Phytochemical Composition and Antioxidant Potential of *Brassica*  

Haq Nawaz, Muhammad Aslam Shad and Saima Muzaffar  

Additional information is available at the end of the chapter  

http://dx.doi.org/10.5772/intechopen.76120

---

**Abstract**

The edible parts of *Brassica* plants are a rich source of phytochemical compounds which possess strong antioxidant potential. These plants contain a variety of phytochemical compound including phenolics, polyphenols, phenolic acids, flavonoids, carotenoids (zeaxanthin, lutein, β-carotene), alkaloids, phytosterols chlorophyll, glucosinolates, terpenoids, and glycosides. These plants possess strong antioxidant potential in terms of metal reducing, metal chelating, lipid reducing and free radical scavenging activities. These also have a positive effect on the activity of antioxidant enzymes such as glutathione peroxidase, superoxide dismutase, catalase, and ascorbate peroxidase. Among various species of genus *Brassica* studied for their phytochemical composition and antioxidant activity, *Brassica oleracea* leaves, florets and seeds have better phytochemical and antioxidant profile. *Brassica juncea*, *Brassica napus*, *Brassica rapa* and *Brassica nigra* are also the phytochemical and antioxidant rich species of genus *Brassica*. The phytochemical profile and antioxidant potential of *Brassica* plants make them the preferable candidates for nutritional and pharmaceutical applications.

**Keywords:** antioxidant potential, antioxidant enzymes, *Brassica* plants, free radical scavenging capacity, bioactive phytochemicals, phytochemical composition

---

**1. Introduction**

*Brassica* is a genus of plants family *Cruciferae* also called *Brassicaceae* which consists of about 350 genera and almost 3500 species. *Brassica* is the most important of all the genera of this family. Most of the species this genus have worldwide importance due to their economic, nutritional, medicinal, and pharmaceutical value. These species are cultivated as vegetables,
oilseed crops, animal forage and medicinal herbs throughout the world. Oilseed crops of *Brassica* produce 14% of the world’s vegetable oil, the third most important source of edible oil after soybean and palm.

The genus *Brassica* is classified as:

| Kingdom     | Planta         |
|-------------|----------------|
| Division    | Tracheophyta   |
| Subdivision | Spermatophyta  |
| Class       | Angiospermae   |
| Subclass    | Dicotyledonae  |
| Order       | Papaverales    |
| Family      | Cruciferae or Brassicaceae |
| Genus       | Brassica       |

Some commonly used *Brassica* species of nutritional and medicinal importance are enlisted below [1]:

| Species         | Subspecies/var. | Common name                                               |
|-----------------|-----------------|-----------------------------------------------------------|
| *Brassica oleracea* |                 |                                                           |
| Capitata F. alba |                 | White Cabbage                                             |
| Capitata F. rubra|                 | Red or purple cabbage                                     |
| Capitata L.     |                 | Green cabbage                                             |
| Italica         |                 | Italian broccoli, Chinese broccoli                        |
| Gemmifera       |                 | Brussels sprouts                                          |
| Sabellica L.    |                 | Curly kale                                                |
| Acephala L.     |                 | Kale                                                      |
| Alboglabra      |                 | Chinese kale, kailan                                      |
| Botrytis        |                 | Cauliflower, Italian cauliflower                          |
| Sabauda         |                 | Savoy cabbage                                             |
| Gongylodes      |                 | Kohlrabi, stem turnip, Knol khol                         |
| Costata         |                 | Portuguese cole, Tronchuda cabbage                        |
| *Brassica juncea* |                 |                                                           |
| Czern L.        |                 | Mustard, Indian mustard, Leaf mustard,                    |
| *Brassica juncea* |                 |                                                           |
| Coss L.         |                 | Green mustard                                             |
| *Brassica juncea* |                 |                                                           |
| Integrifolia    |                 | Korean leaf mustard, Multi-shoot mustard                 |
| *Brassica rapa or.* |               |                                                           |
| *Brassica campestris* |           |                                                           |
| Rapiéra L./Rapa L |                 | Sarson, Turnip rape, Field mustard, Bird,                 |
|                 |                 | rape, canola, Turnip top.                                |
B. oleracea is the most important species of genus Brassica due to its cultivation, consumption and nutritional and medicinal value. The members of this species are commonly called as cabbage, kale, broccoli, cauliflower and Brussels sprouts. These are equally used as vegetables for human and forage for animals. B. juncea, B. napus, B. nigra, B. napus, B. carinata and B. rapa are the other commonly used species of this genus which are used as vegetables and a source of vegetable oil. The parts of Brassica plants used as food and medicine include root, shoot, stem, leaves, leaf buds, flower buds, florets, landraces, sprouts, inflorescence, seeds, seed oil, and callus. The Brassica plants are very rich and economical source of a variety of nutritional (carbohydrates, lipids, protein, vitamins, and minerals) and phytochemical components of medicinal value.
| Species/subspecies      | Phytochemical components and biological activity                                                                                                                                                                                                 | Reference       |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| *B. oleracea* Capitata F. *alba* | Leaves are rich source of phytochemicals including phenolics, phenolic acids, sophoroside-glucosides and vitamin C with good antioxidant activity in terms of PORS and ORAC.                                                                                                                                                                                                 | [5, 34, 35]     |
| *B. oleracea* Capitata L. | Leaves and flower buds contain phenolic acids, phenols, polyphenols, tannins, saponins, carotenoids (zeaxanthin, lutein, β-carotene), alkaloids, phenols, phytosterols and chlorophyll, glucosinolates, terpenoids flavonoids, glycosides, steroids, anthocyanins and aliphatic and aromatic amines. It shows antioxidant activity in terms of FRAP, ICA, LARC, hydroxyl and DPPH radical scavenging activities. Leaves possess antioxidant enzymes including POD, SOD, and CAT, inhibit DNA methylation, and prevent DNA damage and threats of cancer and cardiovascular diseases. | [6, 21, 36–41] |
| *B. oleracea* | Leaves are rich in phytochemicals including phenolics, carotenoids (zeaxanthin, lutein, β-carotene) glucosinolates, anthocyanins and vitamin C with good antioxidant activity in terms of free radical scavenging capacity.                                                                                                                                                                                                 | [15, 35, 40]    |
| *B. oleracea* Italic | Florets and stem contain phenolics, phenolic acids, polyphenols, sophoroside-glucosides, flavonoids, alkaloids, steroids, phenols, tannins, saponins, glutathione, glucosinolates (glucoraphanin, glucobrassicin, neoglucobrassicin), terpenoids, coumarins, cumins, cardiac glycosides, xanthoproteins, glycosides, carotenoids (zeaxanthin, lutein, β-carotene), tocopherols, phytosterols, chlorophyll, free sugars and vitamin C, and possesses antioxidant activity. It possesses antioxidant enzymes including POD, SOD, and CAT. It inhibits DNA methylation and prevents DNA damage and threats of cancer and cardiovascular diseases. It also possesses Antiproliferative, neuroprotective, antidiabetic, and antigenotoxic activities. | [5, 21, 29, 42–50] |
| *B. oleracea* Gemmifera | Seeds also possess antioxidant activity (ABTS, DPPH and SOA radical scavenging activity).                                                                                                                                                                                                                                                                          | [51]            |
| *B. oleracea* Sabellica L. | Leaves are rich in phytochemicals including phenolic acids, phenols, flavonoids, glucosinolates, thiocyanates, carotenoids (zeaxanthin, lutein, β-carotene), phytosterols and chlorophyll. It possesses antioxidant activity in terms of free radical scavenging capacity and antioxidant enzymes activity (POD, SOD, and CAT). It inhibits DNA methylation, prevent DNA damage and threats of cancer and cardiovascular diseases. | [35, 40]        |
| *B. oleracea* Acephala L. | Leaves contain phenolics, polyphenols, glucosinolate, sugars, flavonoid, and flavonoids glycoside and show antioxidant activity in terms of FRAP, DPPH radical scavenging activity                                                                                                                                                                                                 | [38, 52]        |
| *B. oleracea* Botrytis | Florets and leaves contain phenolics, polyphenols, alkaloids, saponins, tannins, steroids, flavonoids, glucosinolates, volatiles, reducing sugars and vitamin C. The aqueous and ethanolic extracts of root and leaves show antioxidant activity in terms of Fe reducing, Cu reducing, and Fe⁶⁺ chelating activity, ORAC, and DPPH, ABTS, and SOA radical scavenging activity. Florets possess antioxidant enzymes including POD, SOD, and CAT. It inhibits DNA methylation, prevent DNA damage and threats of cancer and cardiovascular diseases. It also possesses thrombolytic and cytotoxic activities. | [10, 42, 47, 54–57] |
| Species/subspecies | Phytochemical components and biological activity | Reference |
|-------------------|------------------------------------------------|------------|
| *B. oleracea* Sabauda | Leaves are rich in phytochemicals including phenolics, chlorophyll, and glucosinolate (sinigrin) with good antioxidant and pro-oxidant activity in terms of ABTS and DPPH radical scavenging capacity. | [7, 30, 35] |
| *B. oleracea* Gongylodes | The extracts of knobs in various solvents have been found to improve the antioxidant status of liver and kidneys of diabetic animals by increasing the SOD and CAT activities. | [21] |
| *B. oleracea* Costata | Seeds, sprouts, and leaves possess the ability to reduces hypochlorous acid, inhibit hydroxyl, SO, and DPPH radicals. These also show a concentration-dependent increase in the activity of antioxidant enzyme SOD. | [3, 4] |
| *B. juncea* L. Czern. | Leaves contain flavonoids, terpenoids, tannins, reducing sugars vitamin C, benzenepropanoic acid, n-eicosane, n-pentacosane and n-tetracontane. It enhances the activity of antioxidant enzymes including GPx, CAT, and APx. Seeds contain sinigrin, quercetin, catechin, sophoroside-glucosides and vitamin E and seed oil possesses antioxidant activity in terms of FRAP, Fe chelating and DPPH and SOA radical scavenging activity. It also possesses cytotoxic activity. | [5, 12, 13, 15, 28, 54, 58, 59] |
| *B. juncea* L. Coss | It contains phenolic compounds with antioxidant activity in terms of FRAP and DPPH radical scavenging activity. | [58] |
| *B. juncea* integrifolia | Germplasm contain glucosinolates (sinigrin gluconasturtin and progoitrin). | [16] |
| *B. rapa* L. Rapifera or *B. campestris* | Root, stem, leaves, and flowers contain phenolics including 3-p-coumaroylquinic, caffeic, ferulic and sinapic acids, kaempferol sophoroside-glucosides and organic acids including aconitic, citric, ketoglutaric, malic, shikimic and fumaric acids. Roots possess antioxidant activity in terms of FRSC, RP, ILPO, and DPPH and SOA radical scavenging capacity. It also possesses cytotoxic activity. | [4, 54, 60–62] |
| *B. rapa* L. Pekinensis | Leaves possess antioxidant activity in terms of Fe reducing, oxygen radical absorbing capacity, and are also active against DPPH and ABTS radicals. | [63] |
| *B. rapa* L. Parachinesis | Leaves contain phenolics, flavonoids, and anthocyanins possessing antioxidant activity in terms of DPPH radical scavenging activity. | [9] |
| *B. napus* Napobrassica | Root and leaves possess antioxidant activity in terms of FRAP, inhibit lipid peroxidation and increase the SOD and GPx activity. | [32] |
| *B. nigra* L. Koch | Leaves, Seeds and callus contain phenolics (gallic acid, catechin, epicatechin, myricetin, quercetin, and rutin), flavonoids, tannins, saponins, sinigrin, cyanogenic and cardiac glycosides, alkaloids, glutathione reducing sugar, phlobatannins and volatile oil and possess antioxidant and antiradical activity (ORAC, FRAP, and DPPH and ABTS radical scavenging capacity). | [11, 14, 22, 25, 64–66] |

ABTS: 2, 2-azinobis-(3-ethylbenzothiazoline-6-sulphonic acid), APx ascorbate peroxidase, CAT: catalase, DPPH: 2, 2-diphenyl-1-picrylhydrazyl, FRAP: ferric reducing antioxidant power, FRSC: free radical scavenging capacity, GPx: glutathione peroxidase, ICA: iron chelating activity, ILPO: inhibition of lipid peroxidation, LARC: linoleic acid reduction capacity, ORAC: Oxygen radical absorbance capacity, POD: peroxidase, PORSC: peroxide radical scavenging capacity, RP: reducing power, SO: superoxide, SOA: superoxide anion, SOD: superoxide dismutase.

**Table 1.** Bioactive phytochemical components and biological activities of some commonly used *Brassica* species.
2. Phytochemical composition

2.1. Phytochemical quality

Phytochemicals are non-nutritious chemicals that are derived from plants and provide defense against diseases in humans. They are oxidation preventive and sweep out free radicals, the byproducts of biochemical processes. They provide safeguard against different neurological, cardiac and many other physiological ailments and protect important biomolecules from oxidative damage [2]. Brassica plants are the rich source of phytochemical compounds of medicinal importance. A large no of Brassica plants has been studied for their bioactive phytochemical components and antioxidant potential. The bioactive compounds and antioxidant potential of commonly used species of Brassica plants are given in Table 1. The bioactive phytochemical compounds commonly found in most of the Brassica species include polyphenols, phenolic acids, flavonoids, carotenoids (zeaxanthin, lutein, β-carotene), alkaloids, tannins, saponins, anthocyanins, phytosterols chlorophyll, glucosinolates, phytosteroids, terpenoids, glycosides, vitamin C, Vitamin E and aliphatic and aromatic amines [3–16]. B. oleracea var. Capitata, B. oleracea var. Italica, B. oleracea var. Botrytis, B. juncea, B. rapa and B. nigra contain a treasure of phytochemical compounds of medicinal and pharmaceutical importance. Due to the presence of these compounds, Brassica plants show biological activities against various diseases and have been found to effective in treating various diseases in human. The edible parts of these plants show antimicrobial, antibacterial, antidiabetic, antimalarial, antiaging, antiulcer, anti-hyperglycemic, anti-hyperlipidemic, anti-proliferative, neuroprotective, antidiabetic, anti-genotoxic and antioxidant activities [17–25].

2.2. Phytochemical content

The major phytochemical compounds quantitatively estimated in various species of Brassica include phenolics, flavonoids, ascorbic acid (Vit. C) glucosinolates, carotenoids, and tocopherols. Tables 2 and 3 present the phytochemical content (total phenolic content: TPC, total flavonoid content: TFC, ascorbic acid content: AAC, total glucosinolate content: TGC, total...
| Species/subspecies | Parts used | Extracting solvent | TPC (GAE) | TFC | AAC | References |
|--------------------|------------|--------------------|-----------|-----|-----|------------|
| B. oleracea Capitata L. | Leaves | 80% methanol | 3.64 μM/g dw | | | [37] |
| | Leaves | Varying polarity solvents | 34–520 mg/100 g dw | 3.20–8.30 g/100 g extract | | [41] |
| | | Varying polarity solvents | 402–556 mg/100 g fw | | | [6] |
| | Flower buds | 80% methanol, phosphoric acid | 4.14 mM/g dw | | 62–72 mg/100 g fw | [37] |
| | leaf buds | Water | 53.85 mg/g | | | [68] |
| B. oleracea Italica | Florets | Ethanol, methanol, acetone | 17.9–23.6 mg/g extract | 12.5–17.5 mg CE/100 g | | [67] |
| | | Water | 48.76 μg/ml extract | 69.64 μg/ml extract | 25.0–29.48 μg/ml extract | [46] |
| | Florets, Leaves | Methanol, phosphoric acid | 533.6–740 mg/100 g | 317–816 mg CE/100 g | 298.6–474.7 mg/100 g | [47] |
| | | Florets | Methanol | 43–75 mg/kg dw | 2.1–4.0 mg/kg dw | [29] |
| | Inflorescence | Water | 1.816 mg/g fw | | | [48] |
| B. oleracea Gemmifera | Sprouts | Ethanol, methanol, acetone | 18.12–20.4 mg/g extract | 12.1–15.4 mg CE/100 g | | [67] |
| | | 70% methanol, phosphoric acid | 133–140 mg/100 g fw | | 129–127 mg/100 g fw | [35] |
| B. oleracea Alboglabra | Leaves | Water | 35.64 mg/g dw | 13.98 mg QE/g dw | | [52] |
| | Edible portion | Ethanol | 30.51–38.30 mg/g extract | 28.99–70.69 mg QE/g extract | | [9] |
| B. oleracea Acephala L. | Edible Leaves | Ethanol | 574.9 mg/100 g fw | 62.27 mg/100 g fw | | [53] |
| | 6.37 mM/100 g | | | | |
| B. oleracea Botrytis | Edible floret | 80% ethanol | 782.43 mg/100 g dw | 267.21 mg CE/100 g dw | 769.23 mg/100 g | [69] |
| B. oleracea Botrytis Cimosa | Edible portion | Ethanol | 2.24 mM/g | | | |
| | Inflorescence | Water | 30.4 mg/g | | | [68] |
carotenoid content: TCC, and total tocopherol content: TTC) of various extracts of some edible parts of commonly used *Brassica* species. The aqueous and organic extracts of the various parts of *Brassica* plants have been found to contain the considerable amounts of phenolics, flavonoids, carotenoids, ascorbic acid, and tocopherols which advocate the suitability of *Brassica* plants for pharmaceutical applications. Among *Brassica* species, *B. oleracea* var. Capitata, *B. oleracea* var. Italica, and *B. juncea* are high in phenolics, flavonoids and carotenoids.

| Species/subspecies | Parts used | Extracting solvent | TPC (GAE) | TFC | AAC | References |
|--------------------|------------|-------------------|-----------|-----|-----|------------|
| *B. oleracea* Sabauda | Leaves | Methanol | 350–1345 μg/100 g | 90–780 mg CE/100 g | 396–649 mg/100 g | [47] |
| *B. oleracea* Capitata | Leaves | Methanol | 102.71 mg/100 g fw | | | [60] |
| *B. juncea* L. Czern. | Leaves | Water | | 0.1 mg/g fw | | [70] |
| *B. rapa* Rapifera L. | Root | 70% ethanol | 0.21–2.59 g/100 g dw | | | [61] |
| *B. rapa* Pekinensis L. | Leaves | 75% Methanol | 150–347 mg/100 g | 61.9–328.70 | 7.04–13.68 | [63] |
| *B. nigra* L. | Seeds oil | | 142.86 μg/ml | 23.43 μg CE/ml | | [64] |

AAC: Ascorbic acid content, CE: Catechin equivalent, dw: Dry weight, fw: Fresh weight, GAE: Gallic acid equivalent, QE: Quercetin equivalent, RE: Rutin equivalent, TFC: Total flavonoid content, TPC: Total phenolic content.

Table 2. Phenolic, flavonoids and ascorbic acid content of commonly used *Brassica* species.
| Species/subspecies | Parts used | Extracting solvent | TGC | TCC | TTC mg/100 g fw | References |
|--------------------|------------|--------------------|-----|-----|----------------|------------|
| B. oleracea Capitata F. Alba | Leaves | Hexane | 4.35–10.07 mg/100 g fw | 0.008–0.22 | [35] |
| | Terminal leaf buds | Water | 4.33 mg/g | | [68] |
| B. oleracea Capitata L. | Leaves, Flower buds | 80% Methanol | 0.28–12.51 μM/g dw | | [37] |
| B. oleracea Capitata F. Rubra | Leaves | Hexane | 2.73–2.80 mg/100 g fw | 0.61–0.11 | [35] |
| | Terminal leaf buds | Water | 4.35 mg/g | | [68] |
| B. oleracea Italica | Florets, Leaves | Methanol | 2.12–9.66 μM/g dw | | [47] |
| B. oleracea Gemmifera | Sprouts | Hexane | 2.31–2.6 mg/100 g fw | 0.545–0.83 | [35] |
| B. oleracea Botrytis Cimosa | Edible portion | Acetone, petroleum ether | 126.22 mg/100 g dw | | [69] |
| | Inflorescence | Water | 2.62 mg/g | | [68] |
| | Florets, leaves | Methanol | 1.97–8.80 μM/g dw | | [47] |
| B. oleracea Sabauda | Leaves | Hexane | 5.55–6.25 mg/100 g fw | 0.011–0.078 | [35] |
| B. oleracea Capitate var. abruada | Leaves | Methanol | 195.22 μM/100 g fw | | [7] |
| B. oleracea Gongyloides | Stem | | 20.69 mg/g | 0.79 mg/g | [68] |
| B. rapa Rapifera L. | Root | Water | 2.04 mg/g | | [68] |
| B. rapa Pekinensis L. | Leaves | 75% Methanol | 3.93–18.87 | | [63] |

TCC: Total carotenoid content, TGC: Total glucosinolate content, TTC: Total tocopherol content.

Table 3. Glucosinolate, total carotenoids and tocopherol content of commonly used Brassica species.
3. Antioxidant potential

Antioxidants are the compounds which prevent the oxidation of the biomolecules by reducing the oxidizing agents and being self-oxidized. These compounds have the ability to scavenge the free radicals produced during the redox reactions occurring in the living and nonliving systems and prevent the free radical chain reactions. In this way, the antioxidant compounds minimize the oxidative stress and prevent the oxidative damage to food materials and living organisms. Brassica plants are known to possess antioxidant properties due to the presence of antioxidant phytochemicals mainly the polyphenols, flavonoids and ascorbic acid. Most of these phytochemical compounds act as antioxidants due to their hydrogen donating and reducing abilities. Polyphenols are the phytochemicals which act as metal ion chelators and interfere with oxidation reactions including lipid peroxidation by donating the proton to free radicals. Phenoxy radicals are relatively stable to stop the oxidation chain reaction. Therefore, they stop the initiation of new oxidation chain reaction and terminate the propagation routes by capturing free radicals [26]. Polyphenols are used for the treatment of hypertension, vascular fragility, allergies and hypercholesterolemia due to their antimicrobials, antiulcer, antiarrheal, and anti-inflammatory activities. Flavonoids possess metal ion chelating and free radical scavenging potential [27]. These phytochemicals comprise a vast antioxidant, antiproliferative and inhibitory action on inflammatory cells especially mast cells. Ascorbic acid is a water-soluble vitamin which possesses strong antioxidant potential and protects against oxidative damage.

The antioxidant activities of various extracts of some edible parts of commonly used Brassica species are presented in Tables 4 and 5. The Brassica plants have been found to possess metal

| Species/subspecies | Parts used | Extracting solvent | TAOA | FRAP | ICA | References |
|-------------------|------------|--------------------|------|------|-----|------------|
| B. oleracea Capitata L. | Leaves | 80% Methanol | 18.3 μM TE/g dw | [72] |
| | | Series of solvents | 574 g GAE/100 g dw | |
| | Flower buds | 80% methanol | 15.37 μM TE/g dw | [37] |
| B. oleracea Italica | Sprouts | 74.48–93.2% | 35–75 g Fe²⁺E/kg dw | [29] |
| | Inflorescence | Water | 0.998 mM FeSO₄/g fw | [48] |
| B. juncea L. Czern. | Seed oil | Ethanol, hexane | 55.15% | [13] |
| | Leaf, stem | Hexane methanol water | 2.25–3.12 mM FeSO₄/100 g sample | [58] |
| B. juncea L. Coss | Leaf, stem | Hexane methanol water | 3.23–7.75 mM FeSO₄/100 g sample | [58] |
| B. rapa Rapifera L. | | | 1.68 mM/L | [31] |
| Species/subspecies | Parts used | Extracting solvent | TAOA | FRAP | ICA | References |
|-------------------|------------|---------------------|------|------|-----|------------|
| B. rapa Pekinensis L. | Leaves, root | | 87–714.5 μM TE | | | [63] |
| B. napus Napobrassica | Leaves | | | 0.91–2.31 Units | | | [32] |
| B. nigra L. | Seed oil | | | 23.85% | | | [64] |

FRAP: Ferric reducing antioxidant power, GAE: Gallic acid equivalent, ICA: Iron chelating activity, TAOA: Total antioxidant activity, TE: Trolox equivalent.

Table 4. Total antioxidant activity, metal reducing and metal chelating ability of commonly used Brassica species.
| Species/subspecies | Parts used          | Extracting solvent | DPPH          | SOA             | ABTS             | References |
|-------------------|---------------------|--------------------|---------------|-----------------|------------------|------------|
| B. oleracea       | Leaves              | Water              | IC<sub>50</sub>: 18 μg/ml |                 |                  | [52]       |
| Alboglabra        |                     | Ethanol            | 1.26–2.72% IC<sub>50</sub>; 0.90–0.99 mg/ml | [9]             |
| B. oleracea       | Florets             | 80% ethanol        | 68.91%        |                 |                  | [69]       |
| Botrytis          | Seed                | DCM                | IC<sub>50</sub>; 1.51–2.75 mg/ml | IC<sub>50</sub>; 0.17–0.26 mg/ml | [54]       |
| Cimosa            | Edible portion      | Ethanol            | EC<sub>50</sub>; 6.51 mg/l |                  |                  | [8]        |
| B. oleracea       | 70% methanol        |                    | 1.38–1.68 μM AAE/g fw | IC<sub>50</sub>; 5.55–6.25 mg/ml | 2.89–3.74 μM TE/g fw | [35] |
| Sabauda           | Edible leaves       | Ethanol            | IC<sub>50</sub>; 1.53 mg/ml |                  | 33.22 μM TE/g fw | [8, 53] |
| B. oleracea       | Seed                | Hexane             | 40.2–70.2%    | IC<sub>50</sub>; 2.76–5.79 mg/ml | IC<sub>50</sub>; 0.059–0.46 mg/ml | [13] |
| Acephala          | Root                | DCM                |                |                  |                  | [54]       |
| L. Czern          |                     |                    | Hexane        | 4.23–6.41 mM TE/100 g sample |                | [58]       |
| B. juncea         | Hexane              |                    | 6.86–8.18 mM TE/100 g sample |                |                  | [58]       |
| L. Coss           |                     |                    |                |                  |                  |           |
| B. rapa           | Root                | 70% ethanol        | IC<sub>50</sub>; 0.23–2.00 mg/ml |                 |                  | [61]       |
| Rapifera L.       | Root                | Methanol           | 13–26%        |                 |                  | [71]       |
| Shoot             |                     |                    |                |                  |                  |           |
| Leaves            |                     |                    |                |                  |                  |           |
| Root aerial parts |                     |                    |                |                  |                  |           |
| Seed              | DCM                | 70% ethanol        | 11.11–86.3%   | IC<sub>50</sub>; 2.78–5.92 mg/ml | IC<sub>50</sub>; 0.003–0.03 mg/ml | [54] |
| B. rapa           | Leaves              | 75% methanol       | 92–239 μM TE  | 175–393 μM TE   |                  | [63]       |
| Pekinensis L.     |                     |                    |                |                  |                  |           |
| B. rapa           | Leaves              | Ethanol            | 5.5–6.26% IC<sub>50</sub>; 0.35–1.01 mg/ml |                  |                  | [9]        |
| Parachinesis      |                     |                    |                |                  |                  |           |
| B. nigra L.       | Oilseed             | Ethanol            | 89.25%        |                  |                  | [64]       |
| Leaves            | Ethanol             | 5.09–68.08%        |                |                  |                  | [22]       |

AAE: Ascorbic acid equivalent, ABTS: DPPH: EC<sub>50</sub>: Effective concentration required for 50% inhibition, IC<sub>50</sub>: Inhibitory concentration required for 50% inhibition, SOA: Superoxide anion radical, TE: Trolox equivalent.

Table 5. Free radical scavenging potential of commonly used Brassica species.
reducing, metal chelating, lipid reducing and free radical scavenging activities [24, 28–30]. These also possess antioxidant enzyme activities as these have been found to enhance the activities of some antioxidant enzymes including glutathione peroxidase, superoxide dismutase, catalase, heme oxygenase and ascorbate peroxidase [21, 31–33] (Table 6). *B. oleracea* plants have been studied most for their antioxidant activities among the *Brassica* species and found to possess strong antioxidant potential in terms of reducing power and free radical scavenging capacity. The strong antioxidant potential of *Brassica* plants highlights their medicinal and therapeutic importance.

### 4. Factors affecting the antioxidant activity of *Brassica* plants

Antioxidant activity of *Brassica* plants has been studied to be effected by various factors including solvent polarity, extraction time, temperature, cooking methods and nutritional and environment stress (Table 7). The increase in the polarity of the extracting solvent, extraction time and salinity stress has resulted in an increase in the antioxidant activity of *Brassica* plants. However, an increase in the temperature results in a reduction in the antioxidant potential of these plants. The steam boiling and microwave cooking methods result in a time-dependent decrease in the phytochemical content and antioxidant activity while water boiling, water blanching, steam boiling, steam blanching, microwave heating and stir-frying result in the reduction of antioxidant potential of *Brassica* vegetables.

| Species/subspecies | GPx       | SOD       | CAT       | HO         | APx         | References |
|-------------------|-----------|-----------|-----------|------------|-------------|------------|
| *B. oleracea*     |           |           |           |            |             | [21]       |
| Gongylodes        | 41.26–42.35 U/mg protein (liver), 34.43–39.38 U/mg protein (kidney) | 42.06–43.70 U, (Liver) 5.50–4.59 U (kidney) |
| *B. juncea*       | 1.58x10^3 U/mg GSH utilized/ min/mg protein | 3.75 μM H_2O_2 disposed/ min/g protein | 0.05–0.32 μM biliverdin reduced/ min/mg protein | 0.52–0.61 mM APx oxidized/ min/mg protein | [33]       |
| *B. rapa* Rapifera L. | 6981 U/L | 220 U/ml |          | 95.23 μM/ml | [31]       |
| *B. napus* Napobrassica | 4.18–19.92 U/mg protein | 66.80–202.30 U/mg protein |          |           | [32]       |

APx: ascorbate peroxidase, CAT: Catalase, GPx: Glutathione peroxidase, GSH: Glutathione, HO: Heme oxygenase, SOD: Superoxide dismutase.

Table 6. Antioxidant enzyme activities of commonly used *Brassica* species.
5. Conclusion

The edible of *Brassica* plants have been found to be a rich source of phytochemical compounds which possess strong antioxidant potential. These plants possess strong antioxidant potential in terms of metal reducing, metal chelating, lipid reducing and free radical scavenging and antioxidant enzymes activities. *Brassica oleracea* has been found to possess better phytochemical and antioxidant profile among *Brassica* plants. *Brassica juncea*, *Brassica napus*, *Brassica rapa* and *Brassica nigra* are also phytochemical and antioxidant rich species of genus *Brassica*. The considerable amount of phytochemicals and antioxidant potential make the *Brassica* plants the preferable candidates for nutritional and pharmaceutical applications.

### Conflict of interest

I confirm that there are no conflicts of interest.

### Author details

Haq Nawaz*†, Muhammad Aslam Shad1 and Saima Muzaffar²

*Address all correspondence to: haqnawaz@bzu.edu.pk

1 Department of Biochemistry, Bahuddin Zakariya University, Multan, Pakistan

2 Institute of Chemical Sciences, Bahuddin Zakariya University, Multan, Pakistan

---

| Factors          | Effects                                                                                                                                                                                                 | References |
|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Solvent polarity| Antioxidant activity increases with increasing the polarity of extracting solvent.                                                                                                                                 | [61]       |
| Extraction/      | Increase in extraction time resulted in an increase in phytochemical content and antioxidant activity.                                                                                                     | [41]       |
| treatment Time   |                                                                                                                                                                                                          |            |
| Temperature      | High temperature resulted in a rapid decrease in flavonoid content of *B. oleracea* var. Italica.                                                                                                          | [73]       |
| Cooking method   | Steam boiling and microwave cooking showed a time-dependent decrease in phytochemical content and antioxidant activity of green broccoli.                                                              | [46, 69]   |
|                  | Water boiling, water blanching, steam boiling, steam blanching, microwave heating and stir-frying resulted in the reduction of antioxidant potential of cauliflower.                                           |            |
| Salinity stress  | Extracts of *B. juncea* L. under salinity stress have been found to be helpful in decreasing the oxidative stress by increasing the activity of antioxidant enzymes.                                     | [33]       |

Table 7. Factors affecting the phytochemical composition and antioxidant activity of some commonly used *Brassica* species.
References

[1] Genus *Brassica* [Internet]. Worldw. Veg. [cited 2018 Feb 4]. Available from: http://theworldwidevegetables.weebly.com/genus-Brassica.html

[2] Uttara B, Singh AV, Zamboni P, Mahajan RT. Oxidative stress and neurodegenerative diseases: A review of upstream and downstream antioxidant therapeutic options. Current Neuropharmacology. 2009;7:65-74

[3] Ferreres F, Valentão P, Llorach R, Pinheiro C, Cardoso L, Pereira JA, et al. Phenolic compounds in external leaves of tronchuda cabbage (*Brassica oleracea* L. var. costata DC). Journal of Agricultural and Food Chemistry. 2005;53:2901-2907

[4] Sousa C, Valentão P, Pereira DM, Taveira M, Ferreres F, Pereira JA, et al. Phytochemical and antioxidant characterization of *Brassica oleracea* var. Costata extracts. Recent Progress in Medical Plants. 2009;24:311-339

[5] Cartea ME, Francisco M, Soengas P, Velasco P. Phenolic compounds in *Brassica* vegetables. Molecules. 2010;16:251-280

[6] Ahmed MF, Rao AS, Ahemad SR, Ibrahim M. Phytochemical studies and antioxidant activities of *Brassica oleracea* L. Var. Capitata. International Journal of Pharmacy and Pharmaceutical Sciences. 2012;4:374-378

[7] Fernández León AM, Lozano Ruiz M, González Gómez D, Ayuso Yuste MC, Fernández León MF. Bioactive compounds content and total antioxidant activity of two savoy cabbages. 2014

[8] Fratianni F, Cardinale F, Cozzolino A, Granese T, Pepe S, Riccardi R, et al. Polyphenol composition and antioxidant activity of two autochthonous Brassicaceae of the Campania region, southern Italy. Food and Nutrition Sciences. 2014;5:66

[9] Unal K, Susanti D, Taher M. Polyphenol content and antioxidant capacity in organically and conventionally grown vegetables. Journal of Coast Life Medicine. 2014;2:864-871

[10] Kamal AM, Chowdhury KAA, Shill LK, Hossain MR, Islam N, Anaytulla IA, et al. Phytochemical screening, cytotoxic and thrombolytic activity of extract of *Brassica oleracea* flower (cauliflower). Global Journal of Pharmacology. 2015;9:115-120

[11] Danlami U, Orishadipe Abayomi T, Lawal DR. Phytochemical, nutritional and antimicrobial evaluations of the aqueous extract of *Brassica Nigra* (Brassicaceae) seeds. American Journal of Applied Chemistry. 2016;4:161-163

[12] Sharma A, Kumar V, Kanwar MK, Thukral AK, Bhardwaj R. Phytochemical profiling of the leaves of *Brassica juncea* L. using GC-MS. International Food Research Journal. 2017:24

[13] Singh Y, Malik CP. Phenols and their antioxidant activity in *Brassica juncea* seedlings growing under HgCl2 stress. Journal of Microbiology and Biotechnology Research. 2017;1:124-130
[14] Al Shahawany AW, Al Hattab ZN, Al Tahhan SF. Qualitative and quantitative analysis of Sinigrin in different parts in vitro and in vivo of Brassica nigra plants. Biomedicine. 2016;4:19-24
[15] Chauhan ES, Tiwari A, Singh A. Phytochemical screening of red cabbage (Brassica oleracea) powder and juice-a comparative study. Journal of Medicinal Plants. 2016;4:196-199
[16] Kim HW, Ko HC, Baek HJ, Cho SM, Jang HH, Lee YM, et al. Identification and quantification of glucosinolates in Korean leaf mustard germplasm (Brassica juncea var. integrifolia) by liquid chromatography–electrospray ionization/tandem mass spectrometry. European Food Research and Technology. 2016;242:1479-1484
[17] Chen J, Zhang J, Xiang Y, Xiang L, Liu Y, He X, et al. Extracts of Tsai tai (Brassica chinensis): Enhanced antioxidant activity and anti-aging effects both in vitro and in Caenorhabditis elegans. Food & Function. 2016;7:943-952
[18] Suresh S, Waly MI, Guizani N, Rahman MS. Broccoli (Brassica oleracea) extract combats Streptozotocin-induced diabetes and oxidative stress in rats. The FASEB Journal. 2016;30:404-406
[19] Wang W, Wang X, Ye H, Hu B, Zhou L, Jabbar S, et al. Optimization of extraction, characterization and antioxidant activity of polysaccharides from Brassica rapa L. International Journal of Biological Macromolecules. 2016;82:979-988
[20] Soengas P, Sotelo T, Velasco P, Cartea ME. Antioxidant properties of Brassica vegetables. Functional Plant Science and Biotechnology. 2011;5:43-55
[21] Sharma I, Aaradhya M, Kodikonda M, Naik PR. Anti-hyperglycemic, anti-hyperlipidemic and antioxidant activity of phenolic rich extract of Brassica oleraceae var gongylodes on streptozotocin induced Wistar rats. Springerplus. 2015;4:212
[22] Tripathi A, Punekar R, Jain V, Tyagi CK, Chandekar A, Vyas A. Antioxidant and anti-ulcer potential on leaves of Brassica nigra L. against gastric ulcer. International Journal of Phytomedicine. 2017;9:144-150
[23] Muluye AB, Melese E, Adinew GM. Antimalarial activity of 80% methanolic extract of Brassica nigra (L.) Koch. (Brassicaceae) seeds against Plasmodium berghei infection in mice. BMC Complementary and Alternative Medicine. 2015;15:367
[24] Simlai A, Chatterjee K, Roy A. A comparative study on antioxidant potentials of some leafy vegetables consumed widely in India. Journal of Food Biochemistry. 2014;38:365-373
[25] Obi RK, Nwanebu FC, Ndubuisi UU, Orji NM. Antibacterial qualities and phytochemical screening of the oils of Curcubita pepo and Brassica nigra. Journal of Medicinal Plants Research. 2009;3:429-432
[26] Mandal SM, Chakraborty D, Dey S. Phenolic acids act as signaling molecules in plant-microbe symbioses. Plant Signaling & Behavior. 2010;5:359-368
[27] Chawla S, Saxena A, Seshadri S. In-vitro availability of iron in various green leafy vegetables. Journal of the Science of Food and Agriculture. 1988;46:125-127
[28] Kumari N, Avtar R, Thakral BSN. Antioxidant potential in seed meal of different Indian mustard genotypes. Journal of Oilseed Brassica. 2016;1:63-67

[29] Nicoletto C, Santagata S, Pino S, Sambo P. Antioxidant characterization of different italian broccoli landraces. Horticultura Brasileira. 2016;34:74-79

[30] Quassinti L, Gianfranceschi G, Lupidi G, Miano A, Bramucci M. Antioxidant and pro-oxidant activities of savoy cabbage (Brassica oleracea L. Var. Sabauda) sprout extracts. Journal of Food Biochemistry. 2016;40:542-549

[31] Gul S, Ahmed S, Gul H, Shad KF, Zia-Ul-Haq M, Badiu D. The antioxidant potential of Brassica rapa L. on glutathione peroxidase, superoxide dismutase enzymes and total antioxidant status. Revista Romana de Medicina de Laborator. 2013;21:161-169

[32] Jovičić D, Vasin J, Nikolić Z, Petrović G, Tamnidžić G, Ignjatov M, et al. Antioxidant capacity of oilseed rape (Brassica napus) in different soil types. Turkish Journal of Agriculture and Forestry. 2017;41:463-471

[33] Verma K, Dixit S, Shekhawat GS, Alam A. Antioxidant activity of heme oxygenase 1 in Brassica juncea (L.) Czern.(Indian mustard) under salt stress. Turkish Journal of Biology. 2015;39:540-549

[34] Podsędek A. Natural antioxidants and antioxidant capacity of Brassica vegetables: A review. LWT-Food Science Technology. 2007;40:1-11

[35] Sosnowska D, Redzynia M, Anders B. Antioxidant capacity and content of Brassica oleracea dietary antioxidants. International Journal of Food Science and Technology. 2006;41:49-58

[36] Ogbede S, Saidu A, Kabiru A. Phytochemical compositions, Antihyperlipidemic and Hepatoprotective effects of Brassica oleracea Var. Capitata L. leaf extracts on triton-induced Hyperlipidemic rats. International Journal of Medical Science and Clinical Invention. 2014;1:345-351

[37] Sotelo T, Cartea ME, Velasco P, Soengas P. Identification of antioxidant capacity-related QTLs in Brassica oleracea. PLoS One. 2014;9:e107290

[38] Grønbæk M. Effects of cultivation strategies on phytochemicals and sensory properties of cabbage (Brassica oleracea L. var. capitata L.) and curly kale (Brassica oleracea L. var. sabellica L.). Aarhus University, Department of Food Science; 2014

[39] Thaipratum R. Evaluation of antioxidant activities of cabbage (Brassica oleracea L. var. capitata L.). World Academy of Science, Engineering and Technology International Journal of Biology and Biomolecular Agricultural Food Biotechnology Engineering. 2014;8:591-593

[40] Hedges LJ, Lister CE. Nutritional Attributes of Brassica Vegetables. Crop Food Res Confid Rep. 2006

[41] Nawaz H, Shad MA, Rauf A. Optimization of extraction yield and antioxidant properties of Brassica oleracea Convar Capitata Var L. leaf extracts. Food Chemistry. 2018;242:182-187
[42] Sharma P, Kapoor S. Biopharmaceutical aspects of *Brassica* vegetables. Journal of Pharmacognosy and Phytochemistry. 2015;4

[43] Fulltext [Internet]. [cited 2018 Jan 29]. Available from: https://www.researchgate.net/profile/Carolyn_Lister/publication/268516193_Nutritional_attributes_of_Brassica_vegetables/links/546e86de0cf29806ec2eb695.pdf

[44] Miraj S. Broccoli (*Brassica oleracea* var. Italica): Potential candidate in the health management. Der Pharmacia Lettre. 2016;8:61-65

[45] Renaud EN, van Bueren ETL, Myers JR, Paulo MJ, van Eeuwijk FA, Zhu N, et al. Variation in broccoli cultivar phytochemical content under organic and conventional management systems: Implications in breeding for nutrition. PLoS One 2014;9:e95683

[46] Porter Y. Antioxidant properties of green broccoli and purple-sprouting broccoli under different cooking conditions. Bioscience Horizon. 2012;5:hzs004

[47] Bhandari SR, Kwak J-H. Seasonal variation in phytochemicals and antioxidant activities in different tissues of various broccoli cultivars. African Journal of Biotechnology. 2014:13

[48] Wu H, Zhu J, Yang L, Wang R, Wang C. Ultrasonic-assisted enzymatic extraction of phenolics from broccoli (*Brassica oleracea* L. var. italica) inflorescences and evaluation of antioxidant activity in vitro. Food Science and Technology International. 2015;21:306-319

[49] Singh B, Chaturvedi S, Walia S, Kaushik G, Thakur S. Antioxidant potential of broccoli stalk: A preliminary investigation. Mediterranean Journal of Nutrition and Metabolism. 2011;4:227-230

[50] Shah MA, Sarker MMR, Gousuddin M. Antidiabetic potential of *Brassica oleracea* Var. Italica in type 2 diabetic Sprague dawley (sd) rats. International Journal of Pharmacognosy and Phytochemistry Research. 2016;8:462-469

[51] Ligen Z, Yuanfeng W, Yuke S, Lei Z, Mupunga J, Jianwei M, et al. Broccoli seed extracts but not sulforaphane have strong free radical scavenging activities. International Journal of Food Science and Technology. 2017;52:2374-2381

[52] Agarwal A, Raj N, Chaturvedi N. A comparative study on proximate and antioxidant activity of *Brassica oleracea* (kale) and *Spinacea oleracea* (spinach) leaves. International Journal of Advanced Research Biological Sciences. 2017;4:22-29

[53] Sikora E, Bodziarczyk I. Composition and antioxidant activity of kale (*Brassica oleracea* L. var. acephala) raw and cooked. Acta Scientiarum Polonorum. Technologia Alimentaria. 2012;11:239-248

[54] Chaudhary A, Choudhary S, Sharma U, Vig AP, Arora S. In vitro evaluation of *Brassica* sprouts for its antioxidant and Antiproliferative potential. Indian Journal of Pharmaceutical Sciences. 2016;78:615-623

[55] Lo Scalzo R, Picchi V, Migliori CA, Campanelli G, Leteo E, Ferrari V, et al. Variations in the phytochemical contents and antioxidant capacity of organically and conventionally grown Italian cauliflower (*Brassica oleracea* L. subsp. botrytis): Results from a three-year field study. Journal of Agricultural and Food Chemistry. 2013;61:10335-10344
Cabello-Hurtado F, Gicquel M, Esnault M-A. Evaluation of the antioxidant potential of cauliflower (*Brassica oleracea*) from a glucosinolate content perspective. Food Chemistry. 2012;132:1003-1009

Köksal E, Gälçin İ. Antioxidant activity of cauliflower (*Brassica oleracea* L.). Turkish Journal of Agriculture and Forestry. 2008;32:65-78

Puangkam K, Muanghorm W, Konsue N. Stability of bioactive compounds and antioxidant activity of Thai cruciferous vegetables during in vitro digestion. Current Research Nutrition in Food Science Journal. 2017;5:100-108

Parikh H, Khanna A. Pharmacognosy and phytochemical analysis of *Brassica juncea* seeds. Pharmacognosy Journal. 2014;6

Fernandes F, Valentão P, Sousa C, Pereira JA, Seabra RM, Andrade PB. Chemical and antioxidative assessment of dietary turnip (*Brassica rapa* var. rapa L.). Food Chemistry. 2007;105:1003-1010

Ryu JP, Kim DC, In M-J, Chae HJ, Lee SD. Antioxidant potential of ethanol extract of *Brassica rapa* L. root. Journal of Medicinal Plants Research. 2012;6:1581-1584

Beltagy AM. Investigation of new antimicrobial and antioxidant activities of *Brassica rapa* L. International Journal of Pharmacy and Pharmaceutical Sciences. 2014;6:84-88

Seong G-U, Hwang I-W, Chung S-K. Antioxidant capacities and polyphenolics of Chinese cabbage (*Brassica rapa* L. ssp. Pekinensis) leaves. Food Chemistry. 2016;199:612-618

Olgun Ç, Özkan OE, Güney B, Pattabanoglu ES, Güney K, Gür M. Chemical composition and antimicrobial activity in cold press oil of fennel, Anise, white and black mustard seeds. Indian Journal of Pharmaceutical Educational Research. 2017;51:S200-S204

Kumar M, Sharma S, Vasudeva N. In vivo assessment of antihyperglycemic and antioxidant activity from oil of seeds of *Brassica nigra* in streptozotocin induced diabetic rats. Advanced Pharmaceutical Bulletin. 2013;3:359

Lee YH, Choo C, Waisundara VY. Determination of the Total antioxidant capacity and quantification of phenolic compounds of different solvent extracts of black mustard seeds (*Brassica nigra*). International Journal of Food Properties. 2015;18:2500-2507

Jaiswal AK, Abu-Ghannam N, Gupta S. A comparative study on the polyphenolic content, antibacterial activity and antioxidant capacity of different solvent extracts of *Brassica oleracea* vegetables. International Journal of Food Science and Technology. 2012;47:223-231

Anitha T. Studies on Invitro antioxidant properties of *Brassica* vegetables. International Journal of Pharmaceutical, Chemical and Biological Sciences. 2014;4

Ahmed FA, Ali RF. Bioactive compounds and antioxidant activity of fresh and processed white cauliflower. BioMed Research International. 2013;2013

Chauhan PK, Jaryal M, Kumari K, Singh M. Phytochemical and in vitro antioxidant potential of aqueous leaf extracts of *Brassica juncea* and Coriandrum sativum. International Journal of Pharmaceutical Sciences and Research. 2012;3:2862
[71] Iqbal S, Younas U, Chan KW, Saeed Z, Shaheen MA, Akhtar N, et al. Growth and antioxidant response of Brassica rapa var. rapa L.(turnip) irrigated with different compositions of paper and board mill (PBM) effluent. Chemosphere. 2013;91:1196-1202

[72] Fulltext [Internet]. [cited 2018 Jan 29]. Available from: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0107290

[73] Balouchi Z, Peyvast G-A, Ghasemnezhad M, Saadatian M. Changes of antioxidant compounds of broccoli (Brassica oleracea l. var. Italica) during storage at low and high temperatures. Journal of Horticulture, Biology and Environment. 2011;2(2):193-212