

## **Cruciferous Vegetables** By Rachael Link, MS, RD

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Cruciferous vegetables such as broccoli, cauliflower, Brussels sprouts, arugula, and kale are considered pillars of a healthful diet and have secured a slot in nearly every set of dietary guidelines around the globe. They're easy to prepare and versatile and can liven up any dish almost instantly.

In recent years, emerging research has continued to strengthen the purported benefits of this unique family of plants, with studies showing that cruciferous vegetables host an impressive array of antioxidants, nutrients, and sulfur-containing compounds, all of which are responsible for their potent medicinal and health properties.

In addition, although patients with thyroid issues and hormone problems once were advised to eliminate cruciferous vegetables from their diets, many recent studies show that these ingredients are unlikely to have an effect on thyroid function—especially when cooked—and can be enjoyed by nearly everyone in moderation.

This continuing education course explores the research on the health effects of cruciferous vegetable consumption, including its potential impact on inflammation, cancer, glycemic control, heart health, and hormone balance. It also addresses the most common concerns about cruciferous vegetables, particularly those related to thyroid health and digestion.

### **Cruciferous Vegetable Classification**

Cruciferous vegetables are any type of vegetable in the *Brassicaceae* family of plants, also known as the *Cruciferae* family. The name is derived from the New Latin word for “cross-bearing,” which is due to the crosslike shape of the four petals found in many species.<sup>1</sup>

There are about 375 different genera and roughly 3,200 unique species within the *Brassicaceae* family.<sup>2</sup> However, many of the most commonly cultivated crops belong to a single species, *Brassica oleracea*, which includes plants such as kale, cabbage, collard greens, cauliflower, Brussels sprouts, and broccoli. Of these vegetables, nearly every part of the plant is cultivated and used as a food product, including the leaves, stems, flowers, buds, roots, and seeds.

In addition to the *Brassica* genus, other cruciferous vegetable genera include *Armoracia*, *Barbarea*, *Diplotaxis*, *Eruca*, *Lepidium*, *Nasturtium*, *Raphanus*, and *Wasabia*.

Apart from *Brassica*, most of these genera contain only one or two edible plant species. Within the *Eruca* genus, for instance, arugula is the only edible vegetable, while watercress is most notable among plants in the *Nasturtium* genus.<sup>3</sup> Certain types also are considered edible but aren't commonly consumed. Siberian kale, wrapped heart mustard cabbage, and field pepperweed are a few examples of cruciferous vegetables that often aren't cultivated commercially and may not be as recognizable to consumers.

The table on page 48 lists some of the most common edible cruciferous vegetables as well as their respective scientific classifications.

### **Nutritional Value**

Besides similarities in terms of appearance and classification, most cruciferous vegetables have a comparable nutrient profile. They're generally good sources of fiber, vitamin C, vitamin K, and phytonutrients such as sulforaphane. In addition, they're rich in other micronutrients such as vitamin A and potassium and sulfur-containing compounds called glucosinolates, which are responsible for their pungent arom and bitter flavor.<sup>2</sup>

Glucobrassicin is one of the most notable glucosinolates found in cruciferous vegetables. When the vegetables are chopped or chewed, glucobrassicin is exposed to the enzyme myrosinase, which hydrolyzes glucobrassicin to produce a glucose molecule and an aglycone known as thiohydroximate-O-sulfonate. The release of a sulfate ion then causes the formation of an intermediate compound, 3-indolyl-methyl-isothiocyanate, which is later split into a thiocyanate ion and indole-3-carbinol.<sup>4</sup>

Indole-3-carbinol is an important phytochemical associated with several significant health benefits. It's produced primarily in raw cruciferous vegetables because myrosinase is deactivated during the cooking process, ultimately hindering the hydrolysis of glucobrassicin into indole-3-carbinol. This process still may occur during digestion due to small amounts of myrosinase activity in the intestines, but to a much lesser degree when consumed cooked rather than raw.<sup>4</sup>

Cooking cruciferous vegetables also can alter other aspects of nutritional content. For example, water-soluble vitamins such as vitamin C are dramatically reduced during the cooking process. A study by Yuan and colleagues evaluated the effects of different cooking methods on the nutritional value of broccoli and found that stir-frying broccoli and then boiling it led to the greatest nutritional loss, causing a 38% decrease in vitamin C content. This was closely followed by methods such as boiling alone, microwaving, and stir-frying alone. However, microwaving, steaming, and stir-frying all were mostly effective at retaining the overall content of carotenoids, which are insoluble in water and less heat sensitive than vitamin C.<sup>5</sup>

Concentrations of other antioxidants can be increased during cooking. In a study by Miglio and colleagues, steaming, boiling, and frying broccoli all improved scores of several tests used to determine antioxidant content, including Trolox equivalent antioxidant capacity, total radical-trapping antioxidant parameter, and ferric reducing antioxidant power.<sup>6</sup>

## Types of Cruciferous Vegetables and Scientific Classifications

Common Name	Scientific Name
Arugula	<i>Eruca sativa</i>
Bok choy	<i>Brassica rapa</i> subsp. <i>chinensis</i>
Broccoli	<i>Brassica oleracea</i>
Brussels sprouts	<i>Brassica oleracea</i>
Cabbage	<i>Brassica oleracea</i>
Cauliflower	<i>Brassica oleracea</i>
Collard greens	<i>Brassica oleracea</i>
Daikon	<i>Raphanus sativus</i> L. var. <i>longipinnatus</i>
Horseradish	<i>Armoracia rusticana</i>
Kale	<i>Brassica oleracea</i>
Kohlrabi	<i>Brassica oleracea</i> var. <i>gongylodes</i>
Maca	<i>Lepidium meyenii</i>
Mizuna	<i>Brassica rapa</i> var. <i>niposinica</i>
Mustard greens	<i>Brassica juncea</i>
Radishes	<i>Raphanus raphanistrum</i> subsp. <i>sativus</i>
Turnip	<i>Brassica rapa</i> subsp. <i>rapa</i>
Wasabi	<i>Wasabia japonica</i>
Watercress	<i>Nasturtium officinale</i>

SOURCE: USDA NATURAL RESOURCES CONSERVATION SERVICE

### Health Benefits of Cruciferous Vegetables Reduction of Inflammation

Several studies have found that higher consumption of cruciferous vegetables is associated with multiple reduced markers of inflammation. In particular, cruciferous vegetables have been

linked to lower levels of tumor necrosis factor-alpha (TNFalpha), interleukin 1 beta (IL-1-beta), and interleukin 6.<sup>7,8</sup>

Chronic inflammation is thought to be at the root of a variety of health problems, and some research suggests it may contribute to the development of conditions such as heart disease, diabetes, obesity, and cancer.<sup>9</sup> Systemic inflammation also is involved in the pathology of autoimmune disorders such as rheumatoid arthritis, type 1 diabetes, multiple sclerosis, inflammatory bowel disease, and psoriasis.<sup>10</sup>

Cruciferous vegetables are high in anti-inflammatory antioxidants that can help prevent oxidative stress, fight free radical damage, and potentially aid in disease prevention. For example, kale is rich in beta-carotene and vitamin C, especially when consumed raw rather than cooked. According to a study by Sikora and Bodziarczyk, cooking kale decreased concentrations of vitamin C, polyphenols, and beta-carotene by 89%, 56%, and 5%, respectively.<sup>11</sup>

Meanwhile, Brussels sprouts and broccoli are high in kaempferol, a natural flavonol with potent anti-inflammatory properties.<sup>12,13</sup> In 2013, an animal study by Kong and colleagues demonstrated how powerful this compound can be by measuring the effects of kaempferol on inflammatory markers in rabbits. Kaempferol was administered at doses of 30 mg/kg or 150 mg/kg, and rabbits were fed either a normal or high-cholesterol diet for 10 weeks. At the end of the study, levels of TNF-alpha and IL-1-beta were decreased, while serum concentrations of superoxide dismutase, a type of antioxidant that prevents free radical damage, were increased in rabbits treated with kaempferol.<sup>14</sup>

Indole-3-carbinol is another naturally occurring anti-inflammatory compound that's produced by the breakdown of glucobrassicin. It helps inhibit the production of nitric oxide, which is associated with a decrease in the synthesis of inflammatory markers such as TNF-alpha and interleukin 10 by immune cells.<sup>15-17</sup>

### ***Anticancer Effects***

Some research shows that regular consumption of cruciferous vegetables may be associated with a reduced risk of several types of cancer, especially stomach, colon, rectal, and lung cancers.<sup>18,19</sup> It may be linked to a lower risk of bladder, breast, prostate, ovarian, and endometrial cancers as well, although current research is limited and inconsistent.<sup>18,20,21</sup>

This reduced risk is likely due to the presence of certain cancer-fighting compounds, such as selenium and glucosinolate hydrolysis products, found in cruciferous vegetables. These compounds may aid in cancer prevention by altering the metabolism of estrogen, preventing oxidative damage caused by reactive oxygen species, slowing the growth of tumor cells, and promoting apoptosis in cancer cells.<sup>22</sup>

Other compounds present in cruciferous vegetables also may offer protection against cancer. Sulforaphane, for instance, has been shown to block cancer cell proliferation, induce apoptosis, prevent metastasis, and slow the progression of benign tumor cells into malignant tumors in certain in vitro studies. It also has been shown to induce phase 2 enzymes, which

offer chemoprotection against cancer formation by increasing the generation of antioxidants and preventing oxidative damage to DNA.<sup>23-25</sup>

Kaempferol may be effective at killing cancer cells while preserving the viability of healthy cells.<sup>26</sup> In vitro studies show that kaempferol also may help decrease angiogenesis—the formation of new blood vessels—a process closely linked to cancer development that helps provide tumor cells with oxygen and nutrients, enabling them to grow and spread to other parts of the body.<sup>27</sup> Specifically, kaempferol has been shown to inhibit vascular endothelial growth factor, a type of signal protein that's considered a marker of angiogenesis.<sup>28</sup>

Meanwhile, indole-3-carbinol can help regulate estrogen levels and suppress the growth of breast, colon, prostate, and endometrial cancer cells in vitro.<sup>29,30</sup> Although the exact mechanisms remain unclear, it's thought to interact with several signaling pathways directly involved in cancer development. Certain reaction products of indole-3-carbinol, such as diindolylmethane, have been shown to play a role in the induction of specific phase 1 detox enzymes that can aid in the breakdown of carcinogenic substances. It also may promote autophagy of cancer cells and protect against damage to DNA.<sup>31</sup>

Although many of these compounds have been isolated and processed into powders and capsules, supplementation may not have the same impact as eating whole cruciferous vegetables. In fact, according to a review published by Katz and colleagues, cruciferous vegetables contain an intricate array of indole metabolites that work synergistically to aid in cancer prevention, giving them an advantage over individual compounds or antioxidants available in supplement form.<sup>31</sup>

### ***Improved Glycemic Control***

Cruciferous vegetables can have a powerful effect on glycemic control, and several studies have found that higher intake may be associated with a lower risk of type 2 diabetes.<sup>32</sup> For example, in a meta-analysis conducted by Carter and colleagues, consuming 1.35 servings of cruciferous vegetables per day was correlated with a 14% reduction in the risk of developing diabetes compared with consuming 0.2 servings daily.<sup>33</sup>

Not only are cruciferous vegetables high in dietary fiber, which can slow the absorption of glucose to help manage blood sugar levels, but they're also a good source of antioxidants and other natural compounds that can promote glycemic control.<sup>34</sup>

Studies show that several types of cruciferous vegetables can offer benefits for serum glucose levels and insulin resistance. For example, Bahadoran and colleagues evaluated the effects of broccoli sprouts on insulin resistance in individuals with type 2 diabetes by administering 10 g of broccoli sprout powder, 5 g of broccoli sprout powder, or a placebo daily to participants over a four-week period. By the end of the study, consumption of 10 g/day of broccoli sprout powder was found to significantly decrease serum insulin levels and reduce scores for the Homeostatic Model Assessment of Insulin Resistance.<sup>35</sup>

Kale has been shown to be beneficial for blood sugar levels. In one study, Kondo and colleagues found that consuming 7 g (0.25 oz) of kale powder alongside a high-carbohydrate

meal significantly suppressed postprandial glucose levels compared with a placebo in 42 participants. Of note, consuming 7 g in a single dose was shown to be equally as effective at decreasing postprandial glucose as a higher dosage of up to 14 g (0.49 oz).<sup>36</sup>

Although current research is limited to animal models, some studies have found that cabbage also may possess antidiabetic effects. One study by Islam and Choi reported that consuming freeze-dried Chinese cabbage improved glucose tolerance and lowered fasting blood glucose levels in rats within four weeks.<sup>37</sup> Another study by Kataya and Hamza showed that red cabbage lowered blood sugar levels, improved kidney function, and increased antioxidant capacity in rats with diabetes, something that could aid in the treatment of diabetic nephropathy.<sup>38</sup>

### ***Obesity Prevention***

Cruciferous vegetables can be a vital component of a healthful weight-loss diet. In fact, a large meta-analysis conducted by Bertoia and colleagues demonstrated that each daily serving of cruciferous vegetables was associated with significant weight loss, totaling an average of 0.68 lbs over a four-year period.<sup>39</sup>

Several mechanisms may explain the antiobesity effects observed with cruciferous vegetable consumption. First, they have a low energy density, which may be predictive of weight loss over time.<sup>40</sup> A study by Flood and colleagues evaluated the correlation between BMI and energy density of foods consumed in healthy adults older than 18 and reported that decreased energy density of foods was predictive of weight loss. Over the course of the study, participants in the quartile representing the greatest decrease in energy density had a mean change in BMI of  $-3.34 \text{ kg/m}^2$ , most of which occurred within the first six months of the trial. Compared with those in the quartile representing the smallest decrease in energy density, this was an average difference of about  $-1.95 \text{ kg/m}^2$  over the 18-month period.<sup>41</sup>

In addition to their low energy density, cruciferous vegetables generally are high in fiber, which can support satiety and weight loss.<sup>42,43</sup> According to a review published by Howarth and colleagues, increasing daily fiber intake by 14 g per day for at least two days may be associated with a 10% decrease in daily energy intake, plus an average weight loss of 1.9 kg (4.2 lbs) over 3.8 months.<sup>44</sup>

### ***Improvements in Heart Health***

Multiple studies have found that cruciferous vegetable consumption can improve several aspects of heart health. Intake has been linked to a lower risk of not only total and CVD mortality but also development of CVD itself.<sup>45</sup> One review by Pollock analyzed the effects of leafy green and cruciferous vegetable consumption on CVD risk and showed a 15.8% reduced incidence of CVD for those in the highest quartile of cruciferous vegetable consumption compared with those in the lowest quartile.<sup>46</sup>

Several types of cruciferous vegetables also have been shown to improve lipid profiles, which could enhance heart health and help reduce heart disease risk. For example, a study by Kim and colleagues noted that men with hypercholesterolemia consuming 150 mL of kale juice

each day for 12 weeks increased HDL cholesterol by 27% and reduced LDL cholesterol concentration and atherogenic index of plasma by 10% and 24.2%, respectively.<sup>47</sup>

Another study by Suido and colleagues evaluated the effects of a canned vegetable mixed beverage containing broccoli and cabbage on lipid levels in adults with hypercholesterolemia. After consuming two 160-g cans per day for three weeks, total cholesterol and LDL cholesterol levels both decreased by an average of 0.65 mmol/L.<sup>48</sup>

For this reason, it should come as no surprise that heart-healthy eating patterns such as Dietary Approaches to Stop Hypertension, Therapeutic Lifestyle Changes, and Mediterranean diets all emphasize the importance of consuming plenty of vegetables, including cruciferous vegetables, as part of a balanced and nutritious diet.

### ***Hormone Balance***

Certain cruciferous vegetables and extracts have been shown to have antiestrogenic effects due to the presence of indole glucosinates, a type of phytochemical found within plants of the *Brassica* genus that can shift estrogen metabolism by increasing urinary estrogen excretion to help balance hormone levels.<sup>49</sup>

In particular, indole-3-carbinol has been shown to modify levels of circulating estrogen while also decreasing urinary excretion of metabolites such as estradiol, estriol, 16-alpha hydroxyestrone, and estrone, all of which may be positively associated with an increased risk of certain types of reproductive cancers.<sup>50</sup> Preliminary research also suggests that consumption of cruciferous vegetables may increase the ratio of specific estrogen metabolites that may help protect against breast cancer.<sup>49</sup> This also may have far-reaching effects on other hormone-sensitive forms of cancer as well, including prostate cancer, endometrial cancer, cervical cancer, colon cancer, and leukemic cells.<sup>51-53</sup>

Hormonal imbalances may contribute to other issues as well, including irregular menstruation, bloating, weight gain, infertility, and polycystic ovary syndrome.<sup>54</sup> In men, high levels of estrogen can cause problems such as erectile dysfunction, infertility, and gynecomastia.<sup>55,56</sup> However, existing research on the potential hormone-balancing effects of cruciferous vegetables mostly is limited to in vitro studies. Additional high-quality, large-scale studies are needed to determine how cruciferous vegetable consumption may affect hormone levels and hormone-related conditions in the general population.

### **Common Concerns Associated With Consumption**

Despite the many health benefits associated with cruciferous vegetables, some concerns need to be addressed. Many patients with thyroid conditions such as hypothyroidism and Hashimoto's disease are advised to avoid cruciferous vegetables due to their content of goitrogens, a substance that can interfere with thyroid gland function by inhibiting the uptake of iodine in the thyroid.

However, recent research suggests that the goitrogens found in cruciferous vegetables are most likely to affect those with an iodine deficiency or those consuming excessive amounts of the vegetables (eg, multiple servings every day). For instance, a study by Truong and

colleagues looked at the relationship between thyroid cancer and consumption of goitrogen-containing cruciferous vegetables and iodine-rich foods. While they found an association between high cruciferous vegetable consumption and thyroid cancer, it was observed only in women with very low intakes of iodine at less than 96 mcg/day, which is just 64% of the DV.<sup>57</sup>

Furthermore, cooking cruciferous vegetables can deactivate myrosinase, an enzyme responsible for the release of goitrin, which is considered the active goitrogenic principle.<sup>58</sup> For this reason, it's typically recommended to cook cruciferous vegetables before consumption, particularly for those with concerns about thyroid function.

Of note, while cooking cruciferous vegetables can help block the release of goitrin, it also may limit the hydrolysis of glucobrassicin, which is converted into indole-3-carbinol.<sup>4</sup> Cooking cruciferous vegetables also can reduce the content of water-soluble vitamins such as vitamin C and vitamin B<sub>6</sub>.<sup>5</sup> However, pairing these vegetables with a variety of other nutrient-rich foods can be an effective way to offset any potential nutrient losses associated with cooking.

In addition, some people may experience digestive symptoms after consuming cruciferous vegetables. Gas, bloating, and abdominal discomfort are a few of the most common side effects associated with cruciferous vegetable consumption. This is because they're typically high in fiber as well as raffinose, a complex carbohydrate that's fermented in the gut, causing a buildup of gas in the colon.<sup>59</sup> Staying well hydrated, increasing intake gradually, and chewing foods slowly all can help ease symptoms related to increased fiber consumption. Enzymes such as alpha-galactosidase can help break down gas-causing complex carbohydrates such as raffinose and are available in over-the-counter products such as Beano.<sup>60</sup>

Keep in mind that most cruciferous vegetables are high in vitamin K, an important fat-soluble vitamin involved in blood clotting. Patients taking anticoagulants such as Coumadin (warfarin) should be mindful about vitamin K intake from cruciferous vegetables and other green vegetables, as sudden changes in consumption could potentially impact the efficacy of these medications.<sup>61</sup>

### **Culinary Uses**

When encouraging clients to increase their consumption of cruciferous vegetables, RDs should be sure to emphasize their versatility. Cruciferous vegetables can be prepared and enjoyed in a variety of ways as part of a well-rounded meal, snack, or side dish.

Broccoli, for example, can be steamed, roasted, baked, or boiled and added to stir-fries, casseroles, stews, and slaws. Leafy greens such as kale, cabbage, and arugula can be enjoyed as a base for salads or used in omelets, pasta dishes, pizza, smoothies, and more. Brussels sprouts often are roasted or sautéed and paired with honey, balsamic vinegar, nuts, cheese, or lemon juice to help balance their flavor.

Cauliflower is a popular low-carb, low-calorie alternative to other ingredients such as rice, grains, and potatoes. It can be ground into a fine consistency and used to make tortillas, pizza crust, breadsticks, and baked goods, as well as cauliflower gratin, rice, casseroles, falafel, and



tots. Other cruciferous vegetables such as cabbage and collard greens can be swapped in for wraps, tortillas, and buns for those cutting back on carbohydrates.

Cruciferous vegetables can be added to smoothies, sauces, sandwiches, salads, and soups for a quick and convenient way to take advantage of the many health benefits these vibrant vegetables have to offer.

### **Takeaways for RDs**

Cruciferous vegetables are versatile and nutritious and are associated with a long list of potential health benefits. They're low in calories and high in fiber and supply several key vitamins, minerals, and health-promoting compounds that can aid in the prevention of chronic disease. In particular, research suggests that cruciferous vegetables may help regulate estrogen levels, decrease inflammation, support glycemic control, promote heart health, increase weight loss, and protect against cancer. Keep in mind, however, that further high-quality clinical trials are needed to evaluate the extent of some of these potential benefits in humans.

Patients with certain autoimmune conditions or thyroid issues often are advised to limit or avoid cruciferous vegetables to minimize their intake of goitrogens. However, research consistently shows that cruciferous vegetables are unlikely to impact thyroid health, especially when cooked and consumed by those with an adequate intake of iodine.

However, patients taking anticoagulants such as warfarin should be advised to moderate intake of vitamin K–rich foods, including cruciferous vegetables. Sudden shifts or changes in vitamin K consumption may impact the efficacy of these medications, which may have serious implications on health.

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## Quiz

**1. Which of the following species contains many of the most commonly cultivated varieties of cruciferous vegetables?**

- A. *Brassica juncea*
- B. *Nasturtium officinale*
- C. *Armoracia rusticana*
- D. *Brassica oleracea*

**2. Cooking cruciferous vegetables is likely to decrease the content of which of the following compounds?**

- A. Indole-3-carbinol
- B. Vitamin K
- C. Carotenoids
- D. Glucobrassicin

**3. The goitrogens found in cruciferous vegetables are most likely to affect thyroid function in those deficient in which micronutrient?**

- A. Iodine
- B. Iron
- C. Selenium
- D. Zinc

**4. In one study, consuming 150 mL of kale juice daily was found to do which of the following?**

- A. Increase estrogen excretion
- B. Decrease atherogenic index of plasma
- C. Improve insulin sensitivity
- D. Decrease levels of interleukin 10

**5. Which of the following compounds found in cruciferous vegetables is likely responsible for its effects on estrogen levels?**

- A. Kaempferol
- B. Sulforaphane
- C. Indole-3-carbinol
- D. Vitamin K

**6. In a large meta-analysis, Bertoia and colleagues found that each serving of cruciferous vegetables was associated with how much weight loss over a four-year period?**

- A. 0.15 lbs
- B. 0.27 lbs
- C. 0.68 lbs
- D. 1.23 lbs

**7. Which cooking method is likely to lead to the greatest loss in vitamin C content?**

- A. Boiling
- B. Stir-frying
- C. Stir-frying and boiling
- D. Microwaving

**8. Which of the following is not considered a cruciferous vegetable?**

- A. Spinach
- B. Arugula
- C. Cauliflower
- D. Kale

**9. Which compound is responsible for the pungent aroma and bitter flavor of cruciferous vegetables?**

- A. Beta-carotene
- B. Vitamin C
- C. Kaempferol
- D. Glucosinolate

**10. Regular consumption of cruciferous vegetables consistently has been linked to a lower risk of which type of cancer?**

- A. Skin
- B. Colon
- C. Brain
- D. Kidney