hydrolysis by myrosinase, myrosinase inactivation, cell lysis and leaching of glucosinolates, their breakdown products and myrosinase in cooking water, thermal degradation of glucosinolates and their breakdown products, increase in the chemical extractability, and loss of enzymatic cofactors (Verkerk et al., 2009). The objectives of this paper were to evaluate how the process of traditional cooking in water changes the content of total and individual glucosinolates and their breakdown products (indole-3-carbinol, indole-3-acetonitrile, 3,3′-diindolylmethane, total indoles and total isothiocyanates) in common *Brassica* vegetables (green and purple cauliflower, rutabaga).

The concentration of glucosinolates and isothiocyanates in *Brassica*-vegetable-based food is far more variable than previously thought. Interestingly, in recent years, many studies have reported different influences of cooking on the chemical compositions of vegetables (Palermo, Pellegrini, & Fogliano, 2014). In this study, analysis was carried out not only for changes in total glucosinolates, but also in individual glucosinolates and, innovatively, their breakdown products, influenced by the cooking process. To the best of our knowledge there are, unfortunately, very few studies that could investigate not only the amount of glucosinolates and their profile, but also their breakdown products. The majority of studies published to date have focused on other cultivars of *Brassicas*. Less information is available about other *Brassicas*, e.g. coloured varieties of