

Glucosinolates in Cruciferous Vegetables: A Comprehensive Review of its Toxicity and Effective Reduction Techniques

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ABSTRACT

Plants are considered as an efficient source of energy and food for almost all organisms. They protect themselves from dangers by adopting a fighting mechanism which involves releasing inborn chemicals called secondary metabolites. These secondary metabolites such as glucosinolate are found in cruciferous families and they can have adverse effects on health if an exposure of short or long tenure occurs. Exposure can be fatal for humans by affecting organs such as kidneys, reproductive system and immune function and may cause chronic irreversible negative health problems. So, to overcome the negative health effects of these metabolites, different conventional and innovative food processing technologies have been studied that could remarkably diminish most of the harmful substances in food to the acceptable level.

Keywords: Glucosinolates, Cruciferous vegetables, Glucosinolate reduction techniques, Glucosinolate toxicity

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Introduction

Food is the fundamental need of every living organism such as animals and humans, comprised of different nutrients for the basic functions of life [1]. The basic source of food includes animals and plants, and some plant components are also used for this purpose [2]. A wide range of secondary metabolites is also produced by food crops which are of no use because of the absence of essential nutrients. The structure of these secondary metabolites varies from simple organic compounds to complex molecular structures like proteins and amino acids [3]. The inborn plant metabolites play an environmental effect in plants organic functions, defense mechanism and increased productivity among all the plant metabolites [4]. Furthermore, some of these metabolites are reluctant to predators and can cause harmful effects for humans too [3]. The secondary metabolites produced by plants can cause a negative impact on human health which can be of acute or chronic toxicity [5].

Studies have showed that, a large number of traditional and emerging food-processing techniques such as microwave [6], storage [7], gamma irradiation [8], high pressure processing [9], genetic engineering [10], microwave [11], salicylic acid treatment [12] etc. are found as valuable reduction techniques for glucosinolate detoxification. This review discusses various studies about the toxicity of glucosinolate and its mitigation by traditional and innovative food processing techniques.

Table 1: Basic and Vegetative names of cruciferous family

Basic Name	Vegetative Name
Broccoli	Brassica oleracea
Cabbage	Brassica oleracea
Cauliflower	B. oleracea
Chinese Cabbage	Brassica pokiness and B.chinensis
Portuguese tronchuda cabbage	Portuguese kale plants
Kale	B. oleracea
Brussels Sprouts	Brassica oleracea var.gemmifera
Mustard Green	Brassica juncea
Radish	Raphanusraphanistrum subsp. sativus
Turnip	Brassica rapa subsp. rapa
Horseradish	Armoraciasticana
Collards	Brassica oleracea var. sabellica
Rutabaga	B. napus var. napobrassica
Kohlrabi	B. oleracea var. gongylodes

Glucosinolates

The class of chemical compounds which belong to cruciferae family like cabbage, cauliflower and broccoli etc. are called Glucosinolates (GLSs). These have been a part of human diets, used in animal feed and serve as a crucial ingredient for different condiments. These chemical compounds have both positive and negative effects depending upon the time of exposure with a specific organism [13].

Structure of glucosinolates

The chemistry of glucosinolates involves a core aglycone structure that includes a β-D-thioglucose conneted to a sulfonated oxime group, with an additional variable side chain (R) that originates from one of eight natural amino acid precursors: aliphatic glucosinolates, primarily from methionine (Met), isoleucine (Ile), leucine (Leu), or valine (Val) whereas indole glucosinolates extracted from tryptophan (Trp), and aromatic glucosinolates extracting from phenylalanine (Phe) or tyrosine (Tyr) [14]. Glucosinolates (GSL), are stable compounds, which require enzymatic reactions for their hydrolysis and transformation into isothiocyanates (ITC) and indoles. This hydrolysis process depends on the enzyme myrosinase, a β-thioglucosidase which is present within specialized vacuoles in plant cells called myrosin bodies. When plant tissues are broken down during digestion in the gastrointestinal tract, GSL and myrosinase are released, which allow their subsequent breakdown [15] (Fig. 1).

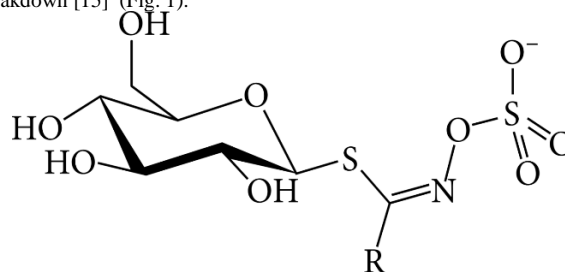


Fig. 1: Molecular structure of Glucosinolate

Secondary Metabolites

Secondary metabolites are the least important for an organism's survival when compared to primary metabolites. Primary metabolites are found in all dividing cells inherently, while secondary metabolites occur by chance. The organism's life is normally unaffected by the minimum presence of secondary metabolites, and they are not regarded as essential nutrients like other macro- and micronutrients [16]. The most important secondary metabolite in cruciferae family is the glucosinolate. However, glucosinolates may have various positive health effects, but consuming food from these plants can also cause harmful outcomes.

Table 2: Glucosinolate content in cruciferous vegetables (per 100g, raw) and its effects.

Cruciferous Vegetables	Glucosinolates (mg)	Plant part	Effect (^a µmol/g dry weight)	References
Horseradish	9–12.5 ^b	Roots	GI irritation, bloody vomiting, diarrhea	[17] [16]
Turnip	698	Various Parts	^b GI irritation, goiter, anemia, hepatic and renal lesions	
Mustard				
Rutabaga	458			
Broccoli	1297			
Cauliflower	1178			
Collards	11.4–36.4 ^b			
Kale	1206			
Brussels Sprouts	1013			
Kohlrabi	829			
Cabbage	1069	All parts	^b (in excess)	
Radish	676			

Glucosinolate detoxification methods

1. Cooking

Cooking is considered as a viable method which can reduce the food's glucosinolate content. This results in the reduction of food's total glucosinolate content after cooking in frozen *brassica* vegetable as compared to fresh vegetables with same treatment. Blanch freezing before boiling could be the reason for this because boiling makes the vegetables soft.

2. Microwave

Microwave treatment has a significant influence on total glucosinolate content of the vegetables if we increase the exposure time. Glucosinolate content of varieties (V1 & V2) decreased significantly by increasing the exposure time [6].

3. Storage

Storage also has an impact on glucosinolate content. A different set of data was obtained for the glucosinolate content of all samples (whole flower, floret, quarterly floret & floret shredded) which showed contrasting results. The results obtained by the different researches showed that the glucosinolate content was found fluctuating across the different species, under the set of similar and different conditions of experiments [7].

4. Gamma radiation

Treatment with gamma radiation had major effects on the glucosinolate content as a result of gamma irradiation treatment which caused a reduction of glucobrassicin, glucoiberin, and sinigrin in different proportions in comparison to the samples with no Gamma treatment. The type 2 kGy dose showed the best results across the scientific studies [8].

5. CRISPR/Cas9

Using CRISPR/Cas9 technology, researchers edited genes in the glucosinolate transporter (GTR) family in mustard to incorporate lines with specifically low levels of glucosinolates in the seeds, while keeping these compounds in high proportion in other plant parts for stronger plant defense system [10].

6. Salicylic acid

Salicylic acid treatment reduces the glucosinolate content of broccoli [12]. [18] stated that the glucosinolate content also decreases as the broccoli becoming yellow with more reduction in the content of glucoraphanin and glucobrassicin.

7. Morphotype

Morphotype influences the glucosinolate content in the seeds of winter oil seed rape. There are various studies have been conducted where the lowest, higher and highest value of this parameter was obtained in the population cultivar Chrobry, semi-dwarf hybrid and seeds of the long-stem PT 271 morphotype respectively [19]. [20] showed the cultivar Monolit has the lowest value of content.

8. Boiling

Boiling reduces the glucosinolate content as compared with the steam and sous-vide treatment. 10 minutes of boiling reduces the glucosinolate content drastically. Furthermore, boiling for longer times such as 25 min may reduce the glucosinolate content to low level in comparison to the raw material while there is not a very prominent effect with steam and sous-vide treatments. 40 minute treatment just enhances the coumaroyl-diglucoside in case of steam and sous-vide treatments [21].

Table 3: Processing methods for glucosinolate reduction

Vegetables	Method	Parameters	Results	References
Mustard	Microwave treatment	Frequency of 2460 MHz, power- 910 W, Time- 0.2, 4.6 min. but best result with 6.2 min.	Glucosinolates level reduced from 20.89 µM g ⁻¹ to 3.12 µM g ⁻¹	[6]
Broccoli floret shredded	Storage	Temperature - 20°C, Humidity 95%, Storage-3 days	Glucosinolate content dropped to 6.55 ± 0.37 mmol g ⁻¹ DW as compared to control sample	[7]
Cauliflower	Gamma Irradiation	Dosage-0.5, 1 and 2 kGy	Reduction of 61%, 39% and 35% in glucobrassicin, glucoiberin and sinigrin respectively, compared to non-irradiated (control) sample	[8]
Broccoli	HPP	Pressure- 700 MPa for 2 min	80% of glucosinolates changed into healthy isothiocyanates	[9]
Mustard	Genetic engineering	Changing of various homologues of GTR1 and GTR2 genes	reduction in glucosinolate content (SGC) from 142.09 µmoles g ⁻¹ DW to 6.41 µmoles g ⁻¹ DW	[10]
Broccoli	Microwave	Power- 900 W, Duration- 11 min	62.6% glucosinolate content diminished in microwave processing	[11]
Broccoli	Salicylic acid treatment	Precooling- 4 °C, 18 h, Salicylic acid concentration - 2 mmol L ⁻¹ , Storage - 4.5 °C, 75–79% relative humidity; 20 days	Glucoraphanin reduction - 85%, Glucobrassicin reduction - 89%, Neglucobrassicin reduction - 23%. These three contribute 88% of the total glucosinolate content.	[12]
Broccoli quarterly floret	Storage	Temperature - 20°C, Humidity 95%, Storage-3 days	Glucosinolate content dropped to 10.16 ± 0.33 mmol g ⁻¹ DW as compared to control sample (21.92 ± 0.48 mmol g ⁻¹ DW)	[7]
Rape Seed	Growth Stimulants effect on morphotype	Highest average air temp.- 10.1 °C, Highest average precipitation- 419.0 mm, Nitrogen doses- 3, Soil pH- 5.68 to 5.75, Morphotypes- 3	Cultivar Chrobry showed the lowest population of glucosinolate	[19]
Violet Cauliflower	Boiling	Time- 10, 25, 40 min. Boiled in 1.6 L of plain water, Temp.- 95° C	Levels of glucobrassicin reduced after 9 min of boiling whereas they were not affected by 9 min of steaming or sous-vide	[21]

Conclusion

In conclusion, glucosinolates, a secondary metabolite that is present in cruciferous vegetables, while offering some health benefits, can cause potential health risks subject to long-term exposure because of its toxic effects on human health by effecting organs such as kidneys and immune system. Different conventional and advanced food processing techniques have been studied to lower glucosinolate content, i.e., cooking, microwave treatments, storage, gamma irradiation, and genetic engineering. These methods successfully lower glucosinolate levels and make vegetables safe for consumption without reducing their nutritional value. Results from various studies have proved that these techniques lower glucosinolate level to a greater extent, thus making them completely safe for consumption. Further studies need to be done to optimize these methods which can improve food safety and could significantly improve the properties of cruciferous vegetables and reduce the risk linked with glucosinolate intake.

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