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Review Article

Functional Properties and Health Benefits of Cruciferous Vegetables

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Abstract

In recent years, the trend of consumption foods high in fiber and low in calories has been increasing due to consumers demands for a healthy and balanced diet. Hence, the vegetables-rich dietary regimes are becoming progressively important all over the world. The vegetables in Cruciferae (Brassicceae) family have worldwide consumption and popularity since scientific investigations confirm these vegetables are related to lower incidences of many chronic diseases such as type-2 diabetes, osteoporosis, obesity, cardiovascular disease and cancer. Beside on essential nutrients that promote the body, member of cruciferous vegetables have also contain healthy beneficial phytochemical compounds including carotenoids, anthocyanins, flavonoids, antioxidant enzymes, sulfur containing glucosinolates, coumarins, tocopherols and terpenoids. It is known that these compounds have anti-inflammatory, antimicrobial, antioxidant, antiobesity, cardioprotective, and gastroprotective activities. Pharmacological effects and nutritionally valuable compounds enhance the popularity of the plants in Brassicaceae family and lead to future functional food applications

Keywords: Cruciferous vegetables, health benefits, glucosinolates, sulforaphane

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Introduction

The Cruciferae (or Brassicaceae) family contains 300 genera (*Brassica*, *Camelina*, *Crambe*, *Sinapis*, and *Thlaspi*) including approximately 4000 species. Among these genus, especially *Brassica* species, such as particularly *Brassica oleracea*, *B. rapa* L., and *B. napus* are economically significant around the world (1-5). The most common known vegetables in Brassicaceae are broccoli, Brussel sprout, cabbage, canola, cauliflower, collard green, kale, mustards, oilseed rape, radish, and turnip (6,7). It is known that the regular consumption of these group vegetables are mainly supporting to human health particularly in the reducing of chronic diseases risks, including type-2 diabetes, osteoporosis, obesity, cardiovascular disease, and cancer. Owing to health promoting effects, Brassicceae vegetables are becoming progressively important and widely used in cuisine both cooked and fresh cut (6,8-11). The vegetables in Cruciferae, the species of *Brassica* such as; cauliflower, cabbage, broccoli, and Brussels sprouts are efficient at decreasing cancer risk (12,13). The Brassicaceae family have significant phytochemicals, which are mainly alcaloids, carotenoids including *β*-carotene and lutein, glucosinolates, phenolics such as flavonoids, phenolic acids, polyphenols (14), glucosides, terpenoids, and tocopherols (6,15-17). Also, the other biologically important compounds of vegetables in Brassicaceae are shown in Figure 1 (6).

The health-promoting effects of cruciferous vegetables are related to the compounds common known antioxidants such as ascorbic acid, carotenoids, glucosinolates, phenolics, and tocopherols (18). From these compounds, especially glucosinolates found in high concentration in broccoli, cauliflower, mustard, radish, and white cabbage are more healthy phytochemicals. Sulforaphane, breakdown metabolite of glucosinolates (e.g., isothiocyanate) formed by the activating of myrosinase from glucoraphanin exhibits anticarcinogenic effects (19-21). The enzyme myrosinase is inactivated with heat treatment, such as cooking and steaming of vegetables (6). Microbiome in gut displays a significant role in the metabolisms of the compounds, glucosinolates and also isothiocyanates (e.g., sulforaphane) (22). Regarding to gut microbiome, the cruciferous vegetables procure the balance of intestinal flora and hence, the compounds in the family should be investigated up-close for future studies (11).

2. Biologically healthy compounds in cruciferous vegetables and their functional properties

The recent studies, both in vitro and in vivo, have concentrated on the compounds promoting human health in the cruciferous vegetables (23,24). The biological properties and effects of Brassicacea on health originate from their main compounds, including ascorbic acid, carotenoids, glucosinolates, phenolics, and tocopherols. The biological activity and complementary mechanisms of their activities are shown in Figure 2 and Table 1, respectively (6,25-29).

As shown in Table 1, the compounds of Brassicaceae have different mechanisms of the biological activities. Ascorbic acid is a highly concentration compounds found in especially leafly-stalk vegetables such as broccoli, Brussel sprouts, cabbage, cauliflower, kale, tronchuda (30). This compound exhibits to play a great role in the protection of mycocardium and prohibiting of LDL-induced overexpression in the vascular endothelial growth factor (31,32). The content of this compound in *Brassica* species depends on some factors such as cultivar of vegetable, fertilization with sulphur and handling conditions (33-36).

The other important compound carotenoids, particularly *β*- and *γ*-carotene, and *β*-cryptoxanthin are both pigments and the precursors of vitamin A (37). The colors of orange-yellow and yellow are originated from carotenoids including lutein, zeaxanthin in cruciferous vegetables (6,8,38). Also, flavonoids and anthocyanins are the other color sources in these plants (6). Owing to contain double bonds carotenoids are in charge of scavenging of free radicals and also removing of singlet oxygen. It is known that *β*-carotene in serum level is the higher, the risk of diseases such as cancer, cardiovascular, myocardial infarction is lower. Furthermore, metabolic syndrom factors correlate with negatively with *β*-cryptoxanthin and *β*-carotene levels in serum (39,40). It is important that these vegetables are a regular part of their daily diet due to protection of body health.

The main characteristic phytochemicals are sulfur-containing compounds, including glucosinolates and s-methyl cysteine sulfoxide found in cruciferous vegetables (41-43). The glucosinolates are classified into three groups as shown in Figure 3. Depending on the variety, vegetables contain a distinctive variety of glucosinolates. The broccoli contain different form of glucosinolates, such as glucobrassicin, glucoraphanin, and neoglucobrassicin. Also, glucoraphanin is the well-known compund in broccoli (42,44,45) (Figure 4). On the other hand, glucobrassicin, gluconasturtin and glucotropaeolin are the most abundant compounds of Brussels sprouts, turnip and cress, respectively (13,46).

The glucosinolates are biologically inactive as long as they are not physically damaged, such as cutting, crumbling and smashing. In the case of physical effect, disjuncting from the cell of plants, the compound releases from ruptured cells and then are hydrolysed to isothiocynates by enzyme myrosinase, *β*-thioglucosidase (19,20,47,48). After hydrolysis, the unpleasant and pungent smell of the the breakdown product, which is characteristic smell of broccoli and cauliflower, is felt by sense of smell. On the other hand, the aromatic constituents in glucosinolates group are glucobarberin, gluconasturtiin, glucosibarin, glucosinalbin, and glucotropaeolin (49).

In general, these sulfur-containing compounds have allelopathic, bactericidal, fungicidal, and nematocidal functions and properties (50). The hydrolysis compounds, the isothiocyanates are also protective benefits on health. The most common chemopreventive compounds in cruciferous vegetables are ascorbigen, benzyl isothiocyanate, indoles 3,3-diindolylmethane, indole-3-carbinol, phenethyl isothiocyanate, sulforaphane. (21,47,48,51).

Due to these compounds, the vegetables in cruciferous vegetables have health benefits not only in prohibiting chronic diseases, but also in decreasing the risk of cancer types. *In-vitro* studies confirm that the broccoli extracts have been determined to have inhibitor effects on breast cancer cells owing to breakdown products, such as indoles, isothiocyanates, sulforaphane after hydrolysis of glucosinolates (19,21,42). Metabolites of isothiocyanate, indoles and also other compounds in the cruciferous vegetables display a great role in protection from cancer (21,52).

The other significant phytochemicals in Brassicaceae is phenolic compounds, including anthocyanins, hydroxycinnamic acids, flavonoids. These components provide color and taste to several fruits and vegetables and also containing biological activities and effects, such as inhibition of oxidation in LDL cholesterol, scavenging of free radicals and thus neutralizing of reactive oxygen species (53). Besides, it is known that support the restriction of adipose growing and incrementation of glucose uptake in adipocytes and cells in muscles by GLUT4, glucose transporter (54,55). The phenolics in cruciferous vegetables are hydroxycinnamic acids (e.g., caffeic, ferulic, and synapic acids) (56-59) and flavonoids (e.g., glycosylated isorhamnetin, kaempferol, and quercetin) with strong antioxidant activities and have various biological properties including immunomodulator, preventing cancer (60,61). Besides, it was reported that both quercetin and epicatechin may advance the production of insulin in rat islets (62). Furthermore, the leaf of turnip (*Brassica rapa*) extracts, a good source of flavonoids and tannins, exhibited anti-hyperglycemic activity in diabetic rats (63).

3. Conclusion

The Cruciferae (or Brassicaceae) family is rich source of phytochemicals, including ascorbic acid, carotenoids, glucosinolates, phenolics, terpenoids, tocopherols, etc. The cruciferous vegetables have recently increased in popularity worldwide due to these bioactive compounds have health-promoting effect, such as anticancer, antiinflammatory, antiobesity, antioxidant, antitumor, and neuroprotective. The amount and diversity of these compounds may vary depending on the variety, agricultural process, environmental factors, germination, and physical treatment such as cutting, smashing. The bioactive compounds in the cruciferous vegetables possess health benefits both in prohibiting chronic diseases and in decreasing the risk of cancer types. Since, cruciferous vegetables family is are a great source of bioactive compounds, consumption of these vegatables promotes body functions and may prevent disease. Thus, it may provided to select both non-pharmacological and cost-effective approaches for human health.

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Tables

Table 1. The mechanism of the compounds activities in cruciferous vegetables (64)

Compounds	Activity Mechanisms	References
Ascorbic acid	The reducing and neutralizing of reactive oxygen species, preventing of LDL oxidation	(31,65)
Carotenoids	Scavenging of the radicals and removing of single oxygen	(39)
Glucosinolates	Hedging of invasion effect in cancer cell (in vitro), regulating the enzymes activities in phases I and/or II	(19,66)
Phenolics	Neutralizing of reactive oxygen species, inhibition of oxidation in LDL-cholesterol, chelating of metal ions redox active	(53)

Figures

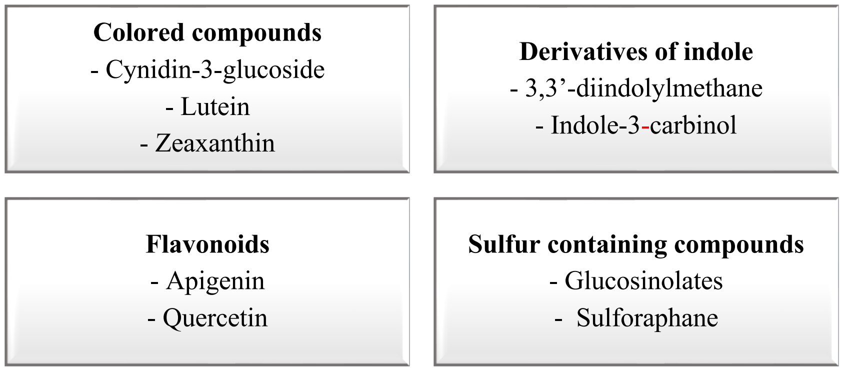

Figure 1. Biologically important compounds in cruciferous vegetables (6)

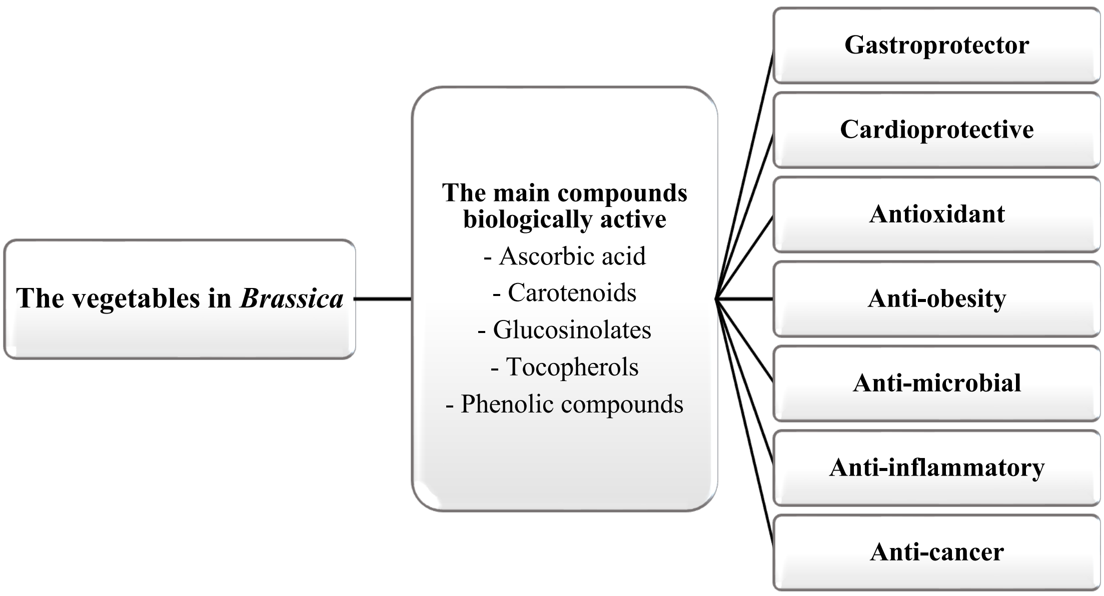

Figure 2. The main biological activities of the major compounds in the cruciferous vegetables (6)

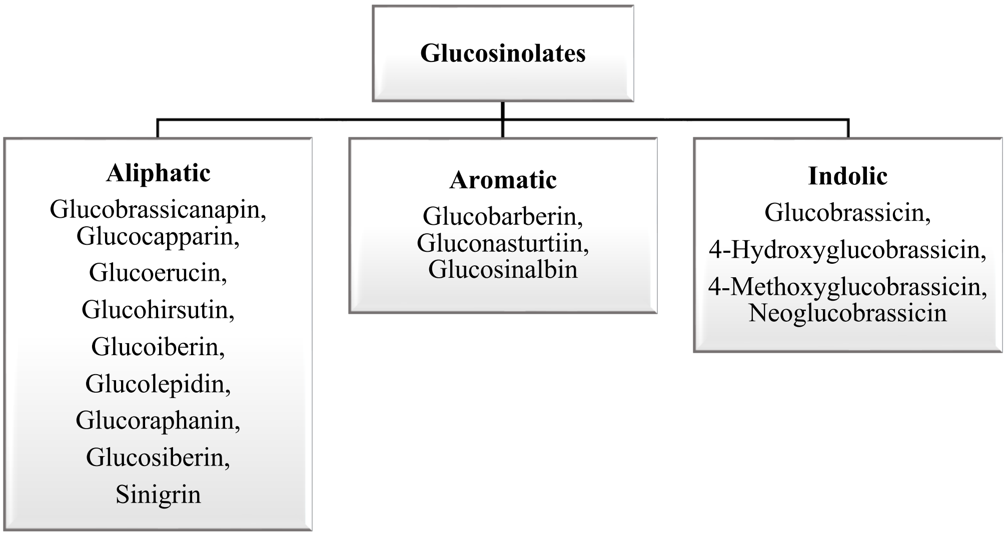

Figure 3. The classification of glucosinolates (49)

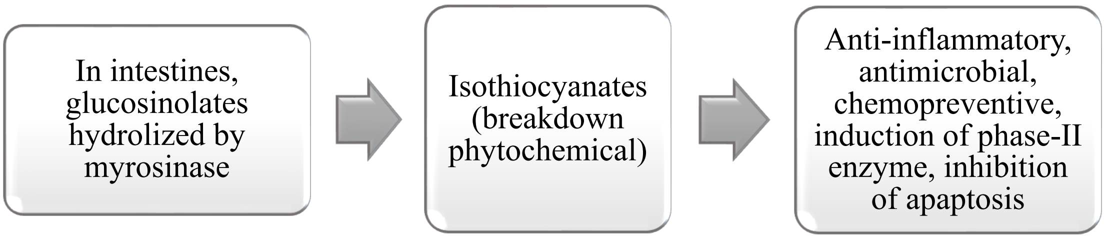

Figure 4. The biological effects of isothiocyanates (21,47,48,51)