

Review

A review of the influence of postharvest treatments on quality and glucosinolate content in broccoli (*Brassica oleracea* var. *italica*) heads

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Abstract

The parameters for maintaining visual and nutritional quality in broccoli heads after harvest are well understood, with low temperature maintenance being of paramount importance. Recently, much attention has been focussed on the phytochemicals contained within broccoli, glucosinolates in particular, that may help prevent the onset of certain cancers and cardiovascular disease. Relatively little is known, however, of the effects of commonly used postharvest handling procedures designed to maintain broccoli quality on glucosinolate content. This review looks at the effects of temperature, relative humidity, storage under controlled atmosphere (CA) or modified atmosphere packaging (MAP) and processing on glucosinolate content in broccoli heads. In addition, the significant effect of cooking on glucosinolate content is reviewed. The most important postharvest conditions necessary for maintaining broccoli quality are low temperature (<4 °C) and high relative humidity. These conditions maintain cellular integrity and in the process appear to maintain glucosinolate content by preventing the mixing of glucosinolates with myrosinase. One of the most important processes in the postharvest chain that has the most critical effect on glucosinolates, however, is the cooking method employed, with steaming for 2 min being the most effective way to maintain glucosinolate content. Crown Copyright © 2006 Published by Elsevier B.V. All rights reserved.

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1. Introduction

It is well known that from the time of harvest quality declines in fruit and vegetables and many nutrients are lost rapidly, particularly if produce is not cooled effectively (Kays, 1991). This quality decline includes visual symptoms, such as loss of turgor and yellowing of green produce, as well as loss of important nutrients, such as sugars (Pramanik et al., 2004) and vitamin C (Gil et al., 1999; Lee and Kader, 2000). While much is known about the fate of macro- and micro-nutrients and vitamins within vegetables after harvest, comparatively little is known about the fate of phytochemicals. For the purposes of this review, phytochemicals can be defined as compounds found naturally within plants that have health protecting qualities when consumed, but are not essential nutrients (i.e. not proteins, carbohydrates, fats, minerals, and vitamins).

Fresh broccoli contains a wide range of phytochemicals, including glucosinolates, flavonols and carotenoids. There is strong epidemiological evidence that a high consumption of brassica vegetables, including broccoli, is associated with a decreased risk for lung, stomach, colon and rectal cancers, most likely due to their glucosinolate content (Van Poppel et al., 1999). More recent epidemiological studies, however, provide less compelling evidence per se for an inverse relationship between brassica consumption and incidence of other cancers, such as prostate (Giovannucci et al., 2003). These researchers suggest future studies concentrate on the early phases of cancer development, as it was considered more likely that brassica consumption would inhibit development of early stage, rather than more advanced tumours.

In addition, genomic studies have recently begun to add more detail to epidemiological studies, which by their nature result in broad conclusions. For example, 40% of the human population may have an increased requirement for brassicas because their genotype puts them at elevated risk of some cancers. People with the common *GSTM1* null genotype have a

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slightly elevated risk of bladder cancer (Engel et al., 2002), and there has been a suggestion that the anti-cancer role provided by isothiocyanates may be stronger in this genotype (Lin et al., 1998).

From a human health perspective, the most studied group of phytochemicals found in broccoli are the isothiocyanates, hydrolysis products of glucosinolates, which have been identified as the primary components having anti-cancer activity. At this stage of our understanding, the most bioactive isothiocyanates found in broccoli are sulforaphane (derived from glucoraphanin), allyl isothiocyanate (derived from sinigrin) and indole-3-carbinol (derived from glucobrassicin). In plants isothiocyanates have antibacterial and antifungal activity, and provide important protection from insect and herbivore attack (Rosa et al., 1997). In vitro studies have demonstrated that a range of isothiocyanates, such as sulforaphane, both inhibit Phase I enzymes, responsible for the activation of carcinogens, and induce Phase II detoxification enzyme systems, thereby increasing the body's cancer defence mechanisms (Zhang et al., 1992; Talalay et al., 1995; Johnson, 2000; Munday and Munday, 2004). Isothiocyanates have also been implicated in the inhibition of cancer cell proliferation and induction of apoptosis (Musk et al., 1995; Huang et al., 1998; Smith et al., 1998), as well as inhibition of *Helicobacter pylori*, the bacteria responsible for stomach ulcers (Fahey et al., 2002). Sulforaphane derived from broccoli sprouts, has also recently been linked to prevention of cardiovascular disease in an animal model study using rats (Wu et al., 2004).

Glucosinolates are hydrolysed by the enzyme myrosinase, a thioglucosidase, to form unstable thiohydroxamate-O-sulfonates, which then rapidly break down chemically to form a range of reactive chemicals including isothiocyanates (Rosa et al., 1997) (Fig. 1). Glucosinolates are stable compounds, localised in vacuoles, and are physically separated from myrosinase in intact plants, indicating there are probably no breakdown products normally present (Fahey et al., 2001). Myrosinase is located in vacuole-like structures in special, isolated myrosin cells (Chen and Andreasson,

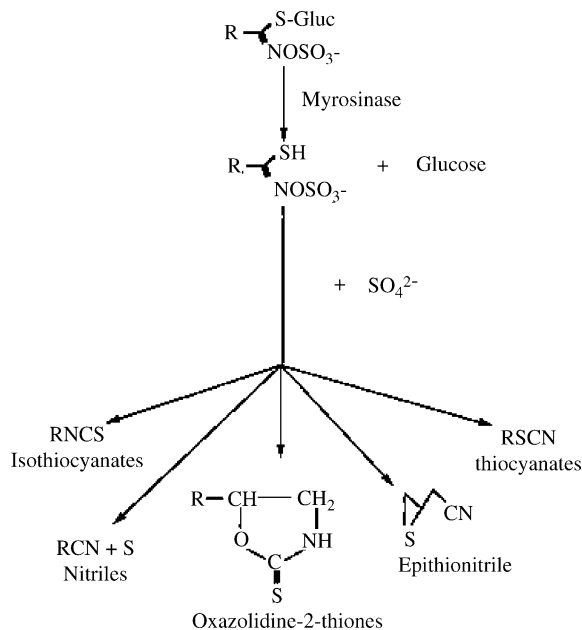


Fig. 1. The glucosinolate breakdown pathway, showing products after myrosinase action.

2001). Upon decompartmentalisation, however, glucosinolates are rapidly hydrolysed when mixed with myrosinase, which removes the sugar from the glucosinolates, resulting in isothiocyanates, nitriles, organic cyanides, and ionic thiocyanate (SCN⁻) (Fahey et al., 2001). Typically, postharvest physical disruption of the plants (e.g. chewing, chopping, blending, juicing, cooking, freezing/thawing and high temperature) leads to loss of cellular compartmentalisation and subsequent mixing of glucosinolates and myrosinase to form isothiocyanates (Rosa et al., 1997).

Glucosinolate types vary widely between brassica species, while content varies between varieties (Jeffery et al., 2003). Generally there are three classes of glucosinolates found within brassicas: aromatic (derived from phenylalanine), aliphatic and alkenyl (derived from methionine) and indole, or indolyl, derived from tryptophan (Wallsgrave and Bennett,

Table 1
Glucosinolates identified in broccoli, with relative abundance (%)

Trivial name	Systematic name	Class	Relative abundance (%)
Glucoraphanin	4-Methylsulphinylbutyl	Aliphatic	55.5
Glucobrassicin	3-Indolylmethyl	Indolyl	8.6
Gluconapin	3-Butenyl	Alkenyl	7.8
Progoitrin	(2R) 2-Hydroxy-3-butenyl	Alkenyl	7.8
Napoleiferin	2-Hydroxy-4-pentenyl	Indolyl	5.5
4-Methoxyglucobrassicin	4-Methoxy-3-indolylmethyl	Indolyl	3.1
Gluconasturtiin	2-Phenylethyl	Aromatic	3.1
Glucobrassicinapin	4-Pentenyl	Indolyl	2.3
Glucoalyssin	5-Methylsulphinylpentyl	Aliphatic	1.6
4-Hydroxyglucobrassicin	4-Hydroxy-3-indolylmethyl	Indolyl	1.6
Neoglucobrassicin	<i>N</i> -Methoxy-3-indolylmethyl	Indolyl	1.6
Sinigrin	2-Propenyl	Alkenyl	0.8
Gluciberin	3-Methylsulphinylpropyl	Aliphatic	0.7

After Kushad et al. (1999).

1995). Glucosinolate content is heavily influenced by genetics, but content can also be altered significantly by the environment that the crop was grown under (Rosa et al., 1997; Brown et al., 2002). The most common glucosinolates found in broccoli, and mentioned in this review, are glucoraphanin (aliphatic), sinigrin, progoitrin, gluconapin (alkenyl), and the indoles glucobrassicin and neoglucobrassicin (Table 1; Kushad et al., 1999).

There are many ways in which produce is treated after harvest, and it is not yet known whether the best postharvest practices for maintaining quality will result in the optimum retention of phytochemicals. Cooking is often neglected as an important process in the postharvest chain stretching from harvest to ingestion, and recent research has shown that cooking method has perhaps the most profound effect on glucosinolate content in broccoli. To date, a generally agreed recommendation on cooking method that retains phytochemical content and bioefficacy has not been widely circulated. This review attempts to answer these questions for glucosinolates contained within broccoli heads and florets. Where evidence from broccoli is scarce, studies on other brassicas are considered.

2. Time and temperature

Broccoli heads deteriorate rapidly after harvest, and cool temperatures (0–4 °C) are essential to maintain quality (Toivonen and Forney, 2004). Glucosinolate levels mirror visual quality in broccoli as they generally decrease during postharvest handling, with low temperatures (<4 °C) clearly slowing the loss of both quality and glucosinolates. Glucoraphanin content in broccoli florets declined by 82% after 5 days at 20 °C, but by only 31% at 4 °C (Rodrigues and Rosa, 1999). Similarly, Rangkadilok et al. (2002) reported a 50% decrease in glucoraphanin in ‘Marathon’ heads after 7 days at 20 °C, but no decrease after 7 days at 4 °C. In contrast, Howard et al. (1997) found that sulforaphane decreased by approximately 50% after 21 days storage at 4 °C, and the greatest decreases occurred within the first 7 days after harvest. It is not known whether this decline was due to a similar decrease in glucoraphanin or loss of myrosinase activity.

Indole glucosinolates, however, increased in concentration during 9 days storage at 10 °C in ‘Marathon’ florets (Hansen et al., 1995), and total glucosinolates did not change significantly, indicating that the rise in indole glucosinolates may have masked any decline in alkenyl forms such as glucoraphanin. Similarly, the indoles 4-hydroxy-glucobrassicin and 4-methoxy-glucobrassicin increased significantly after chopping and 48 h storage of broccoli at room temperature (approximately 20 °C), while all other glucosinolates decreased (Verkerk et al., 2001).

Freezing broccoli is commonly used in the food industry and is always preceded by a blanching step to inactivate enzymes that cause product deterioration. In general, glucosinolate content in broccoli was best maintained by freezing

(Rodrigues and Rosa, 1999), providing myrosinase was inactivated prior to freezing by blanching or some other heat treatment. If there was no blanching step before freezing, however, glucosinolates were completely broken down by myrosinase soon after thawing (Rosa et al., 1997; Johnson, 2000). While blanching broccoli before freezing was necessary, it also affected isothiocyanate formation, as a period of 2 min in water at 93 °C resulted in a 47–65% reduction in sulforaphane in broccoli tissue (Howard et al., 1997), probably due to leaching of glucosinolates and to partial myrosinase inactivation.

3. Relative humidity (RH)

A high RH of 98–100% is recommended to maintain postharvest quality in broccoli (Toivonen and Forney, 2004). Relative humidity only appears to be a critical factor in glucosinolate retention when postharvest temperatures rise above approximately 4 °C. For example, glucoraphanin content declined by >80% in broccoli heads left at low RH and 20 °C for 5 days (Rodrigues and Rosa, 1999). Similarly, broccoli heads stored in open boxes (low RH) at 20 °C showed a 50% decrease in glucoraphanin content during the first 3 days of storage, whereas heads stored in plastic bags with high RH (>90%) showed no significant loss at the same temperature (Rangkadilok et al., 2002). The decrease in glucoraphanin coincided with a marked loss of visual quality (i.e. yellowing), indicating probable loss of membrane integrity and mixing of glucosinolates with myrosinase. When broccoli was stored at 4 °C, however, there was no difference in glucoraphanin content after 7 days in either open boxes at ambient humidity (approximately 60% RH) or in plastic bags (approximately 100% RH) (Rangkadilok et al., 2002). It appears, therefore, that if broccoli is kept cold (i.e. less than 4 °C) there may be no benefit in maintaining 100% humidity, but if broccoli is kept at 20 °C it is necessary to maintain high RH with packaging to retain both visual quality and glucosinolate content.

4. Controlled atmosphere (CA) storage

CA storage is very effective in maintaining broccoli quality, and can double postharvest life (Toivonen and Forney, 2004). Ideal atmospheres to maintain quality were 1–2% O₂; 5–10% CO₂ when temperatures were kept between 0 and 5 °C (Cantwell and Suslow, 1999). Care needs to be taken that O₂ does not drop below 1% as this can cause the development of off-odours (Forney et al., 1991).

The effect of CA storage on glucosinolate content in broccoli, however, remains unclear. ‘Marathon’ broccoli heads stored for 25 days at 4 °C, under a CA atmosphere of 1.5% O₂; 6% CO₂ contained significantly higher glucoraphanin levels than heads stored in air at the same temperature (Rangkadilok et al., 2002). Alternatively, Hansen et al. (1995)

imposed lower O₂ (0.5%) and higher CO₂ (20%) and found that CA had no effect on the relative content of glucoraphanin, glucoiberin, glucobrassicin, neoglucobrassicin, or 4-methoxyglucobrassicin, compared to air, when “Marathon” heads were stored for 7 days at 10 °C. The total glucosinolate content, however, increased by 42% under air and 21% under 0.5% O₂ + 20% CO₂ compared to freshly harvested broccoli, whilst total glucosinolate content declined by 15% in heads held under 20% CO₂ with zero O₂, probably due to cell damage and enzymatic degradation of glucosinolates. Glucoraphanin and glucoiberin contents reflected the rises in total glucosinolates. Transferring heads to air after storage had no effect on glucosinolate content. The reported increase in glucoraphanin under air is puzzling, as it contradicts much of the storage work showing a decline in glucosinolates in broccoli heads held in air at 4 and 20 °C (Howard et al., 1997; Rodrigue and Rosa, 1999; Rangkadilok et al., 2002).

5. Modified atmosphere packaging (MAP)

It is often difficult to maintain low temperatures throughout the broccoli distribution and marketing phase, and in fluctuating temperatures MAP can help extend shelf life (Elkashif et al., 1983). Optimum broccoli quality was obtained when atmospheres within MAP reached 1–2% O₂ and 5–10% CO₂ (Jacobsson et al., 2004). MAP is also known to maintain levels of other phytochemicals, such as carotenoids, and vitamin C content in broccoli florets (Barth and Zhuang, 1996).

Temperature has a marked effect on glucosinolate retention when broccoli is kept under MAP. When broccoli heads were stored at 4 °C there was no difference in the glucoraphanin levels between air and MAP after 10 days storage (Rangkadilok et al., 2002). The MA bags used were low-density polyethylene (LDPE) bags (sealed with no holes) and at 4 °C atmospheres of approximately 3% O₂; 11% CO₂ were reached after 7 days, which further modified to 0% O₂; 13% CO₂ after 10 days. At 20 °C, however, broccoli in air lost 50% of its glucoraphanin in 7 days. In contrast, under MAP there was no significant decrease in glucoraphanin over 10 days (Rangkadilok et al., 2002). In this case, the MA bags used were LDPE bags with two micro-holes approximately 750 µm in diameter on each side of the bag, and the atmosphere reached 1% O₂ and 18% CO₂ after 7 days.

In comparison with the glucosinolate content of freshly harvested broccoli, glucoraphanin content of ‘Marathon’ broccoli heads stored for 7 days at 1 °C under MAP using 11 µm LDPE bags decreased by approximately 48% (Vallejo et al., 2003). A further 17% was lost after 3 days at 15 °C. Atmospheres within the MA packs reached 17% O₂; 2% CO₂ after 7 days at 1 °C, indicating only minor atmosphere modification.

The question arises whether it is relative humidity or atmosphere modification that is beneficial in retaining glucosinolate content after harvest. If temperatures rise above 4 °C, as they commonly do in the retail environment, then

both atmospheres and RH are important factors in maintaining glucosinolate levels. At higher temperatures, CA studies show that O₂ levels below 1.5% and CO₂ above 6% maintained or improved glucosinolate levels (Hansen et al., 1995; Rangkadilok et al., 2002). We can conclude, therefore, that both CA storage and MAP appear to be useful tools in maintaining glucosinolate content after harvest, in that the atmospheres reached and/or RH achieved may have prevented membrane degradation and subsequent mixing of glucosinolates with myrosinase. However, far more work is necessary to confirm this view and more clearly elucidate the atmospheres that may best maintain glucosinolate content.

6. Processing and cooking

Any processing step that causes a disruption of cellular integrity may result in a loss of glucosinolates, due to the mixing of glucosinolates with myrosinase, but this is dependent on the type of glucosinolate (de Vos and Blijleven, 1988; Rosa et al., 1997; Barrilari et al., 2002). After chopping and storage of both broccoli and cabbage at room temperature (approximately 20 °C) there were significant reductions in aliphatic glucosinolates (e.g. glucoraphanin), but an increase in some indole glucosinolates (Verkerk et al., 1997, 2001). Total glucosinolates and the indole 4-methoxyglucobrassicin, in particular, were also found to increase in whole (un-chopped) broccoli heads during storage at 20 °C in air by Hansen et al. (1995).

Drying of intact broccoli at 50–65 °C maintained glucosinolates and myrosinase activity and it is only when the product was re-hydrated that glucosinolates were hydrolysed (Rosa et al., 1997). Dehydrating brassicas may inactivate myrosinase, but this depends on species and method of dehydration used. Bailey et al. (1961) reported that myrosinase was deactivated in dehydrated cabbage, but dehydration conditions were not provided. On the other hand, drying cabbage or Brussels sprouts overnight in a forced-draft oven at 50 °C did not inactivate myrosinase (Daxenbichler et al., 1977). In this study, autolysis of the dried material yielded predominantly isothiocyanates compared with nitriles in fresh tissue, indicating that the epithiospecifier protein (ESP) may have been inactivated at 50 °C, while myrosinase was not. Feeding freeze dried (for 7 days) or dehydrated broccoli (18 h in a vacuum oven at 60 °C) to rats resulted in significantly higher induction of quinone reductase, compared to hydrolysed broccoli (Hwang and Jeffery, 2004). As glucosinolate or isothiocyanate contents were not provided after freeze drying, dehydration or hydration, we can only assume that rats fed freeze dried or dehydrated broccoli ingested more glucosinolates and/or isothiocyanates compared to rats fed hydrolysed broccoli, which resulted in greater quinone reductase induction.

Matusheski et al. (2001, 2004) found that the epithiospecifier protein (ESP) favoured nitrile production over isothiocyanates in broccoli under certain conditions and indicated

that heating broccoli may result in a more bioactive product. Heating broccoli at 60 °C for 5 min, or more, inactivated ESP, resulting in more sulforaphane being produced, providing myrosinase had not been inactivated (Matusheski et al., 2004). Myrosinase was inactivated at 100 °C for 5–15 min, so any heat treatment of 60–70 °C for 5–10 min would inactivate ESP, but not myrosinase and result in higher sulforaphane production. As sulforaphane had a far more potent effect on Phase I and II enzymes than sulforaphane nitrile (Matusheski and Jeffery, 2001), the health effects of predominant sulforaphane production could be significant. Other processing conditions, such as pH, also had a significant effect on sulforaphane:sulforaphane nitrile production. A neutral or alkaline pH resulted in predominately sulforaphane production, whereas an acidic pH (3.5, typical of salad dressings), resulted in more sulforaphane nitrile (Matusheski and Jeffery, 2001).

The postharvest process that has arguably the most effect on glucosinolate and other phytochemical content is cooking. Many nutrients, vitamins and phytochemicals are known to significantly decline during cooking. Ascorbic acid, carotenoids and phenolics in broccoli all decreased significantly with time during boiling or microwave cooking (Zhang and Hamazu, 2004). Glucosinolate content in broccoli heads also declined significantly during cooking. Sones et al. (1984) found that the total glucosinolate content of broccoli boiled for 10 min was approximately 40% less than for fresh broccoli. Glucosinolates were primarily lost from broccoli tissue through leaching into the cooking water, but the rate of loss was dependent on the type of cooking used (Rosa and Heaney, 1993; Howard et al., 1997; Dekker et al., 2000; Conaway et al., 2000; Vallejo et al., 2002; McNaughton and Marks, 2003). A small proportion of glucosinolates may also be broken down thermally during cooking (Heaney et al., 1985). Boiling broccoli, cabbage, cauliflower and Brussels sprouts for 40 min, or steaming for 10 min, resulted in significant thermal degradation of indole glucosinolates (Slominski and Campbell, 1989). However, it is unlikely that thermal degradation is a major cause of glucosinolate decline when brassicas are cooked for less than 10 min (Rosa et al., 1997).

The type and time of cooking used can also dramatically affect the glucosinolate content in broccoli at the time of consumption, with a five to 10-fold difference in the level of glucosinolates available resulting from differences in cooking (Dekker et al., 2000). Microwaving and boiling resulted in the largest losses in glucosinolates in broccoli (Howard et al., 1997; Conaway et al., 2000; Dekker et al., 2000; Vallejo et al., 2002; McNaughton and Marks, 2003). Steaming, on the other hand, appeared to minimise the loss of glucosinolates (Howard et al., 1997; Rosa et al., 1997; Conaway et al., 2000), although the degree of loss varied. Some individual glucosinolates were more thermolabile than others: glucoraphanin and neoglucobrassicin were more tolerant of cooking than other glucosinolates (Vallejo et al., 2002). There is also a significant variety-dependent variation in the decline

in glucosinolates after cooking in broccoli, as well as other brassicas (Rosa et al., 1997).

Cooking may also be an important factor in determining whether isothiocyanate production dominated over nitriles. Sulforaphane nitrile was the principal breakdown product of glucoraphanin, due to the action of ESP, when a number of broccoli cultivars were macerated raw at room temperature (Howard et al., 1997; Matusheski et al., 2001; Mithen et al., 2003; Matusheski et al., 2004). Sulforaphane production increased, however, after cooking broccoli at 60 °C for 5 or 10 min, as temperatures >50 °C were sufficient to knock out ESP activity (Matusheski et al., 2004). Choosing the right broccoli variety could also improve the amount of sulforaphane consumed. The sulforaphane:sulforaphane nitrile ratio varied widely between broccoli varieties and appeared to be genetically determined (Matusheski et al., 2001, 2004; Mithen et al., 2003).

The stability of isothiocyanates formed during cooking or processing is still not clear. Rose et al. (2000) reported that phenylethyl isothiocyanate (PEITC) from watercress was not found in aqueous extracts due to its volatility, and many other alkenyl and methylthioalkyl isothiocyanates were similarly volatile. More recently, however, Ji et al. (2005) found that PEITC was stable in aqueous buffers (pH 7.4) with a half-life of 56 h at room temperature, and 108 h at 4 °C. Thus, it is possible that juices made from cruciferous vegetables could contain significant amounts of isothiocyanates providing they were made within 24 h and were refrigerated.

7. Flavour

Many phytochemicals, including glucosinolates, phenols, and flavonoids are bitter tasting, which poses a quandary for a food industry intent on raising the levels of these compounds in their products to boost perceived health attributes (Drewnowski and Gomez-Carneros, 2000). There are three major glucosinolates in broccoli that may impart a bitter taste: sinigrin, progoitrin and glucobrassicin (Van Doorn et al., 1998; Johnson, 2000; Drewnowski and Gomez-Carneros, 2000). While sinigrin is found in relatively minor levels in broccoli, glucobrassicin and progoitrin are second only to glucoraphanin in abundance, dependent on variety (Table 1; Kushad et al., 1999). In a recent study, there was a high correlation ($R^2_{\text{multiple}} = 0.89$; $p = 0.01$) between bitter taste and sinigrin, gluconapin, progoitrin, glucobrassicin and neoglucobrassicin content in broccoli and cauliflower (Schonhof et al., 2004). This bitterness could be masked, however with a high sugar content. This could be a successful strategy for broccoli breeders who wish to breed high glucosinolate broccoli varieties that will be more acceptable to consumers' taste.

However, research on compounds associated with flavours in broccoli is limited and it is not yet clear whether a high glucoraphanin broccoli cultivar will taste more bitter. Hansen et al. (1995) found no clear relationship between sensory flavour

attributes in broccoli and glucosinolate content. The flavour attributes of 19 cooked broccoli cultivars were compared to glucosinolate content by Baik et al. (2003). All mean intensity ratings were below the level that indicated intense flavour or aroma, and there was no statistical relationship between bitterness and progoitrin, or glucoraphanin content. The authors concluded that other sulphur-containing compounds could be responsible for bitterness in cooked broccoli, while isothiocyanates could be responsible in raw broccoli. At this stage it appears that neither glucoraphanin nor sulforaphane are major contributors to bitter taste in broccoli.

8. Conclusion

The relatively recent discovery of glucosinolates as potential anti-cancer agents has resulted in a far more multidisciplinary research effort with the aim to improve and maintain glucosinolate content in vegetable crops throughout production, postharvest and meal preparation. Based on the papers covered in this review it can be said that the recommended postharvest conditions for maintaining broccoli quality (low temperature, in particular) will also maintain glucosinolate content. The exception to this is cooking—all forms of cooking significantly reduced glucosinolate content. A light steam for 3.5 min, or less, appears to be the best way to prepare cooked broccoli (Vallejo et al., 2002).

Considerable work still needs to be done before we can fully understand the effects of common postharvest practices on not only glucosinolate levels, but also isothiocyanate production, and absorption and bioefficacy in humans. In particular, more work needs to be done on the reaction of individual glucosinolates to postharvest conditions and cooking, as it is possible that aliphatic glucosinolates may react differently to indoles, and indeed may react with each other to increase bioefficacy in a synergistic manner (Staak et al., 1998). Little is also known about the effect of other postharvest factors, such as ethylene, or cytokinin application on glucosinolate content.

From a wider perspective, the requirement to better understand the role and fate of a range of natural and process-induced phytochemicals on both food stability and human health suggests that considerable areas of research remain to be explored.

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