Effect of Postharvest and Industrial Processing on Glucosinolate from Broccoli: A Review

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Abstract: Glucosinolate, is a kind of bioactive sulfur-containing secondary metabolites, which are mainly distributed in cruciferous vegetables such as broccoli, cabbage, cauliflower, turnip, and radish. In recent years, Glucosinolate has been widely studied for its anticancer and cardiovascular activities. The types and contents of Glucosinolate in broccoli are related to many factors, such as the cultivars, growth environment and stages, postharvest practices, and processing treatments. To make full use of the potential activities of Glucosinolate, the effects of postharvest practices and food processing treatments on Glucosinolate have been carried out in recent years. The authors have shown that postharvest processing conditions, for example, temperature, relative humidity, storage under a controlled atmosphere or modified atmosphere packaging, and food processing treatments can significantly affect the contents of Glucosinolate in broccoli. Therefore, this review updates the scientific literature on postharvest and food processing treatments on Glucosinolate in broccoli. In addition, the effect of cooking practice on the content of Glucosinolate is also highlighted.

Keywords: Glucosinolate, Broccoli, Postharvest Treatment, Processing, Cooking

Introduction

Broccoli, one of the most important crops, has been consumed throughout the world (Miao et al., 2017; Sun et al., 2021). China is the largest producer of broccoli, which is followed by India, the United States, Spain, Mexico, and Italy. In the last decade, the consumption of broccoli has increased by several times due to the awareness of the active ingredients including polyphenols, flavonoids, vitamins (V₆, V₆₆, V₁₂, V₇, etc.), minerals (calcium, potassium, sodium, phosphorous, etc.), carotenoids, Glucosinolate (GLS), etc., (Alexandre et al., 2020; Soares et al., 2017). Epidemiological studies have demonstrated that broccoli can reduce the occurrence risk for many types of cancers due to GLS and their hydrolysates (Nugrahedi et al., 2016; Sun et al., 2021). GLS, a group of secondary metabolites containing elements sulfur and nitrogen, are primarily active substances in broccoli (Raiola et al., 2017; Vig et al., 2009). In general, GLS is composed of a β-D-thioglucose group, a sulfonated oxime group, and a side chain derived from amino acids (Barba et al., 2016; Seo and Kim, 2017). More than 120 kinds of GLS have been found in the Brassicaceae family, whereas around 17 varieties of GLS in broccoli have been reported (Table 1, Lafarga et al., 2018; Van Etten and Tookey, 2018). Briefly speaking, according to the derived amino acid precursors, GLS can be classified into three types: Aliphatic type GLS mainly from methionine, isoleucine, leucine, or valine, indole type GLS originated from tryptophan, and aromatic type GLS generated from phenylalanine or tyrosine (Romeo et al., 2018; Soares et al., 2017).

The distribution of GLS in many broccoli cultivars has been studied. GLS contents in broccoli are highly dependent on various factors, for example, the cultivars, developmental stages, preharvest, and postharvest processing treatments (Baenas et al., 2020; Miao et al., 2017; Prieto et al., 2019; Soares et al., 2017). The most common GLS in broccoli, are glucoraphanin (GLA, aliphatic type GLS), sinigrin, progoitrin, glucoraphacin (alkenyl), the indole glucobrassicin and neoglucobrassicin (Table 1). In the report of Farnham et al. (2000), GLA contents in investigated broccoli cultivars varied from 0.04 to 2.94 μmol g⁻¹ fresh weight. Similarly, Wang et al. (2012) indicated that GLA contents varied between 1.57 and 5.95 μmol g⁻¹ dry weight in five Chinese broccoli cultivars. Usually, GLS in broccoli are not directly bioactive, but their hydrolysates have the flavor and anticancer ability (Abdull Razis and Noor, 2013; Baenas et al., 2020). From the health standpoint, the most extensively investigated...
compounds in broccoli are the Isothiocyanates (ITCs), the hydrolysates of GLS, which are regarded as the main bioactive with anti-tumor activity (Miao et al., 2017; Prieto et al., 2019). GLS is distributed in the vacuole, while myrosinase is stored in the cytoplasm. After broccoli cell is damaged by external factors, for example chewing, insects attacking, or cooking processing, the hydrolysis of GLS begins once the contact of GLS and myrosinase occurs (Wu et al., 2021). The hydrolysates like thioglucose, sulfate, and unstable intermediates, are formed through the GLS-myrosinase system. Among the bioactive hydrolysates, the most popular compounds like nitriles, ITCs, thiocyanates, epithionitriles, and vinyl oxazolidinethiones, have been reported (Prieto et al., 2019). The factors, for instance, pH, the availability of ferrous ions, and the presence of myrosinase-interacting proteins can significantly influence the composition of the hydrolysates (Baenas et al., 2020; Nugrahedi et al., 2016; Prieto et al., 2019). However, because GLS are thermally sensible compounds, it is necessary to employ some methods to enhance their storage stability. Generally, all postharvest and processing treatments can cause a decrease in broccoli quality and a change in GLS contents. Many strategies have been employed to reduce GLS loss by radiation processing, heat, microwave, High-Pressure Processing (HPP), Modified Atmosphere Packaging (MAP), pre-freezing processing, freeze-drying, etc., (Aguilar-Camacho et al., 2019; Cai et al., 2016; Deng et al., 2017; Ferreira et al., 2018; Lu et al., 2020b, c; Paulsen et al., 2018; Torres-Contreras et al., 2017, 2018; Villarreal-García et al., 2016; Wang et al., 2016, 2018).

Cooking is not often considered a critical postharvest process. However, at present, numerous studies have shown that cooking can significantly affect GLS content in broccoli (Baenas et al., 2019, 2020; Miao et al., 2017; Nugrahedi et al., 2016; Soares et al., 2017). Therefore, this review updates the latest development on the effects of postharvest treatments and food processing on GLS content in broccoli.

Effect of Postharvest on GLS in Broccoli

Broccoli is one kind of highly perishable vegetable. Storage conditions, for instance, temperature, RH, atmosphere composition, Controlled Atmosphere (CA), MAP, etc., can significantly affect its quality (Baenas et al., 2020; Jones et al., 2006; Miao et al., 2017). Additionally, the treatment of broccoli with sucrose, 1-Methylecyclop propane (1-MCP), or melatonin, is also an effective method to increase the GLS retention (Miao et al., 2017). The effects of postharvest practices on GLS in broccoli were mainly discussed as follows. Some results on the effects of postharvest on GLS were presented in Table 2.

Storage Treatment

The level of GLS in broccoli is strongly affected by storage conditions (Baenas et al., 2020; Banerjee et al., 2014). In general, the stability of GLS in broccoli depends on many factors such as their chemical formula, storage temperature and time, packaging atmosphere, etc., and all these parameters need to be taken into consideration before the broccoli is stored (Jones et al., 2006; Miao et al., 2017).

Storage Temperature and Time

During the storage, the quality of broccoli usually decreases, which is accompanied by a decrease in GLS content (Miao et al., 2017). Among the factors affecting GLS content during broccoli transport and storage, storage time and temperature may be the most important ones. Lowering the temperature (<4°C) can maintain higher levels of GLS in broccoli. In one early study, GLA content in broccoli decreased by 82% after it was stored at 20°C for 5 days, while it declined by around 31% when broccoli was at the storage of 4°C (Rodrigues and Rosa, 1999). Similarly, Rangkadiok et al. (2002) found that GLA level in broccoli cultivar ‘Marathon’ decreased by 55% after it was kept at 20°C for 7 days, while there was not any loss after broccoli was stored at 4°C for the same time. The reasonable explanation was that high temperature could disrupt the cellular integrity of broccoli, and so the improved contact between myrosinase and GLS led to the fast hydrolysis of GLS (Prieto et al., 2019; Zinoviadou and Galanakis, 2017).

Recently, Oliviero et al. (2018) reported that cold storage of broccoli at 4–8°C for 7 days caused the GLS loss (27%).

Pre-cooling treatment is a popular method to increase the quality of broccoli. Wang et al. (2020) employed three methods (0°C cold storage pre-cooling (control), ice pre-cooling, cold water pre-cooling) to improve the quality of broccoli. The results showed that ice pre-cooling and cold water pre-cooling treatments could reduce the GLS loss. Slurry ice precooling was also used to treat broccoli (Liu et al., 2019). The results also demonstrated that it could reduce the GLS loss. Recently, Xie et al. (2021) investigated the effect of the combination of pre-cooling treatment and low-temperature storage (0±1°C) on the storage quality of broccoli. The authors indicated that pre-cooling treatment and low-temperature storage of broccoli could delay yellowing more effectively and maintain higher GLS content in broccoli.

Barba et al. (2016) studied the contents of the total indolyl and aliphatic types GLS in pre-stored broccoli at 0–4°C for 4–7 days and after storage at 10 and 18°C. The authors found that the total GLS and total aliphatic and indolyl types GLS increased after broccoli was stored at 10°C. Storage at 18°C increased the content of 4-hydroxyglucobrassicin. Similarly, Yuan et al. (2010) reported that the level of 4-methoxy glucobrassicin was improved when broccoli was preserved at 20°C. The results indicated that the contents of some indole types of GLS could be increased by postharvest treatment, and thus counteracted the breakdown of GLS induced by myrosinase. Actually, in these studies, the content of total GLS did not change significantly. The authors concluded that the increased level
of indole type GLS could counteract the decrease of aliphatic type GLS (such as GLA) content.

**Relative Humidity (RH)**

It is necessary to remember that RH is the crucial factor to maintain a high quality of broccoli. A high RH of 98~100% is highly recommended to keep the harvested quality of broccoli (Miao et al., 2017). Jones et al. (2006) reported that the most important storage factor to keep the high quality of broccoli was high RH, next to low temperature. GLA in broccoli decreased by more than 80% after it was stored under low RH, 20°C for 5 days. Similarly, GLA level decreased by 50% when broccoli was preserved in open boxes (low RH) at 20°C within the first 3 days, while the GLA loss was not obvious when broccoli was preserved in plastic bags under high RH (>90%) and the same temperature (Rangkadilok et al., 2002). The decrease of GLA in broccoli was generally accompanied by a significant deterioration of the quality, which implied that the hydrolysis generated by myrosinase, might occur. However, the difference in the change of GLA level was not found when broccoli was stored under low temperature (4°C) for 7 days whether in either open boxes with about 60% RH or plastic bags with around 100% RH (Rangkadilok et al., 2002). SHAKEEL et al. (2019) investigated the quality of broccoli under ambient conditions and proposed that the harvested broccoli had better be stored under lower temperatures and higher RH (>60%) to keep the good visual quality. Therefore, it seems that it is not too necessary to use 100% RH if broccoli is stored at a cooling temperature (below 4°C), whereas high RH combined with packaging is necessary to keep the high quality of broccoli when broccoli is preserved at 20°C (Shakeel et al., 2019).

**CA Storage**

CA storage is an effective means to keep the quality of broccoli and has been extensively applied to improve the shelf life of broccoli (Caleb et al., 2016; Fernández-León et al., 2013a, b, c; Singh et al., 2018; Wang et al., 2017). CA conditions should be carefully investigated. Lower concentration of gases in CA (0.5~1.0% O$_2$: 0.5% CO$_2$: 0.5~1.0% O$_2$: 1% CO$_2$: 0.50~1.0% O$_2$: 2% CO$_2$: 1.0% O$_2$: 1.0% CO$_2$) or controlled dynamic atmosphere (0.5%: 1.0%; 2.0% CO$_2$) could cause greater loss of indole-3-carbinol GLS in broccoli compared to the control, after a 3-month storage. The best atmosphere conditions to preserve the quality of broccoli were 1~2% O$_2$ and 5~10% CO$_2$ when it was stored at a temperature from 0 to 5°C (Jones et al., 2006). In the report of Fernández-León et al. (2013a), when broccoli was stored under cooling or room temperature (20°C), the decrease of GLS in broccoli was significantly reduced after it was treated by CA storage (10% O$_2$, 5% CO$_2$). Similarly, the content of GLA in broccoli stored at 4°C and CA (1.5% O$_2$ + 6% CO$_2$) was higher than that under air conditions (Rangkadilok et al., 2002). The authors indicated that higher CO$_2$ levels might induce GLA biosynthesis and/or the decrease of its degradation pathway. However, after being stored for 20 days at 1% O$_2$ or 1% O$_2$ +10% CO$_2$, GLA levels were significantly lower than those under 5°C air condition, and the total GLS level in broccoli cultivar ‘Marathon’ was reduced by 15% under the storage of 10°C for 7 days after it was treated by 20% CO$_2$ (Jones et al., 2006). Therefore, CA conditions such as normal content of O$_2$ and higher content of CO$_2$ are highly suggested for the storage of broccoli.

**Table 1: GLS distributed in broccoli**

| Commonly known name | Chemical name |
|---------------------|---------------|
| Aliphatic type GLS   |               |
| Glucoraphanin       | 4-methylnbutyl-GLS |
| Progoitrin          | (2R)-2-hydroxybut-3-etyl-GLS |
| Glucoerucin         | 4-methylnbutyl-GLS |
| Gluconapin          | 3-butenyl-GLS |
| Epiprogoitrin       | (2S)-2-hydroxy-3-butenyl-GLS |
| Glucoiberin         | 3-methylsulfinylpropyl-GLS |
| Glucoiberverin      | 3-methylthiopropyl-GLS |
| Glucobrassicatinapin| 4-pentenyl-GLS |
| Sinigrin            | 2-propenyl-GLS |
| Glucononin          | 5-methylsulfinylpentyl-GLS |
| Gluconapoleiferin   | 2-Hydroxy-4-pentenyl-GLS |
| Indole type GLS     |               |
| Glucobrassicin      | Indol-3-ylmethyl-GLS |
| 4-Hydroxy-glucoberin| 4-Hydroxy-indol-3-ylmethyl-GLS |
| Neo-glucoberin      | N-methoxyindol-ylmethyl-GLS |
| 4-Methoxy-glucoberin| 4-Methoxy-indol-3-ylmethyl-GLS |
| Aromatic type GLS   |               |
| Gluconastrutin      | 2-phenylethyl-GLS |

*Miao et al. (2017); Nugrahedi et al. (2016); Soares et al. (2017)*

**Table 2: Effects of postharvest treatments on GLS in broccoli**

| Methods                        | Results                                                                 | References                        |
|--------------------------------|-------------------------------------------------------------------------|-----------------------------------|
| Ethylene treatment             | Both aliphatic and indole type GLS (up to two times) levels were improved by ethylene treatment (1000 ppm, 24 h, 20°C). | Villarreal-García et al. (2016)   |
| 1-MCP treatment               | The total GLS content was significantly enhanced by the treatment of 1-MCP (25 μL^-1). | Fernández-León et al. (2013a)    |
| Melatonin treatment           | The degradation of GLS was significantly inhibited after broccoli was treated with melatonin treatment. | Miao et al. (2020)                |
| LED treatment                 | The decrease rate of total GLS was prevented after broccoli was treated by LED. | Jin et al. (2015)                 |
| Stored at 10% O$_2$, 5% CO$_2$| CA storage could effectively low the decrease of GLS in broccoli florets when broccoli was stored at cooling and 20°C. The loss of the GLS content in the MAP sample was about 23%, while it was about 57% in the control. | Fernández-León et al. (2013a)    |
| Stored in MAP using Micro-perforated polypropylene plastic |                                                                          | Fernandez-Leon et al. (2013b)  |
Observed the GLA level declined by 55% when broccoli was under the storage of open-air boxes for 3 days, and the level of GLA decreased by 56% when broccoli was stored in plastic bags for 7 days. The GLS content decreased more obviously when broccoli cultivar 'Parthenon' was under the storage of air conditions than that was stored under modified atmospheres using micro-perforated polypropylene plastic at 5°C for 12 days (Fernández-León et al., 2013b).

The GLS content is also significantly affected by storage temperature when broccoli is under the storage of MAP. No significant difference in GLA content was observed when broccoli was under the storage of air or MAP at 4°C for 10 days (Rangkadilok et al., 2002), whereas, the content of GLA decreased by 50% when broccoli was under the storage of air condition and room temperature for 7 days. Under the same storage temperature, GLA level was not significantly reduced when broccoli was stored under MAP for 10 days (Rangkadilok et al., 2002). Jia et al. (2009) also investigated the effect of MAP processing on the GLS content in broccoli cultivar ‘Youxiu’. In their study, polyethylene bags (40 μm thick) with no holes (M₀), two Micromoles (M₁), and four macro holes (M₂) were used to package broccoli samples, respectively, and then they were under the storage of 4 or 20°C. As for the control, the total GLS level was significantly reduced after it was stored at 4°C over 23 days. In addition, the total aliphatic and indole type GLS contents decreased by 56, and 42%, respectively, under the same storage conditions. However, for broccoli coated with polyethylene bags, the contents of the total aliphatic and indole type GLS were reduced by 26 and 15%, respectively, when it was preserved at 4°C for 23 days. The authors suggested that polyethylene bags (40 μm thick) without hole (M₀) was one of the effective packaging materials to keep the quality of broccoli whether at low or high temperatures. Recently, Zinoviadou and Galanakis (2017) presented the results of broccoli stored at 4 or 20°C in MAP and found the losses of the total aliphatic and indole types GLS decreased. The positive effect generated by MAP during postharvest storage was probably due to the change of amino acid contents since they were the precursors of some types of GLS (Bonte et al., 2017).

The use of Exogenous Metabolic Regulators

Methylcyclopropene (1-MCP)

1-MCP has been extensively applied to the preservation of fruit and vegetables (Miao et al., 2017). Yuan et al. (2010) showed that the employment of 1-MCP at the content of 2.5 μL L⁻¹ could reduce the degradation rate of GLS when broccoli was stored at 20°C. Similarly, in the work of Fernández-León et al. (2013a), after broccoli was treated with 1-MCP at the content of 0.6 μL L⁻¹, the decrease rate of GLS was reduced. Additionally, the use of 1-MCP at the content of 25 μL L⁻¹ could improve the total GLS level when broccoli was preserved at 15°C for 5 days.
(Xu et al., 2013). In short, 1-MCP shows a great potential to be used as a chemical preservative to reduce the degradation of GLS in broccoli.

Melatonin

Melatonin is regarded as one kind of bio-preservatives and has been widely used for the preservation of fruits and vegetables (Arnao and Hernández-Ruiz, 2019; Luo et al., 2018; Miao et al., 2020; Zheng et al., 2019). Miao et al. (2020) studied the effect of melatonin on GLS degradation when broccoli was stored at room temperature. In their work, a higher GLS retention rate and GLA accumulation were observed after broccoli was treated with melatonin at the content of 1.0 μL⁻¹. However, the level of GLS in the control was significantly reduced during the storage. As for the total contents of aliphatic and indolic types GLS, they decreased by 50 and 52%, respectively, after the control was stored for 3 days. Whereas, the total levels of GLS in broccoli handled by melatonin, were reduced by 17 and 35%, respectively, under the same storage time. Wei et al. (2020) also investigated the effect of melatonin treatment on GLS levels in fresh-cut broccoli when broccoli was stored at 4°C. The results showed that the total GLS level in broccoli treated with 100 μm melatonin was 16.08 mmoLkg⁻¹, which was almost two times higher than that in untreated broccoli after all broccoli samples were stored for 20 days. Furthermore, the total level of GLS in melatonin-treated broccoli was still higher than that in untreated broccoli.

Sucrose Treatment

Sucrose also has been employed to delay the senescence, and improve the storage quality of broccoli (Miao et al., 2017). Xu et al. (2016) investigated the effect of sucrose treatment on the levels of GLS in broccoli. The results showed the degradation rate of GLS in sucrose-treated broccoli, was significantly reduced compared to that in the control. Therefore, the authors indicated that sucrose exhibited great potential to be applied in maintaining the quality of broccoli. Generally, GLS contents in broccoli are highly related to two opposing mechanisms (Nugrahedi et al., 2015; 2016; Yuan et al., 2010). One is that GLS can be hydrolyzed by myrosinase, and the other is that the accumulation of GLS can be controlled by an unknown mechanism. According to this hypothesis, the authors inferred that the higher GLS content in sucrose-treated broccoli might be attributed to the regulation of myrosinase activity (Xu et al., 2016).

Besides the discussion above, Methyl Jasmonate (MeJA) and 6-Benzylaminopurine (6-BA) also have been used to maintain GLS content in broccoli (Chiu et al., 2019, 2020; Miao et al., 2017; Xu et al., 2020). 6-BA could significantly improve the retention rate of GLS (Xu et al., 2012). MeJA at the content of 250 μm also could increase the preservation of GLS in broccoli. Even if broccoli was treated by boiling, steaming, or microwaving, the total GLS level in broccoli treated by MeJA was markedly higher than that in uncooked broccoli (Chiu et al., 2019, 2020). Thus, the use of MeJA can improve the remained amount of GLS, and shows a great potential to be applied in the postharvest treatment of broccoli.

Light Treatment

Many authors have carried out the effects of radiation types on the biosynthesis of GLS in broccoli, and the results are different. Casajus et al. (2021) investigated the effect of continuous white light irradiation on the biosynthesis of GLS in broccoli during the storage. Visible radiation was found to reduce the decline of GLS content. The total GLS content in the control was reduced from 10.1 μmol/g dry tissue to 1.4 μmol/g dry tissue when it was stored for 5 days, whereas the total GLS content in treated broccoli was only reduced to 3.0 μmol/g dry tissue. Continuous white light irradiation treatment, not only could keep GLS levels, but also maintain the visual quality of broccoli at the same time. While, the content of aliphatic type GLS was improved when the visible light of 25 μmol m⁻² s⁻¹ was used to treat broccoli preserved at 18°C, and the content of GLS also increased when the same radiation conditions were employed to treat broccoli stored at 10°C (Rybarczyk-Plonska et al., 2016). Recently, Casajus et al. (2020) found that the senescence of broccoli during the storage was significantly affected by harvesting time. Harvesting time could affect the composition and level of GLS. During the day, with the extension of harvesting time, indolic type GLS content only decreased slightly. The level of aliphatics type GLS was reduced during the whole storage period. The possible reason was that darkness storage might give rise to the degradation of GLS since many studies indicated that light radiation could improve GLS accumulation (Rybarczyk-Plonska et al., 2016). In addition, the reason for the different GLS levels in broccoli harvested at different time points must be not related to the light radiation, since all broccoli samples were stored in the darkness.

Some investigations also have shown that Light-Emitting Diode (LED) lights, including LED green light, red LED irradiation, and yellow LED light, are better than fluorescent lights for maintaining the quality stability of broccoli (Jiang et al., 2019; Loi et al., 2019; Wang et al., 2021). Jin et al. (2015) investigated the effects of the treatments of fluorescent and LED green lights on GLS levels in broccoli. The results showed that the retention rate of the total GLS in broccoli treated with LED green light was significantly higher than that of the samples treated with fluorescent light. So, the authors suggested that LED green light was an effective way to reduce GLS loss, and improve the quality of broccoli.
In addition, emulsion technology and ethanol vapor treatments also have been applied to maintain GLS in broccoli. Wang et al. (2014) investigated the effect of ethanol vapor processing on bioactive substances, for example, polyphenols, total GLS, sulforaphane, etc., and the antioxidant activity of fresh-cut broccoli. The samples were pretreated with 2, 5, 10, or 20% ethanol vapor at 20°C for 6 h, then cut into small florets and stored at 10°C for 10 days. The results showed that the pretreatment with 10% ethanol significantly delayed the decrease of the total GLS content. During the investigated storage, the remained GLS in broccoli treated with 10% ethanol was 1.82 times higher than that of the control. Lu et al. (2020a) studied the effect of a double emulsion system (W/O/W) on the quality of broccoli and indicated that double emulsion technology could improve the quality of broccoli, and maintain higher GLS content.

**Effect of Cooking Process on GLS**

Before it is eaten, broccoli is usually treated by many kinds of cooking practices, for example, steaming, boiling, stir-frying, microwave, stir-frying followed by boiling, etc. The employed cooking process and cooking time can significantly affect the GLS level in broccoli and thus result in the cooked broccoli with different nutritional values (Nugrahedi et al., 2016). Until now, there have been reported on the mechanisms of the change of GLS content, including GLS leakage, GLS hydrolysis, heat-reduced myrosinase inactivation, and the degradation of GLS hydrolysates, etc., (Baenas et al., 2019, 2020; Nugrahedi et al., 2016; Sun et al., 2021). As for the mechanisms involved during the cooking practice for broccoli, it highly depends on the investigated cooking conditions. Generally, among the cooking practices, microwaving and boiling can lead to the greatest GLS drop (Baenas et al., 2020; Wu et al., 2021). However, the decrease in GLS level in steamed broccoli showed the lowest drop (Tabart et al., 2018; Wu et al., 2021).

**Cutting Treatment**

Cutting is a common handling method for broccoli pretreatment, which destroys the tissue of broccoli and thus promotes the formation of GLS hydrolysates (Jia et al., 2009). Torres-Contreras et al. (2017) examined the effect of cutting treatment on GLS in broccoli, which was cut as whole florets, two pieces of florets, four pieces of florets, and shredded pieces of florets. The authors pointed out that the contents of glucorucin and glucosturtin in cut four-piece florets were reduced by 62 and 50%, respectively, and thought that the hydrolysis reaction could occur. In another study, Jones et al. (2006) examined the levels of GLS in shredded pieces of broccoli after broccoli was stored for 48 h at room temperature. The authors found that the contents for most kinds of GLS were reduced, whereas the content of 4-methoxy-3-indolylmethyl GLS increased 15 times (Jones et al., 2006). Through analyzing the content of GLS in the finely shredded broccoli, it was also found that GLS content could be reduced by 75% after 6 h (Prieto et al., 2019; Song and Thornalley, 2007).

**Blanching/Boiling**

Since GLS are sensitive to heat, heat treatments of broccoli will affect the GLS content, and generally leads to a decrease in GLS content (Lafarga et al., 2018). The GLS loss highly depends on the chemical structure of GLS, for instance, the indole type GLS is more sensitive to heat than the aliphatic type GLS (Zinoviadou and Galanakis, 2017). During boiling, broccoli is dipped into water at 100°C, for at least 10 minutes, while blanching involves blanching broccoli in boiling water for up to 3 min, then removing it, and immersing it in cold water (Hanschen et al., 2018; Lafarga et al., 2018; Preciado-Iniga et al., 2018). Among the investigated processes for cooking broccoli, boiling may produce the greatest impact on GLS content. The decrease of GLS content in broccoli treated by cooking practice is mainly due to GLS leakage and the degradation of GLS hydrolysates. The loss amount of GLS is highly related to boiling time (Hanschen et al., 2018; Nugrahedi et al., 2015). Song and Thornalley (2007) compared four cooking practices, for instance steaming, boiling, microwaving, and stir-frying, and found that among these studied processes, only boiling could reduce GLS content significantly. Similarly, Cieslik et al. (2007) compared the effects of blanching and boiling treatments on GLS contents in the chosen cruciferous vegetables including broccoli, curly kale, Brussels sprouts, etc. The results also showed that the total content of GLS decreased significantly after the selected vegetables were treated by blanching and boiling. Recently, Hanschen et al. (2018) also found that boiling and blanching could affect the formation of the hydrolysates in cruciferous vegetables, thus resulting in the difference in GLS levels. Blanching was favorable for the formation of ITCs due to the heating denaturation of the epithio-specifier protein, while boiling could give rise to the leakage of GLS and the hydrolysates into the cooking water.

Mrkic et al. (2010) studied the effect of the combination of blanching and hot air drying (50–100°C) on GLS content in broccoli. The results indicated that GLS content decreased by appropriately 64% after broccoli was treated by water blanching, which was likely attributed to the leakage of GLS into cooking water (Mrkic et al., 2010). Some studies indicated that steam blanching could achieve the same purposes as water blanching (Baenas et al., 2020; Ndiaye et al., 2009). Compared with water blanching, steam blanching has some advantages, for example, the less leakage of GLS, the higher preservation of myrosinase activity. Compared with boiling and branching processes, the fermentation process could reduce GLS. Sosinska and Obiedinski
(2011) investigated the effects of heating treatment, pickling, and fermentation on glucobrassicin levels and the hydrolysates in broccoli and cauliflower. Heating treatment, for example, boiling and steam cooking, could remain the highest glucobrassicin level in selected vegetables, however, pickling and fermentation could cause the greatest loss of glucobrassicin. Xu et al. (2021a, b) investigated the effect of fermentation using animal- and plant-sourced *Pediococcus pentosaceus* on the formations of bioactive compounds in broccoli juice. The results indicated that the total GLS content decreased significantly after broccoli juice was fermented by the investigated *Pediococcus pentosaceus*.

Steaming

Steaming, by reducing the direct contact of broccoli with the cooking water, maybe the most effective method for remaining GLS level in post-harvested broccoli. Many studies have demonstrated that steaming can cause a slight decrease, or even improve the total GLS content (Lafarga et al., 2018; Sun et al., 2021; Wu et al., 2021; Xu et al., 2016; Zinoviadou and Galanakis, 2017). Miglio et al. (2008) studied the effects of three common cooking practices, for instance, boiling, steaming, and frying, on GLS contents. The results indicated that the total level of GLS was improved by 30.8% after broccoli was treated by steaming, however, when broccoli was treated by boiling and frying, the total levels of GLS decreased by 59.0 and 84.0%, respectively (Miglio et al., 2008). Interestingly, Jones et al. (2010) evaluated the effects of three cooking practices named boiling, microwaving, and steaming, on the content of GLS in broccoli. Regardless of treatment time, the higher retention of GLS was observed after broccoli was treated by steaming, whereas boiling and microwave processes could cause more losses of GLS in investigated broccoli. Similarly, Lu et al. (2020b) studied the effect of cooking time on GLA content in broccoli treated by four processes including steaming, boiling, stir-frying, and microwaving. The results showed that GLA content decreased with the extension of cooking time in each cooking method. Steamed broccoli retained a higher content of GLA. Among the investigated methods, the authors thought that the best methods to maintain the highest level of GLS (and/or) their derivatives were steaming (3–50 min) and microwaving (45–590 W). However, Bongoni et al. (2014) reported that the total GLS content increased by 17% after broccoli was treated by steaming. The reason was that the extractability of GLS was improved after broccoli was treated by heating.

Microwave

Many authors consider microwaving an effective method to preserve the GLS content (Table 3; Guo et al., 2017; Soares et al., 2017; Tabart et al., 2018; Xu et al., 2016). Some studies indicated that GLS loss was observed when microwaving was used to treat broccoli even under the optimized microwaving process (Vallejo et al., 2002). So, microwave conditions such as microwave power and time can significantly affect the preservation of GLS (Sun et al., 2021). Conflicting results regarding the effect of microwave processing on GLS content have been reported. Some studies indicated microwave treatment could cause a significant loss of GLS (Jones et al., 2010; Vallejo et al., 2002), whereas other investigations manifested it was a good way to preserve or even improve GLS content (Barakat and Rohn, 2014; Lu et al., 2020c; Soares et al., 2017; Wu et al., 2019). The inconsistent results are ascribed to the employed conditions, such as microwave power, time, etc. (Baenas et al., 2020; Tabart et al., 2018). Vallejo et al. (2002) demonstrated that the total GLS content decreased by 74% after broccoli was cooked using microwave treatment at 1000 W for 5 min, which was mainly attributed to the leakage of GLS into the cooking water. GLA content in broccoli treated by microwave treatment was reduced by 62% (Vallejo et al., 2002). Also, in the study of Jones et al. (2010), GLA content decreased by 15–17% after broccoli was treated by microwaving at 1,100 W for 5 min. However, Song and Thornalley (2007) found that the decrease in GLS level was not significant when broccoli was cooked by microwaving for up to 3 min. With the increase of microwave time to 19 min at 950 W, Tabart et al. (2018) manifested that the total GLS level in broccoli was still not significantly affected. The difference was mainly ascribed to the user conditions such as microwave time, microwave power, etc. Pellegrini et al. (2010) investigated the effects of cooking processes such as boiling, microwaving, and steaming on GLS content in broccoli. The results showed that microwaving was the best cooking practice for preserving GLS content among the investigated methods. The change in the total GLS content was not observed during the microwaving process, but only a slight variation of single-type GLS content was found. The high preservation of GLS was mainly ascribed to the loss of water during the microwaving process (Armesto et al., 2019; Campos et al., 2019; Guo et al., 2017; Tabart et al., 2018; Wu et al., 2019; Zhao et al., 2019). Wu et al. (2017) confirmed that microwave was an effective method to preserve GLS in broccoli. Lu et al. (2020c) investigated the effects of microwave and the low-temperature cooking process, on GLA levels in broccoli. The results showed that GLA content in broccoli cooked by both investigated methods was higher than that in the control. Compared to conventional heating, GLA content could be increased by around 80% after broccoli was cooked by microwaving at 60°C. Therefore, the authors suggested that GLA content could be improved when broccoli was
treated by microwaving treatment with a temperature below 60°C. Paulsen et al. (2021) carried out the effects of microwaving bag cooking and conventional microwaving on GLS content in broccoli. A higher total GLS level (32.3±2.6 µmol/g) was observed when broccoli was cooked using a microwave bag, compared to that in broccoli (26.4±1.3 µmol/g) cooked by conventional microwaving. No significant change in total GLS level was observed when broccoli was cooked in a microwave bag for the first 3–5 min. So, the authors suggested that a microwave bag was a good manner to preserve GLS content in cooked broccoli.

**Frying**

Stir-frying is one of the most widely employed cooking practices in some Asian countries, which involves frying foods using a little number of hot oils (Baenas et al., 2020; Nugrahedi et al., 2017; Tian et al., 2018). Regarding the effect of stir-frying on the retention of GLS, some contradictory results have been shown. In some cases, stir-frying can cause little loss of GLS, while in other studies, it can result in a significant decrease of GLS. The differences in these reports are mainly due to the used stir-frying conditions (Bongoni et al., 2014; Wu et al., 2021). Nugrahedi et al. (2017) reported that stir-frying was an excellent cooking practice to preserve GLS, due to the deactivation of myrosinase at the high temperatures during the process (160–250°C). Nugrahedi et al. (2015) also reported that frying (as well as steaming and microwave cooking) was beneficial for the retention of GLS. Yuan et al. (2009) studied the effects of cooking practices, such as microwaving, steaming, stir-frying, boiling, and stir-frying followed by boiling, on GLS contents in broccoli. The authors showed that the contents of total aliphatic type GLS were markedly reduced by 55, 54, 60, and 41%, respectively, after broccoli was accordingly cooked by stir-frying, stir-frying/boiling, microwaving, and boiling. In contrast, the content of total aliphatic type GLS did not almost change after broccoli was cooked by steaming. All investigated cooking methods could significantly decrease the total contents of the indole type GLS. The loss of total indole type GLS could reach up to 67 and 64%, respectively, when broccoli was accordingly cooked by stir-frying and stir-frying/boiling. Besides, the effect of stir-frying using different edible oils on the GLS level was also studied (Moreno et al., 2007). The results showed that stir-frying with different edible oils could significantly affect GLS content. Stir-frying with sunflower oil and refined olive oil could significantly cause the loss of total GLS of 49 and 37%, respectively, when broccoli was accordingly cooked by stir-frying with refined oil and sunflower oil. However, no significant change in total GLS was observed when broccoli was cooked using the rest investigated oils (Moreno et al., 2007). The thermal degradation of GLS resulted in a significant decrease in GLS content during stir-frying. So, the degradation of GLS was highly dependent on the used cooking edible oils. However, the relationship between stir-frying temperature and the retention or decrease of GLS content was not found. In the study of Song and Thorlalley (2007), no significant change in GLS content was observed when broccoli was cooked at stir-frying temperature up to 200°C for 3–5 min. However, in their study, a high decrease in GLS content was observed when broccoli was cooked by stir-frying and stir-frying/boiling. The differences in the results were due to the used cooking temperature. The myrosinase was denatured rapidly at high cooking oil temperature (200°C), and thus the hydrolysis of GLS did not occur. However, when the cooking oil temperature was around 130–140°C, the hydrolysis of GLS induced by myrosinase was produced. According to these results, the authors indicated that cooking oil temperature had better reach up to 200°C to ensure the preservation of the total GLS.

**Effect of Food Processing on GLS**

**Freezing**

Freezing is one of the most widely employed methods to keep the quality of broccoli (Baenas et al., 2020; Storey and Anderson, 2018). Broccoli usually goes through several treatments, for example, cutting, blanching, washing, and cooling before it is frozen. Indeed, for blanched broccoli, the content of GLS did not change after 3 months of storage (at 20°C), but for the non-blanched broccoli, a decrease of 33% of the total GLS content was observed at 85°C for seven-day storage (Oliviero et al., 2018). Rungapamestry et al. (2008) investigated the effects of blanching and freezing processing on GLS content in broccoli. GLS content in the control could be retained for up to 90 days at 20°C when it was treated by the blanching/freezing process. In addition, the highest remained GLS content was observed after the blanching-frozen broccoli was cooked by stir-frying. Furthermore, Alanis-Garza et al. (2015) evaluated the effect of the freezing process on the retention rate of GLS in seven broccoli cultivars. The results showed that the extractability of total GLS was improved when all studied broccoli cultivars, except cultivar Florapack®, were treated by the freezing process. Similarly, Cai et al. (2016) studied the effects of pre-freezing processing and freezing processing on GLS content in broccoli. The results indicated that pre-freezing processing could significantly reduce the biosynthesis of GLS. The freezing process could cause the decrease of aliphatic type GLS level (44.76%) and total GLS level (35.16%) but did not significantly affect indolic type GLS level (Table 3). In addition, the GLS level also could be improved by the freezing process. As mentioned above, two main mechanisms for the formation of GLS were proposed. One was the accumulation of GLS induced by an unknown pathway, the other was the breakdown of GLS by myrosinase.


### Table 3: Effects of processing methods on GLS levels in broccoli

| Processing methods          | Conditions         | The retention of total GLS | References                        |
|-----------------------------|-------------------|----------------------------|-----------------------------------|
| Microwave                   | 1000 W, 5 min     | ↓74%, GLS were reduced by 0.95, 13.5 and 64.6% for 1 min, 5 min, 10 min, respectively. | Vallejo et al. (2002)            |
|                             | 1000 W, 1–10 min  |                            | Hwang and Kim (2013)              |
|                             | 950 W, 5 min      | ↓90.4%. Sulfuraphane was increased by 99.5% (40°C), 46.6 (50°C), 27.4% (60°C), respectively. | Barakat and Rohn (2014)         |
|                             | 950 W, 40–60°C    |                            | Lu et al. (2020b)                 |
|                             | 300 W, 30 min     | 102.2%                     | Pellegrini et al. (2010)          |
|                             | 1100 W, 2 or 5 min| 83.9 ~104.1%.              | Jones et al. (2010)               |
|                             | 1000 W, 5 min     | 25.5%.                     | Vallejo et al. (2002)             |
|                             | 1000 W, 5 min     | 41.8%.                     | Yuan et al. (2009)                |
|                             | 900 W, 0.5–3 min  | ~100%                      | Song and Thornalley (2007)        |
|                             | 900 W, 2.5 min    | 60%                        | Martínez-Hernández et al. (2013) |
| Pre-freezing and freezing   | 3°C, 8 min; -26°C, 8 min | GLS were reduced by 64.9% at 3°C for 8 min, and reduced by 35.2% at -26°C for 8 min. | Cai et al. (2016)                |
| HPP                         | 300 MPa, 35 min, 20°C or 300 MPa, 15 min, 40°C. | The degradation of 80% of total GLS was found. | No degradation of GLS was observed. Van Eylen et al. (2009) |

The remained GLS content was generally attributed to the balance of both mechanisms during freezing processing. Regarding the freezing process, it not only caused the accumulation of GLS, but also might give rise to the denature of myrosinase, and subsequently lead to the decrease in the formation of GLS hydrolysates. Qiu et al. (2020) studied the effects of microwave thawing, steam thawing, natural thawing, and still water thawing on GLS. No significant differences in GLS level were observed when broccoli was processed by microwave thawing and steam thawing. However, the decrease of ascorbic acid content induced by steam thawing was around 23.7% compared to that treated by microwave thawing. After the treatment of microwave thawing, the contents of total phenolics, GLS, ascorbic acid, and carotenoids were 1.15, 1.20, 1.93, and 1.39 times those of the natural thawing treatment, respectively.

**HPP**

HPP is one kind of extensively applied strategy for preserving and sterilizing foods. When it is applied to foods, it causes the inactivation of enzymes and pathogenic microorganisms and helps to maintain the compounds that can promote our health (Baenas et al., 2020; Lafarga et al., 2018; Zinoviadou and Galanakis, 2017). Experiments have been conducted on the effect of HPP on GLS content. The results showed that the inactivation of myrosinase was at the pressure of 300 or 500 MPa (Zinoviadou and Galanakis, 2017). Van Eylen et al. (2009) investigated the effect of the combination of temperature (20–40°C) and pressure (100–500 MPa) on GLS content. The results manifested that HPP could induce the hydrolysis of GLS, and thus led to the formation of ITCs (Table 3). Therefore, the authors indicated that HPP could be used as an effective method to avoid the decrease in GLS content.

### Conclusion

Broccoli is one of the most popular vegetables due to the high content of GLS. GLS can be applied in many fields, for example, food additives, flavor enhancers, as well as anticancer agents. However, they are highly unstable compounds that can be easily hydrolyzed into some breakdown derivatives. Therefore, the preservation of GLS is critical work and should be considered as a part of the broccoli processing workflow for both food producers and the restoration sector. The high retention of GLS in broccoli can be obtained if correct post-harvest storage conditions, cooking handling, and food processing treatments are chosen. Therefore, the studies on optimizing postharvest conditions, food processing, and cooking handling for broccoli are very important. Postharvest treatments such as CA, cooling, MAP, freezing processing, and as well as 1-MCP and melatonin treatments, are effective methods to reduce GLS loss. Low temperature (<4°C) and high RH may be the most important storage factors to keep the high quality of broccoli, which can keep the integrity of broccoli cells, and reduce the contact of GLS and myrosinase. UV irradiation can effectively reduce microbial contamination in broccoli and improve the preservation of bioactive compounds including GLS. As for cooking practices, microwaving can retain or even increase GLS content in some cases. Boiling can reduce the GLS content significantly. The highly recommended method to cook broccoli is short-time steaming, which may be the best effective method to preserve GLS during cooking. Among thermal treatments, Blanch-freezing treatment does not cause a change in GLS content significantly. HPP, one of the nonthermal treatments, has been regarded as a promising way to maintain high GLS content.
Although many studies on the effects of postharvest and processing on GLS have been investigated, however, many works on this topic are needed to be carried out. The effect of the combination of the heating with other non-thermal methods like HPP on GLS is critical to be investigated in the future and, the underlying mechanisms of how post-harvest processing regulates GLS metabolism are still needed to be further explained. More importantly, the relationship between the changes of individual type GLS and postharvest processing needs to be further investigated.

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Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved.

References

Abdull Razis, A. F., & Noor, N. M. (2013). Cruciferous vegetables: dietary phytochemicals for cancer prevention. Asian Pacific Journal of Cancer Prevention, 14, 1565-1570. doi.org/10.7314/APJCP.2013.14.3.1565

Aguilar-Camacho, M., Welti-Chanes, J., & Jacobo-Velazquez, D. A. (2019). The combined effect of ultrasound treatment and exogenous phytohormones on the accumulation of bioactive compounds in broccoli florets. Ultrasonics Sonochemistry, 50, 289-301. doi.org/10.1016/j.ultsonch.2018.09.031

Aiamla-or, S., Kaewsuksaeng, S., Shigyo, M., & Yamauchi, N. (2012). Impact of UV-B irradiation on chlorophyll degradation and chlorophyll-degrading enzyme activities in stored broccoli (Brassica oleracea L. Italica group) florets. Food Chemistry, 120, 645-651. doi.org/10.1016/j.foodchem.2009.10.056

Aiamla-or, S., Shigyo, M., & Yamauchi, N. (2019). UV-B treatment controls chlorophyll degradation and related gene expression in broccoli (Brassica oleracea L. Italica group) florets during storage. Scientia Horticulurae, 243, 524-527. doi.org/10.1016/j.scienta.2018.09.009

Alanis-Garza, P. A., Becerra-Moreno, A., Mora-Nieves, J. L., Mora-Mora, J. P., & Jacobo Velazquez, D. A. (2015). Effect of industrial freezing on the stability of chemopreventive compounds in broccoli. International Journal of Food Sciences & Nutrition, 66, 282-288. doi.org/10.3109/09637486.2015.1007451

Alexandre, E. M. C., Moreira, S. A., Pinto, C. A., Pintado, M., & Saraiva, J. A. (2020). Analysis of glucosinolates content in food products. In “Glucosinolates: Properties, Recovery and Applications,” ed. by Galanakis, C. M. Academics Press, UK, pp. 213-250. doi.org/10.1016/B978-0-12-816493-8.00007-X

Armesto, J., Gomez-Limia, L., Carballo, J., & Martinez, S. (2019). Effects of different cooking methods on the antioxidant capacity and flavonoid, organic acid, and mineral contents of Galega Kale (Brassica oleracea var. acephala cv. Galega). International Journal of Food Sciences and Nutrition, 70, 136-149. doi.org/10.1080/09637486.2018.1482530

Arnao, M. B., & Hernández-Ruiz, J. (2019). Melatonin: A new plant hormone and/or a plant master regulator? Trends Plant Science, 24, 38-48. doi.org/10.1016/j.tplants.2018.10.010

Baenos, N., Cartea, M. E., Moreno, D. A., Tortosa, M., & Francisco, M. (2020). Processing and cooking effects on glucosinolates and their derivatives. In “Glucosinolates: Properties, Recovery, and Applications,” ed. by Galanakis, C. M. Academics Press, UK, pp. 181-212. doi.org/10.1016/B978-0-12-816493-8.00006-8

Baenos, N., Marhuenda, J., García-Vigueras, C., Zafrilla, P., & Moreno, D. A. (2019). Influence of cooking methods on glucosinolates and isothiocyanates content in novel cruciferous foods. Foods, 8, 257. doi.org/10.3390/foods8070257

Banerjee, A., Variyar, P. S., Chatterjee, S., & Sharma, A. (2014). Effect of post-harvest radiation processing and storage on the volatile oil composition and glucosinolate profile of cabbage. Food Chemistry, 151, 22-30. doi.org/10.1016/j.foodchem.2013.11.055

Barakat, H., & Rohn, S. (2014). Effect of different cooking methods on bioactive compounds in vegetarian, broccoli-based bars. Journal of Functional Foods, 11, 407-416. doi.org/10.1016/j.jff.2014.10.009

Barba, F. J., Nikmaram, N., Roohinejad, S., Khelfa, A., & Koubaa, M. (2016). Bioavailability of glucosinolates and their breakdown products: Impact of processing. Frontiers in Nutrition, 3, 1-12. doi.org/10.3389/fnut.2016.00024

Bongoni, R., Verkerk, R., Steenbekkers, B., Dekker, M., & Stieger, M. (2014). Evaluation of different cooking conditions on broccoli (Brassica oleracea var. Italica) to improve the nutritional value and consumer acceptance. Plant Foods for Human Nutrition, 69, 228-234. doi.org/10.1007/s11130-014-0420-2
Bonte, A., Schweiger, R., Pons, C., Wagner, C., Bruhl, L., Mattheus, B., & Muller, C. (2017). Metabolic changes during storage of Brassica napa seeds under moist conditions and the consequences for the sensory quality of the resulting virgin oil. Journal of Agricultural and Food Chemistry, 65, 11073-11084. doi.org/10.1021/acs.jafc.7b04149

Cai, C., Miao, H., Qian, H., Yao, L., Wang, B., & Wang, Q. (2016). Effects of industrial pre-freezing processing and freezing handling on glucosinolates and antioxidant attributes in broccoli florets. Food Chemistry, 210, 451-456. doi.org/10.1016/j.foodchem.2016.04.140

Caleb, O. J., Ilte, K., Frohling, A., Geyer, M., & Mahajan, P. V. (2016). Integrated modified atmosphere and humidity package design for minimally processed broccoli (Brassica oleracea L. var. Italica). Postharvest Biology and Technology, 121, 87-100. doi.org/10.1016/j.posthharvbio.2016.07.016

Campos, D., Aguilar-Galvez, A., García-Ríos, D., Chirinos, R., Limaymanta, E., & Pedreschi, R. (2019). Postharvest storage and cooking techniques affect the stability of glucosinolates and myrosinase activity of Andean mashua tubers (Tropaeolum tuberosum). International Journal of Food Science and Technology, 54, 2387-2395. doi.org/10.1111/ijfs.14150

Casajus, V., Civello, P., Martinez, G., Howe, K., Fish, T., Yang, Y., Thanhauser, T., Li, L., & Lobato, M. G. (2021). Effect of continuous white light illumination on glucosinolate metabolism during postharvest storage of broccoli. LWT, 145, 111302. doi.org/10.1016/j.lwt.2021.111302

Casajus, V., Demkura, P., Civello, P., Lobato, M. G., & Martinez, G. (2020). Harvesting at different time points of the day affects glucosinolate metabolism during postharvest storage of broccoli. Food Research International, 136, 109529. doi.org/10.1016/j.foodres.2020.109529

Chiu, Y. C., Matak, K., & Ku, K. M. (2019). Methyl jasmonate treated broccoli: impact on the production of glucosinolates and consumer preferences. Food Chemistry, 299, 125099. doi.org/10.1016/j.foodchem.2019.125099

Chiu, Y. C., Matak, K., & Ku, K. M. (2020). Methyl jasmonate treatment of broccoli enhanced glucosinolate concentration, which was retained after boiling, steaming, or microwaving. Foods, 9, 758. doi.org/10.3390/foods9060758

Cieslik, E., Leszczynska, T., Filipiakflorkiewicz, A., Sikora, E., & Pislewski, P. (2007). Effects of some technological processes on glucosinolate contents in cruciferous vegetables. Food Chemistry, 105, 976-981. doi.org/10.1016/j.foodchem.2007.04.047

Darre, M., Valerga, L., Araque, L. C. O., Lemoine, M. L., Demkura, P. V., Vicente, A. R., & Conceição, A. (2017). Role of UV-B irradiation dose and intensity on color retention and antioxidant elicitation in broccoli florets (Brassica oleracea var. Italica). Postharvest Biology and Technology, 128, 76-82. doi.org/10.1016/j.posthharvbio.2017.02.003

Deng, M., Qian, H., Chen, L., Sun, B., Chang, J., Miao, H., Cai, C., & Wang, Q. (2017). Influence of preharvest red light irradiation on main phytochemicals and antioxidant activity of Chinese kale sprouts. Food Chemistry, 222, 1-5. doi.org/10.1016/j.foodchem.2016.11.157

Duarte-Sierra, A., Hasan, S. M. M., Angers, P., & Arul, J. (2020). UV-B radiation hormesis in broccoli florets: glucosinolates and hydroxy-cinnamates are enhanced by UV-B in florets during storage. Postharvest Biology and Technology, 168, 111278. doi.org/10.1016/j.posthharvbio.2020.111278

Duarte-Sierra, A., Nadeau, F., Angers, P., Michaud, D., & Arul, J. (2019). UV-C hormesis in broccoli florets: Preservation, Phyto-compounds and gene expression. Postharvest Biology and Technology, 157, 110965. doi.org/10.1016/j.posthharvbio.2019.110965

Farnham, M. W., Stephenson, K. K., & Fahey, J. W. (2000). The capacity of broccoli to induce a mammalian chemoprotective enzyme varies among inbred lines. Journal of the American Society for Horticultural Science, 125, 482-488. doi.org/10.21273/JASHS.125.4.482

Fernández-León, M. F., Fernández-León, A. M., Lozano, M., Ayuso, M. C., & González-Gómez, D. (2013a). Different postharvest strategies to preserve broccoli quality during storage and shelf life: Controlled atmosphere and 1-MCP. Food Chemistry, 138, 564-573. doi.org/10.1016/j.foodchem.2012.09.143

Fernández-León, M. F., Fernández-León, A. M., Lozano, M., Ayuso, M. C., & González-Gómez, D. (2013b). Altered commercial controlled atmosphere storage conditions for 'Parthenon' broccoli plants (Brassica oleracea L. var. italica). Influence on the outer quality parameters and on the health-promoting compounds. LWT- Food Science and Technology, 50, 665-672. doi.org/10.1016/j.lwt.2012.07.028

Fernández-León, M. F., Fernández-León, A. M., Lozano, M., Ayuso, M. C., Amadio, M. L., Colelli, G., & González-Gómez, D. (2013c). Retention of quality and functional values of broccoli 'Parthenon' stored in modified atmosphere packaging. Food Control, 31, 302-313. doi.org/10.1016/j.foodcont.2012.10.012

Ferreira, S. S., Passos, C. P., Cardoso, S. M., Wessel, D. F., & Coimbra, M. A. (2018). Microwave-assisted dehydration of broccoli by-products and simultaneous extraction of bioactive compounds. Food Chemistry, 246, 386-393. doi.org/10.1016/j.foodchem.2017.11.053
Guo, Q., Sun, D. W., Cheng, J. H., & Han, Z. (2017). Microwave processing techniques and their recent applications in the food industry. Trends in Food Science and Technology, 67, 236-247. doi.org/10.1016/j.tifs.2017.07.007

Hanschen, F. S., Kuhn, C., Nickel, M., Rohn, S., & Dekker, M. (2018). Leaching and degradation kinetics of glucosinolates during boiling of Brassica oleracea vegetables and the formation of their breakdown products. Food Chemistry, 263, 240-250. doi.org/10.1016/j.foodchem.2018.04.069

Hwang, E. S., & Kim, G. H. (2013). Effects of various heating methods on glucosinolate, carotenoid, and tocopherol concentrations in broccoli. International Journal of Food Sciences and Nutrition, 64, 103-111. doi.org/10.3109/09637486.2012.704904

Jia, C. G., Xu, C. J., Wei, J., Yuan, J., Yuan, G. F., Wang, B. L., & Wang, Q. M. (2009). Effect of modified atmosphere packaging on visual quality and glucosinolates of broccoli florets. Food Chemistry, 114, 28-37. doi.org/10.1016/j.foodchem.2008.09.009

Jiang, A., Zuo, J., Zheng, Q., Guo, L., Gao, L., Zhao, S., Wang, Q., & Hu, W. (2019). Red LED irradiation maintains the postharvest quality of broccoli by elevating antioxidant enzyme activity and reducing the expression of senescence-related genes. Scientia Horticulurae, 251, 73-79. doi.org/10.1016/j.scienta.2019.03.016

Jin, P., Yao, D., Xu, F., Wang, H., & Zheng, Y. (2015). Effect of light on quality and bioactive compounds in postharvest broccoli florets. Food Chemistry, 172, 705-709. doi.org/10.1016/j.foodchem.2014.09.134

Jones, R. B., Faragher, J. D., & Winkler, S. (2006). A review of the influence of postharvest treatments on quality and glucosinolate content in broccoli (Brassica oleracea var. Italica) heads. Postharvest Biology and Technology, 41, 1-8. doi.org/10.1016/j.postharbio.2006.03.003

Jones, R. B., Frisina, C. L., Winkler, S., Imsic, M., & Tomkins, R. B. (2010). The cooking method significantly affects glucosinolate content and sulforaphane production in broccoli florets. Food Chemistry, 123, 237-242. doi.org/10.1016/j.foodchem.2010.04.016

Lafarga, T., Bobo, G., Vinas, I., Collazo, C., & Aguilu-Aguayo, I. (2018). Effects of thermal and non-thermal processing of cruciferous vegetables on glucosinolates and their derived forms. Journal of Food Science and Technology, 55, 1973-1981. doi.org/10.1007/s13197-018-3153-7

Liu, R., Zuo, J., Gao, L., Sun, W., Yan, Z., Wang, Q., & Sui, Y. (2019). Effect of slurry ice precooling treatment on quality of broccoli. Modern Food Science and Technology, 35, 77-86.

Loi, M., Lucci, V. C., Fanelli, F., Leonardis, S. D., Creanza, T. M., Ancona, N., Piacolla, C., & Mule, G. (2019). Effect of different Light-Emitting Diode (LED) irradiation on the shelf life and phytonutrient content of broccoli (Brassica oleracea L. var. Italica). Food Chemistry, 283, 206-214. doi.org/10.1016/j.foodchem.2019.01.021

Lu, L., Fang, Y., Li, L., Xu, Y., & Luo, Z. (2020a). Effect of water/oil/water double-preservation emulsion on storage quality of broccoli. Journal of Zhejiang University (Agriculture & Life Sciences), 46, 74-82.

Lu, X., Ma, S., Li, S., Zhang, C., Bao, J., & Zhang, X. (2020b). Effect of cooking time on glucoraphanin and sulforaphane contents in broccoli cooked by different cooking methods. Food Science, 41, 41-47.

Lu, Y., Pang, X., & Yang, T. (2020c). Microwave cooking increases sulforaphane levels in broccoli. Food Science & Nutrition, 8, 2052-2058. doi.org/10.1002/fsn3.1493

Luo, F., Cai, J., Zhang, X., Tao, D., Zhou, X., Zhou, Q., Zhao, Y., Wei, B., Cheng, S., & Ji, S. (2018). Effects of methyl jasmonate and melatonin treatments on the sensory quality and bioactive compounds of harvested broccoli. RSC Advances, 8, 41422-41431. doi.org/10.1039/C8RA07982J

Martinez-Herna'ndez, G. B., Artes-Herna'ndez, F., Go'mez, P. A., & Artes, F. (2013). Induced changes in bioactive compounds of kailan-hybrid broccoli after innovative processing and storage. Journal of Functional Foods, 5, 133-143. doi.org/10.1016/j.jff.2012.09.004

Miao, H., Wang, J., Cai, C., Chang, J., Zhao, Y., & Wang, Q. (2017). Accumulation of glucosinolates in broccoli. In "Glucosinolates, References Series in Phytochemistry," ed. by Merillon, J. M. and Ramawat, K. G. Springer International Publishing, Switzerland, pp. 133-162. doi.org/10.1007/978-3-319-25462-3_16

Miao, H., Zeng, W., Zhao, M., Wang, J., & Wang, Q. (2020). Effect of melatonin treatment on visual quality and health-promoting properties of broccoli florets under room temperature. Food Chemistry, 319, 126498. doi.org/10.1016/j.foodchem.2020.126498

Miglio, C., Chiavarro, E., Visconti, A., Fogliano, V., & Pellegrini, N. (2008). Effects of different cooking methods on nutritional and physicochemical characteristics of selected vegetables. Journal of Agricultural and Food Chemistry, 56, 139-147. doi.org/10.1021/jf072304b

Moreno, D. A., Lopez-Berenguer, C., & García-Viguer, C. (2007). Effects of stir-fry cooking with different edible oils on the phychochemical composition of broccoli. Journal of Food Science, 72, S064-S68. doi.org/10.1111/j.1750-3841.2006.00213.x
Maire, V., Redovnikovic, I., Jolic, S., Delonga, K., & Dragovic-Uzelac, V. (2010). Effect of drying conditions on indole glucosinolate level in broccoli. Acta Alimentaria, 39, 167-174. doi:10.1556/AAlim.39.2010.2.8

Ndiaye, C., Xu, S. Y., & Wang, Z. (2009). Steam blanching effect on polyphenoloxidase, peroxidase, and color of mango (Mangifera indica L.) slices. Food Chemistry, 113, 92-95. doi:10.1016/j.foodchem.2008.07.027

Nugrahedi, P. Y., Dekker, M., & Verkerk, R. (2016). Processing and preparation of brassica vegetables and the fate of glucosinolates. In “Glucosinolates, References Series in Phytochemistry,” ed. by Merillon, J. M. and Ramawat, K. G. Springer International Publishing, Switzerland, pp. 1-23. doi:10.1007/978-3-319-26479-0_10-1

Nugrahedi, P. Y., Oliviero, T., Heising, J. K., Dekker, M., & Verkerk, R. (2017). Stir-frying of Chinese cabbage and pakchoi retains health-promoting glucosinolates. Plant Foods for Human Nutrition, 72, 439-444. doi:10.1007/s11130-017-0646-x

Nugrahedi, P. Y., Verkerk, R., Widianarko, B., & Dekker, M. (2015). A mechanistic perspective on process-induced changes in glucosinolate content in brassica vegetables: A review. Critical Reviews in Food Science and Nutrition, 55, 823-838. doi:10.1080/10408398.2012.688076

Oliviero, T., Verkerk, R., & Dekker, M. (2018). Isothiocyanates from Brassica vegetables-effects of processing, cooking, mastication, and digestion. Molecular Nutrition & Food Research, 62, 1701069. doi:10.1002/mnfr.201701069

Paulsen, E., Barrios, S., Baenas, N., Moreno, D. A., Heinzen, H., & Lema, P. (2018). Effect of temperature on glucosinolate content and shelf life of ready-to-eat broccoli florets packaged in passive modified atmosphere. Postharvest Biology and Technology, 138, 125-133. doi:10.1016/j.postharvbio.2018.01.006

Paulsen, E., Moreno, D. A., Periago, P. M., & Lema, P. (2021). Influence of microwave bag vs conventional microwave cooking on phytochemicals of industrially and domestically processed broccoli. Food Research International, 140, 110077. doi:10.1016/j.foodres.2020.110077

Pellegrini, N., Chiavaro, E., Gardana, C., Mazzeo, T., Contino, D., Gallo, M., Riso, P., Fogliano, V., & Porrini, M. (2010). Effect of different cooking methods on color, phytochemical concentration, and antioxidant capacity of raw and frozen Brassica vegetables. Journal of Agricultural and Food Chemistry, 58, 4310-4321. doi:10.1021/jf904306r

Preciado-Iniga, G. E., Amador-Espejo, G. G., & Barcenas, M. E. (2018). Blanching and antimicrobial mixture (potassium sorbate-sodium benzoate) impact the stability of a tamarillo (Cyphomandra betacea) sweet product preserved by hurdle technology. Journal of Food Science and Technology, 55, 740-748. doi:10.1007/s13197-017-2985-x

Prieo, M. A., Lopez, C. J., & Simal-Gandara, J. S. (2019). Glucosinolates: Molecular structure, breakdown, genetic, bioavailability, properties, and healthy and adverse effects. Advances in Food and Nutrition Research, 90, 305-350. doi:10.1016/bs.afnr.2019.02.008

Qiu, H., Wang, H., & Guo, L. (2020). Effect of different thawing methods on the quality of quick-frozen broccoli. Science and Technology of Food Industry, 41, 266-270.

Raiola, A., Errico, A., Petruk, G., Monti, D. M., Barone, A., & Rigano, M. M. (2017). Bioactive compounds in Brassicaeae vegetables with a role in the prevention of chronic diseases. Molecules, 23, 15. doi:10.3390/molecules23010015

Rangkadilok, N., Tomkins, B., Nicolas, M. E., Premier, R. R., Bennett, R. N., Eagling, D. R., & Taylor, P. W. J. (2002). The effect of post-harvest and packaging treatments on glucoraphanin concentration in broccoli (Brassica oleracea var. Italica). Journal of Agricultural and Food Chemistry, 50, 7386-7391. doi:10.1021/jf0203592

Rodrigues, A. S., & Rosa, E. A. S. (1999). Effect of postharvest treatments on the level of glucosinolates in broccoli. Journal of the Science of Food and Agriculture, 79, 1028-1032. doi:10.1002/(SICI)1097-0010(19990515)79:7<1028::AID-JSFA322>3.0.CO;2-I

Romeo, L., Iori, R., Rollin, P., Bramanti, P., & Mazzon, E. (2018). Isothiocyanates: An overview of their antimicrobial activity against human infections. Molecules, 23, 624. doi:10.3390/molecules23030624

Rungapamestry, V., Duncan, A. J., Fuller, Z., & Ratcliffe, B. (2008). Influence of blanching and freezing broccoli (Brassica oleracea var. Italica) before storage and cooking on glucosinolate concentrations and myrosinase activity. European Food Research and Technology, 227, 37-44. doi:10.1007/s00191-007-0690-0

Rybakczyk-Plonska, A., Hagen, S. F., Borge, G. I. A., Bengtsson, G. B., Hansen, M. K., & Wold, A. B. (2016). Glucosinolates in broccoli (Brassica oleracea L. var. Italica) as affected by postharvest temperature and radiation treatments. Postharvest Biology and Technology, 116, 16-25. doi:10.1016/j.postharvbio.2015.12.023
Rybarczyk-Plonska, A., Hansen, M. K., Wold, A. B., Hagen, S. F., Borge, G. I. A., & Bengtsson, G. B. (2014). Vitamin C in broccoli (Brassica oleracea L. var. Italica) flower buds is affected by postharvest light, UV-B irradiation, and temperature. Postharvest Biology and Technology, 98, 82-89. doi.org/10.1016/j.postharvbio.2014.06.017

Seo, M. S., & Kim, J. S. (2017). Understanding of MYB transcription factors involved in glucosinolate biosynthesis in Brassicaceae. Molecules, 22, 1549. doi.org/10.3390/molecules22091549

Shakeel, M., Khan, S. N., Saleem, Y., Burgess, P. J., & Shafiq, S. (2019). Colour, water, and chlorophyll loss in harvested broccoli (Brassica oleracea L. Italica) under ambient conditions in Pakistan. Scientia Horticulturae, 246, 858-861. doi.org/10.1016/j.scienta.2018.11.041

Singh, S., Rai, A. K., Alam, T., & Singh, B. (2018). Influence of Modified Atmosphere Packaging (MAP) on the shelf life and quality of broccoli during storage. Journal of Packaging Technology and Research, 2, 105-113. doi.org/10.1007/s41783-018-0030-9

Soares, A., Carrascosa, C., & Raposo, A. (2017). Influence of different cooking methods on the concentration of glucosinolates and vitamin C in broccoli. Food and Bioprocess Technology, 10, 1387-1411. doi.org/10.1007/s11947-017-1930-3

Song, L., & Thornalley, P. J. (2007). Effect of storage, processing, and cooking on glucosinolate content of Brassica vegetables. Food and Chemical Toxicology, 45, 216-224. doi.org/10.1016/j.fct.2006.07.021

Sosinska, E., & Obiedinski, M. W. (2011). Effect of processing on the content of glucobrassicin and its degradation products in broccoli and cauliflower. Food Control, 22, 1348-1356. doi.org/10.1016/j.foodcont.2011.02.011

Storey, M., & Anderson, P. (2018). Total fruit and vegetable consumption increases among consumers of frozen fruit and vegetables. Nutrition, 46, 115-121. doi.org/10.1016/j.nut.2017.08.013

Sun, J., Wang, Y., Pang, X., Tian, S., Hu, Q., Li, X., Liu, J., Wang, J., & Lu, Y. (2021). The effect of processing and cooking on glucoraphanin and sulforaphane in brassica vegetables. Food Chemistry, 360, 130007. doi.org/10.1002/9781119792130

Tabart, J., Pincemail, J., Kevers, C., Defraigne, J. O., & Dommes, J. (2018). Processing effects on antioxidant, glucosinolate, and sulforaphane contents in broccoli and red cabbage. European Food Research and Technology, 244, 2085-2094. doi.org/10.1007/s00217-018-3126-0

Tian, S., Liu, X., Lei, P., Zhang, X., & Shan, Y. (2018). Microbiota: A mediator to transform glucosinolate precursors in cruciferous vegetables into the active isothiocyanates. Journal of the Science of Food and Agriculture, 98, 1255-1260. doi.org/10.1002/jsfa.8654

Torres-Contreras, A. M., Nair, V., Cisneros-Zevallos, L., & Jacobo-Velazquez, D. A. (2017). The stability of bioactive compounds in broccoli is affected by cutting styles and storage time. Molecules, 22, 636. doi.org/10.3390/molecules22040636

Torres-Contreras, A. M., Senes-Guerrero, C., Pacheco, A. Gonzalez-Aguero, M., Ramos-Parra, P. A., Cisneros-Zevallos, L., & Jacobo-Velazquez, D. A. (2018). Genes are differentially expressed in broccoli as an early and late response to wounding stress. Postharvest Biology and Technology, 145, 172-182. doi.org/10.1016/j.postharvbio.2018.07.010

Vallejo, F., Tomas-Barberan, F., & García-Viguera, C. (2002). Glucosinolates and vitamin C content in edible parts of broccoli florets after domestic cooking. European Food Research and Technology, 215, 310-316. doi.org/10.1007/s00217-002-0560-8

Van Etten, C. H., & Toodey, H. L. (2018). Glucosinolates. In “Handbook of naturally occurring food toxicants,” ed. by Rechcigl, M. CRC Press, FL, pp, 15-30. doi.org/10.1201/9781351072946-2

Van Eylen, D., Bellostas, N., Strobel, B. W., Oey, I., Hendrickx, M., Van Loey, A., Sorensen, H., & Sorensen, J. C. (2009). Influence of pressure/temperature treatments on glucosinolate conversion in broccoli (Brassica oleracea L. cv Ittica) heads. Food Chemistry,112, 646-653. doi.org/10.1016/j.foodchem.2008.06.025

Vig, A. P., Rampal, G., Thind, T. S., & Arora, S. (2009). Bio-protective effects of glucosinolates-A review. LWT-Food Science and Technology, 42, 1561-1572. doi.org/10.1016/j.lwt.2009.05.023

Villarreal-García, D., Nair, V., Cisneros-Zevallos, L., & Jacobo-Velázquez, D. A. (2016). Plants as biofactories: Postharvest stress-induced accumulation of phenolic compounds and glucosinolates in broccoli subjected to wounding stress and exogenous phytohormones. Frontiers of Plant Science, 7, 45. doi.org/10.3389/fpls.2016.00045

Wang, H. W., Makino, Y., Inoue, J., Maejima, K., Funayama-Noguchi, S., Yamada, T., & Noguchi, K. (2017). Influence of a modified atmosphere on the induction and activity of respiratory enzymes in broccoli florets during the early stage of postharvest storage. Journal of Agricultural and Food Chemistry, 65, 8538-8543. doi.org/10.1021/acs.jafc.7b02318

Wang, H., Zheng, C., Wang, H., Wang, J., & Zheng, Y. (2018). Effect of pretreatment with ethanol on bioactive compounds and antioxidant activity in fresh-cut broccoli florets. Food Science, 35, 250-254.
Wang, J., Barba, F. J., Frandsen, H. B., Sørensen, S., Olsen, K., Sørensen, J. C., & Orlien, V. (2016). The impact of high pressure on glucosinolate profile and myrosinase activity in seedlings from Brussels sprouts. Innovative Food Science and Emerging Technologies, 38, 342-348. doi.org/10.1016/j.ifset.2016.06.020

Wang, J., Barba, F. J., Sørensen, J. C., Frandsen, H. B., Sørensen, S., Olsen, K., & Orlien, V. (2018). High-pressure effects on myrosinase activity and glucosinolate preservation in seedlings of Brussels sprouts. Food Chemistry, 245, 1212-1217. doi.org/10.1016/j.foodchem.2017.11.018

Wang, J., Gu, H., Yu, H., Zhao, Z., Sheng, X., & Zhang, X. (2012). Genotypic variation of glucosinolates in broccoli (Brassica oleracea var. Italica) florets from China. Food Chemistry, 133, 735-741. doi.org/10.1016/j.foodchem.2012.01.085

Wang, J., Mao, S., Wu, Q., Yuan, Y., Liang, M., Wang, S., Huang, K., & Wu, Q. (2021). Effect of LED illumination spectra on glucosinolate and sulforaphane accumulation in broccoli seedlings. Food Chemistry, 356, 129550. doi.org/10.1016/j.foodchem.2021.129550

Wang, S., Huang, X., Liu, Y., Shi, J., Gao, L., & Wang, Q. (2020). Effect of different procooling methods on shelf life quality of broccoli. Science and Technology of Food Industry, 41, 266-272.

Wei, L., Liu, C., Zheng, H., & Zheng, L. (2020). Melatonin treatment affects the glucoraphanin-sulforaphane system in postharvest fresh-cut broccoli (Brassica oleracea L.). Food Chemistry, 307, 125562. doi.org/10.1016/j.foodchem.2019.125562

Wu, X., Sun, J., Haytowitz, D. B., Harnly, J. M., Chen, P., & Pehrsson, P. R. (2017). Challenges of developing a valid dietary glucosinolate database. Journal of Food Composition and Analysis, 64, 78-84. doi.org/10.1016/j.jfca.2017.07.014

Wu, Y., Lv, C., Zou, L., Sun, J., Song, X., Zhang, Y., & Mao, J. (2021). Approaches for enhancing the stability and formation of sulforaphane. Food Chemistry, 345, 128771. ttps://doi.org/10.1016/j.foodchem.2020.128771

Wu, Y., Shen, Y., Zhu, Y., Mupungu, J., Zou, L., Liu, C., Liu, S., & Mao, J. (2019). Broccoli ingestion increases the glucosinolate hydrolysis activity of microbiota in the mouse gut. International Journal of Food Sciences and Nutrition, 70, 585-610. doi:10.1080/09637486.2018.1554624

Xie, X., Zhang, F., Shi, J., Xie, Y., & Jiang, L. (2021). Effect of pre-cooling treatment and low-temperature storage on storage quality of broccoli. Science and Technology of Food Industry, 42, 302-310.

Xu, D., Zuo, J., Li, P., Yan, Z., Gao, L., Wang, Q., & Jiang, A. (2020). Effect of methyl jasmonate on the quality of harvested broccoli after simulated transport. Food Chemistry, 319, 126561. doi.org/10.1016/j.foodchem.2020.126561

Xu, F., Chen, X., Yang, Z., Jin, P., Wang, K., Shang, H., Wang, X., & Zheng, Y. (2013). Maintaining quality and bioactive compounds of broccoli by combined treatment with 1-methylcyclopropene and 6-benzylaminopurine. Journal of the Science of Food and Agriculture, 93, 1156-1161. doi.org/10.1002/jsfa.5867

Xu, F., Tang, Y., Dong, S., Shao, X., Wang, H., Zheng, Y., & Yang, Z. (2016). Reducing yellowing and enhancing antioxidant capacity of broccoli in storage by sucrose treatment. Postharvest Biology and Technology, 112, 39-46. doi.org/10.1016/j.postharvbio.2015.09.038

Xu, F., Yang, Z., Chen, X., Jin, P., Wang, X., & Zheng, Y. (2012). 6-Benzylaminopurine delays senescence and enhances health-promoting compounds of harvested broccoli. Journal of Agricultural and Food Chemistry, 60, 234-240. doi.org/10.1021/jf2040884

Xu, X., Bi, S., Lao, F., Chen, F., Liao, X., & Wu, J. (2021a). A comprehensive investigation on volatile and non-volatile metabolites in broccoli juices fermented by animal- and plant-derived Pediococcus pentosaceus. Food Chemistry, 341, 128118. doi.org/10.1016/j.foodchem.2020.128118

Xu, X., Bi, S., Lao, F., Chen, F., Liao, X., & Wu, J. (2021b). Induced changes in bioactive compounds of broccoli juices after fermentation by the animal- and plant-derived Pediococcus pentosaceus. Food Chemistry, 357, 129767. doi.org/10.1016/j.foodchem.2021.129767

Xu, Y., Chen, Y., Cao, Y., Xia, W., & Jiang, Q. (2016). Application of a simultaneous combination of microwave and steam cooking to improve the nutritional quality of cooked purple sweet potatoes and save time. Innovative Food Science and Emerging Technologies, 36, 303-310. ttps://doi.org/10.1016/j.ifset.2016.07.014

Yuan, G. F., Sun, B., Yuan, J., & Wang, Q. M. (2009). Effects of different cooking methods on health-promoting compounds of broccoli. Journal of Zhejiang University (Science B), 10, 580-588. ttps://doi.org/10.1631/jzus.B0920051

Yuan, G. F., Sun, B., Yuan, J., & Wang, Q. M. (2010). Effect of 1-methylcyclopropene on shelf life, visual quality, antioxidant enzymes, and health-promoting compounds in broccoli florets. Food Chemistry, 118, 774-781. ttps://doi.org/10.1016/j.foodchem.2009.05.062

Zhai, C., Liu, Y., Lai, S., Cao, H., Guan, Y., San Cheang, W., Liu, B., Zhao, K., Miao, S., Riviere, C., Capanoglu, E., & Xiao, J. (2019). Effects of domestic cooking process on the chemical and biological properties of dietary phytochemicals. Trends in Food Science and Technology, 85, 55-66. doi.org/10.1016/j.tifs.2019.01.004
Zheng, H., Liu, W., Liu, S., Liu, C., & Zheng, L. (2019). Effects of melatonin treatment on the enzymatic browning and nutritional quality of fresh-cut pear fruit. Food Chemistry, 299, 125116. doi.org/10.1016/j.foodchem.2019.125116

Zinoviadou, K. G., & Galanakis, C. M. (2017). Glucosinolates and respective derivatives (isothiocyanates) from plants. In “Food bioactives,” ed. by Puri, M. Springer press, Ponds, pp. 3-22. doi.org/10.1007/978-3-319-51639-4_1