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Nutritional and Bioactive Compounds of Bok-choy: Beneficial Effects on Human Health

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ABSTRACT

Bok-choy is a green leafy vegetable packed with impressive health benefits. Bok choy is rich in many nutritious, such as vitamins, minerals, and dietary fiber, as well as non-nutritive bioactive compounds, such as flavonoids, total glucosinolates, anthocyanins, kaempferol, and quercetin. These bioactive compounds protect chronic diseases, such as inflammation, cancer, Alzheimer's, cardiovascular disease, and other diseases. Bok chow is the best source of nutritional and non-nutrient compounds and should be taken as a part of the diet regularly.

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Introduction

As a source of nutrients and non-nutrients, vegetables and fruits play a vital role in human nutrition, promoting health and preventing diseases (Agudo et al., 2005). consumption of vegetables and fruits could prevent several diseases, such as high blood pressure, coronary heart disease, obesity, stroke risk, cancer, asthma, eye diseases, and osteoporosis (Boeing., et al., 2012; RH., 2003). Moreover, fruits and vegetables are good sources of many micronutrients and non-nutritive bioactive compounds, including vitamins, phytochemicals, polyphenols, carotenoids, minerals such as potassium, calcium, magnesium as well as dietary fiber (Liu., 2013). It is estimated that more than 5000 distinct phytochemicals have been identified in vegetables, fruits, and grains (Liu., 2013). The relationship between diet and health has increased consumer demand for nutritious diets, including vegetables and fruits [5]. Phytochemicals are potent antioxidants that can change metabolic activity and help detoxify carcinogens (Kunnumakkara, 2013). Many common cruciferous vegetables come from the genus Brassica, including broccoli, bok choy, Brussels sprouts, cabbage, cauliflower, collard greens, kale, kohlrabi, mustard, rutabaga, turnips, and Chinese cabbage (Kristal et al., 2002). Brassica vegetables contain several nutrients and phytochemicals with cancer prevention and anti-cancer effects, including high-value vitamins, fibers, minerals, folic acid, carotenoids, and chlorophyll. In addition, Brassica vegetables are unique in that they are rich in glucosinolates (Kristal et al., 2002; Cartea et al., 2011). Studies have been reported that intake of Brassica vegetables inversely related to the risk of lung and prostate cancer (Kristal et al., 2002; Higdon et al., 2007).

Bok-choy (Brassica rapa var. chinensis) is an important annual or biennial vegetable crop in the Brassica family. It is widely planted and consumed in China, Asia, and elsewhere. The consumption in northern Europe and North America is rising. Bok-choy young leaves can be used as salad or garnish, and the mature leaves can be consumed steamed or briefly cooked. This plant has many common names, such as "bok choy, Pak Choy and buk Choy." Bok Choy contains various healthy compounds, such as polyphenols, glucosinolates, flavonoids, vitamins, and minerals (Bhandari et al., 2015; Harbaum et al., 2008), phytonutrient content such as total glucosinolates carotenoids, minerals, ascorbic acid (Hanson et al., 2009). Kaempferol, isorhamnetin, and quercetin hydroxycinnamic acid derivatives have also been detected in various cultivars of bok-choy (Rochfort et al., 2006; Harbaum et al., 2008). Moreover, 15 kinds of anthocyanins were also identified in the purple bok-choy cultivar (Zhang et al., 2014). In addition, 9phenylpropanoid derivatives compounds and 12 types of anthocyanins were also identified in green and purple bokchoy (Jeon et al., 2018). It is a well-known vegetable used as a therapeutic plant in traditional Chinese remedies (Shen et al., 2016).

Nutritional composition of bok-choy and its roles in human health

Consumers are aware of the need to supply plant nutrients to obtain the best health benefits continuously, and more and more tend to demand high-value-added, high-quality products (Cartea et al., 2011). Bok Choy has the general features of low fat and protein content and high value of vitamins, minerals, and fibers (Agriculture., 2008). carotenoids, iron, glucosinolates, calcium, zinc and ascorbic acid (Hanson et al., 2009). Dietary fiber intake can reduce the risk of the following diseases: coronary heart disease and stroke(Liu et al., 1999; Steffen et al., 2003). Hypertension, diabetes (Whelton., et al., 2005; Streppel et al., 2005) Obesity (Lairon et al., 2005); in addition, increasing dietary fiber intake can increase blood lipid concentration (Brown et al., 1999). reduce blood pressure(Keenan et al., 2002). improve blood glucose control in diabetic patients (Anderson et al., 2004). help lose weight(Birketvedt et al., 2005) and seem to improve immune function (Watzl., 2005; Yamada et al .,1999).

Table 1: Nutritional composition in 100 g of the edible portion of bok-choy (raw material(Cartea et al., 2011; U.S. Department of Agriculture).

Water	g	95
Energy	Kcal	13
Protein	g	1.5
Total lipid	g	0.2
Ash	g	0.8

Carbohydrate g	2.18
Dietary Fiber g	1
Sugar g	1.18

National Nutrient Database for Standard Reference (USDA).

Methods & Materials

Brassica crops are rich in many minerals; moreover, they are also a good source of calcium because of the low levels of oxalic and phytic acids. They also show high levels of potassium, which is an essential mineral that participates in different metabolic processes (carbohydrate metabolism, protein synthesis) and maintains adequate levels of human health (heart diseases, blood pressure, osteoporosis) and other minerals, including selenium, which is an important factor from the biological, environmental and health perspectives. Selenium deficiency is very common all over the world. Supplementing nutrition is recommended to increase daily selenium intake (N.A., 2009). A high-potassium diet can also prevent or at least slow the progression of kidney disease, reduce urinary calcium excretion, treatment of hypercalciuria, and may reduce the risk of osteoporosis (He et al., 2008). Moreover, it lowers blood pressure, thus reducing the incidence and mortality of cardiovascular disease. In addition, increased potassium intake has other beneficial effects on health, as described above. The best way to increase potassium intake is to increase the consumption of fruits and vegetables((He et al., 2008; (He et al., 2003).

Selenium is an essential microelement and nutrient for animals, humans, and microorganisms. It exists in the form of amino acids and selenocysteine in selenoproteins, which is very important for the enzymatic function of selenoproteins, such as glutathione peroxidase, iodine deiodinase and thioredoxin reductase (Neve., 2000; Thomson., 2004). Glutathione peroxidase (GSH PX) plays an important role in the defense of free radicals against hydrogen peroxide and lipid peroxidation; thioredoxin reductase (TRR) participates in the nuclear redox state; iodine deiodinase (IDH) participates in the metabolism of thyroid hormones, which is often affected in older people. In addition, selenium has anti-cancer effects, which are believed to be caused by the production of methylselenole, a metabolite that affects gene expression, cell cycle, and immune function (Combs., 2001). Insufficient selenium in the plasma may lead to cancers and cardiovascular diseases (Rayman., 2000; Flores-Mateo., et al., 2006). Furthermore, selenium is involved in the defense against oxidative stress, which can prevent hypothyroidism, prostate cancer, cardiovascular disease, weakened immune system, and mortality (Ellis et al., 2003; Etminan et al., 2005).

Table 2: Nutritional composition of 100 g of edible portion of bok-choy (raw material) (Cartea et al., 2011; N.A., 2008).

Minerals		
Calcium	mg	105
Iron	mg	0.8
Magnesium	mg	19

Phosphorus	mg	37
Potassium	mg	252
Sodium	mg	65
Zinc	mg	0.19
Copper	mg	0.021
Manganese	mg	0.159
Selenium	mcg	0.5

National Nutrient Database for Standard Reference (USDA).

Vitamins

Vegetables are considered to be an essential part of a balanced diet. In particular, Brassica vegetables add considerable visual or aesthetic attraction to a meal because many Brassica vegetables are leafy and green. They are rich in vitamin C, vitamin E, vitamin B-6, vitamin A, β - carotene, lutein, zeaxanthin, vitamin K calcium, carotenoid (vitamin A), dietary fiber, and some beneficial phytochemicals Matter (Fahey., 2003; Jahangir et al., 2009).

Vitamins are essential nutrients for the human body's various biochemical and physiological processes. Their deficiency can lead to disease, and supplementation of these nutrients can alleviate the deficiency symptoms (Zhang., 2016). As we all know, most vitamins cannot be synthesized in the body, so it is necessary to supplement vitamins in the diet. Vitamins differ from other food nutrients because of their unique, organic properties. According to their solubility, they are divided into water-soluble vitamins (C and B complex) and fat-soluble vitamins (A, D, E, K) (McDowell., 2000; Orssaudet al., 2007).

Vitamin A is obtained from plant and animal sources. Animal-derived vitamin A is called retinoic acid, while plant-derived vitamin A is called pro-vitamin A carotenoid (Steffen., et al., 2003). They are essential for vision, cell growth, development, antioxidant activity, and the promotion of appropriate cell communication (Whelton., et al., 2005). Vitamin A deficiency is the main cause of preventable blindness in children and is considered an important public health problem in many developing countries (Song et al., 2017).

Vitamin C (ascorbic acid) is an essential antioxidant in plants and the human body; it is also a common nutritional supplement (Ren et al., 2013). Vitamin C has antioxidant potential and protects cell structure from the harmful effects of free radicals. Its significant iron absorption is crucial in transforming iron into a form that is easy to absorb into the intestine, and vitamin C in the production of collagen, a structural component of the human body. In addition, synthesizing some neurotransmitters depends on vitamin C, especially the neurotransmitters involved in the sense, thought, and command of the whole brain and nervous system. In addition, vitamin C is also a prerequisite for synthesizing 5-hydroxytryptamine, which is necessary for the normal operation of the endocrine, nervous, digestive, and immune systems. Vitamin C can effectively improve the common cold (Douglas et al., 2000; Hemilä et al., 2013). Furthermore, vitamin C scavenges ROS and nitrogen species, which can prevent the oxidative damage of important biological macromolecules such as DNA, protein, and lipid, and also reduce the redox-active transition metal ions in specific biosynthesis enzyme active sites (Carr et al., 1999). Dietary sources of vitamin C include, Bok-choy, broccoli, Brussels sprouts, cauliflower, kale, cabbage, tomatoes, spinach, and asparagus (Carr et al., 1999; Chambial et al., 2013).

Vitamin E has many important functions in vivo due to its antioxidant activity. Vitamin E has been shown to prevent atherosclerosis. In addition, it helps to reduce the production of prostaglandins such as thromboxane, which can cause platelet aggregation. (Rizvi et al., 2014; Zingg., 2007).

Table 3: Nutritional composition of 100 g of edible portion of bok-choy (raw material) (Cartea et al., 2011; N.A., 2008).

Vitamins		
Vitamin C	mg	45
Thiamin	mg	0.04
Riboflavin	mg	0.07
Niacin	mg	0.5
Pantothenic acid	mg	0.08
Vitamin B-6	mg	0.19
Folate	mcg	66
Choline	mg	6.4
B-Carotene, beta	mcg	2681
Vitamin A	IU	4468
Lutein+zeaxanthin	mcg	40
Vitamin E	mg	0.09
Vitamin K	mcg	45.5

National Nutrient Database for Standard Reference (USDA).

Bioactive compound (Polyphenols) of bok-choy

Flavonoids

Flavonoids are one of the most common and largest groups commonly found in plants and are an essential part of the human diet. (Wojdyło., 2007). These compounds' antioxidant and anti-inflammatory properties are well-known (Seifried et al., 2007), and many show anti-cancer potential. Moreover, Flavonoids have been reported to inhibit inflammatory gene expression, angiogenesis, cancer cell proliferation (Luo et al., 2008), and free radical scavengers (Rafat Husain., 1987; Joseph et al., 2014). Furthermore, bioactive compounds have been reported to have protective effects on cardiovascular disease (CVD), cancer, Alzheimer's disease, depression, and other diseases. (Joseph et al., 2014; Wang et al., 2014).

Anthocyanins are the most abundant flavonoids in fruits and vegetables. As one of the main secondary metabolites in plants, it is significant in the food industry and human nutrition. Anthocyanins are considered potential food colorants to replace synthetic pigments. Recently, more and more attention has been paid to their potential health benefits in the prevention of chronic and degenerative diseases, including heart disease and cancer. (Prior., 2004; Hou., 2003), These effects are partly due to their antioxidant capacity. Moreover, epidemiological studies have shown that the consumption of anthocyanins can reduce the risk of cardiovascular disease, diabetes, arthritis, and cancer. (Prior et al., 2006). Furthermore, anthocyanins can scavenge ROS, such as superoxide (O2.–), singlet oxygen (O2), peroxide (ROO–), hydrogen peroxide (H2O2), and hydroxyl radical (OH). (Wang et al., 2000). ROS and free radicals are produced in a wide range of physiological processes. Oxidative stress is the imbalance of ROS production and antioxidant defense and may lead to oxidative damage. This biological state may be due to the lack of antioxidant defense mechanism, ROS production, and the over-activation of the ROS system, which is related to the aging and pathology of many chronic diseases (including cancer, cardiovascular disease, inflammation, and diabetes), Parkinson's disease, Alzheimer's disease, and other pathology (Seifried et al., 2007; Winterbourn., 2008). Additionally, a study reported that the antioxidant effect of anthocyanins in vitro has been demonstrated using several cell culture systems, including the colon (Renis et al., 2008), endothelial (Bagchi et al., 2004), liver (Shih et al., 2007; Meyers et al., 2003), breast (Singletary., et al., 2007). In these culture systems, anthocyanins show a variety of anti-toxic and anti-carcinogenic effects, such as direct scavenging of ROS, improving the absorption capacity of oxygen free radicals, stimulating the expression of type II detoxifying enzyme, reducing the formation of oxidative adducts in DNA, and reducing. Lipid peroxidation can inhibit mutagenesis of environmental toxins and carcinogens and reduce cell proliferation by regulating the signal transduction pathway (Kong., et al., 2003). A study has reported that Nine phenylpropanoid derivatives and 12 anthocyanins were identified in mature Chinese cabbage leaves (Jeon et al., 2018) Table 4. Another study isolated and identified 15 anthocyanins from a purple cabbage variety (Zhang et al., 2014).

Table 4. Phenylpropanoid and anthocynins contents in bok-choy (Zhang et al., 2014; Jeon et al., 2018).

Anthocyanin contents
Cyanidin 3-diglucoside-5-glucoside
Cyanidin 3-(sinapoyl)diglucoside-5-glucoside
Cyanidin 3-(caffeoyl)(p-coumaroyl)diglucoside-5-glucoside
Cyanidin 3-(glycopyranosyl-sinapoyl)diglucoside-5-glucoside
Cyanidin 3-(p-coumaroyl)(sinapoyl)triglucoside-5-glucoside
Cyanidin 3-(sinapoyl)glucoside-5-glucoside
Cyanidin 3-(p-coumaroyl)diglucoside-5-glucoside
Cyanidin 3-(sinapoyl)diglucoside-5-glucoside
Cyanidin 3-(p-coumaroyl)(sinapoyl)diglucoside-5-glucoside
Cyanidin 3-(feruloyl)(sinapoyl)diglucoside-5-glucoside
Cyanidin 3-(sinapoyl)(sinapoyl)diglucoside-5-glucoside

Cyanidin 3-(feruloyl)(sinapoyl)diglucoside-5-glucoside

Cy 3,5-diglucoside

Cy 3-diglucoside-5-(malonyl)glucoside

Cy 3-(hydroxyferuloyl)diglucoside-5-(malonyl)glucoside petunidin 3,5-diglucoside

Cy 3-(malonyl)glucoside(p-hydroxy benzoyl)arabinoside-5-

(malonyl)glucoside

Cy 3-feruloyl(sinapoyl)diglucoside-5-(malonyl)glucoside

Cy 3-hydroxysinapoyl (malonyl)glucoside-5(malonyl)glucoside

Cy 3-dihydroxysinapoyl(malonyl)glucoside-

5(malonyl)glucoside

Cy 3-(hydroxy benzoyl) feruloyl(malonyl) diglucoside-5-

(malonyl) glucoside Cy 3-malonyl (glucoside)-p-

Hydroxybenzoyl (pcoumaroyl) arabinoside-5-(malonyl)glucoside

Quercetin has been the focus of some biological studies in which quercetin has proved its anti-cancer activity in vitro. (Verma., et al., 1988). Quercetin is known to be an effective free radical scavenger and antioxidant and is also considered to protect against cardiovascular disease (Chu., et al., 2000). Moreover, it is known to be an effective free radical scavenger and antioxidant and is also considered to protect against cardiovascular disease (Prior., 2004).

Kaempferol is a polyphenol antioxidant found in various plant parts of fruits and vegetables (Li et al., 2015; Rajendran et al., 2014). kaempferol and its glycosylated derivatives have been proven to have cardiac protection, neuroprotection, anti-oxidation, antibacterial, anti-inflammatory, anti-diabetes, anti-tumor, and anti-cancer activities. Furthermore, kaempferol can help by enhancing the body's antioxidant defense against free radicals, promoting cancer development. (Chen et al., 2013; Calderón-Montaño et al., 2011; Kim et al., 2006). Additionally, kaempferol and quercetin have recently been found to play a synergistic role in inhibiting the proliferation of human intestinal cancer cells. (Ackland et al., 2005).

Table 5: Comparison of Polyphenolic Compounds in Purple and Green Cultivars

	Purple cultivar	Green cultivar
Chlorogenic acid	14.3+0.2	12+0.5
Caffeic acid	32.7+3.5	68.1+4.4
Epicatechin	76.9+10.5	58.4+5.4
p-Coumaric acid	4.7+0.3	9.2+2
Ferulic acid	17.8+0.9	9.4+0.04
Rutin	393.4+12.2	6.8+1.6

Table 6: Phenylpropanoid Contents in Purple and Green cultivars of bok-choy (µg g^{-1} dry weight) (Jeon., et al., 2018)

trans-Cinnamic acid	0.7+0.2	0.4+0.01
Quercetin	3.7+1.3	0
Kaempferol	4+1.1	0
	548.6+17.9	164.5+3.2

Total phenylpropanoid contents were measured in 2-month-old green and purple pakchoi (µg g−1 dry weight). Each value represents the mean of three technical replicates, and the error bars are SDs.

Carotenoids: Carotenoids are pigments found in almost all colored fruits and green leafy vegetables (Milani et al., 2017); humans cannot synthesize carotenoids, so they must be consumed in food or by supplement (Eggersdorfer et al., 2018). Carotenoids can potentially prevent and treat malignant and degenerative diseases and may reduce cancer risk (Clevidence., 1997). The most studied carotenoids are β - carotene, lycopene, lutein, and zeaxanthin. The beneficial effects of carotenoids are believed to be due to their role as antioxidants. Beta carotene may have additional benefits because it can be converted to vitamin A. In addition, lutein and zeaxanthin may be protective against eye disease as they absorb destructive blue light into the eye. (Johnson., 2002).

Glucosinolates are health-promoting phytochemicals in brassica plants. It is reported that the decomposition products of glucosinolates have anti-cancer activity, anti-inflammatory, cardio-protection, and antibacterial properties. (Fahey., et al., 2001; Fahey., et al., 2001). As a part of feed and food, some glucosinolate degradation products have been paid more attention for a long time because of their unique benefits to human nutrition and plant defense. This characteristic makes people think that Brassica food may be functional. The term "functional food" refers to the fact that, if they are normal dietary ingredients, they can provide a sufficient number of bioactive ingredients, which are valuable for improving health. (Cartea et al., 2011). Three aliphatic glucosinolates (GSs), i.e., glucoiberin, gluconapin, glucobrassicanapin, and three indole GSs, i.e., glucobrassicin, 4-methoxy-glucobrassicin, and neo glucobrassicin, were identified in bok-choy vegetables (Table 6.1) (Chen et al., 2008; Schreiner., 2005).

Table 6. Glucosinolates (µmol/g DW) in raw bok-choy (Schreiner., 2005; Nugrahedi., et al., 2017)

Glucoiberin	0.17±0.09
Gluconapin	0.37 ± 0.05
Glucobrassicanapin	1.46 ± 0.14
Glucobrassicin	0.09 ± 0.02
4-Methoxy-glucobrassicin	0.13 ± 0.02
Neoglucobrassicin	0.07 ± 0.02
Total glucosinolates	2.29 ± 0.16

Values are presented as mean ± standard deviation (n = 4)

Most micronutrients, such as vitamins and minerals, have a formally approved recommended daily intake, which varies between countries and regions. Although polyphenols were initially recommended, the difference between polyphenols and vitamins suggests a slightly different approach is needed. This is based on the assumption that each consumption requires a sufficient dose to produce an effect and, unlike minerals and vitamins, the active ingredients are not stored or temporarily stored in the body.

Conclusions

Bok-choy represents an integral part of the human diet worldwide, providing essential nutrients, such as phenols, vitamins, minerals, fiber, soluble sugar, fat, and carotenoids. Moreover, bok choy is a promising source of chemo-preventive dietary ingredients, which may prevent free radicals. This might be helpful for information on identifying appropriate raw materials rich in these protective ingredients and developing safe foods and additives with appropriate antioxidant properties. This review provides much evidence to support the nutritional value of bok choy and will eventually lead people to make better food choices. Bok choy is the best source of the aforementioned dietary ingredients and should be eaten regularly as part of the diet.

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