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Chapter 2

Phytochemical Composition and Antioxidant Potential of *Brassica*

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Additional information is available at the end of the chapter

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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,

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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	Rapifera L./Rapa L	Sarson, Turnip rape, Field mustard, Bird rape, canola, Turnip top.

	Pekinensis L.	Chinese cabbage
	Parachinesis	Chines cabbage, Choi sum, Sawi
Brassica napus	Napobrassica	Oilseed rape, rape, oilseed rape, Canola
Brassica carinata		Ethiopian rapeseed
Brassica nigra	Koch L.	Black mustard
	Viridis	Collards
Brassica juncea	Crispifolia	Curled mustard
	Rosularis	Tatsoi
Brassica hirta	*Sinapis alba*	White or yellow mustard
Brassica elongata		Elongated mustard
Brassica fruticulosa		Mediterranean cabbage
Brassica hilarionis		Hilarion's *Brassica*, St. Hilarion Lahanas
Brassica kaber		Wild mustard, Charlock, Field mustard
Brassica balearica		Mallorca cabbage
Brassica fruticulosa		Mediterranean cabbage.
Brassica hilarionis		St Hilarion cabbage.
Brassica rupestris		Brown mustard
Brassica tournefortii		Asian mustard
Brassica narinosa		Broad beaked mustard
Brassica geniculata		Hoary mustard
Brassica elongate		Elongated mustard
Brassica septiceps		Seven top turnip
Brassica perviridis		Tender green, mustard spinach

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 Capitata *F. rubra*	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 Italica	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]
	Seeds also possess antioxidant activity (ABTS, DPPH and SOA radical scavenging activity).	[51]
B. oleracea Gemmifera	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 Sabellica 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 Acephala L.	Leaves contain polyphenols, Vitamin C and carotenoids (β-carotene) and possess antioxidant activity (ABTS radical scavenging activity).	[53]
Alboglabra	Leaves contain phenolics, Polyphenols, Glucosinolate, and Carotenoids (zeaxanthin, lutein, b-carotene),	[40]
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 Fe^{2+} 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-tetratetracontane. 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 F. Alba	Leaves	Ethanol, methanol, acetone	14.78–18.7 mg/g extract	4.12–8.80 mg QE/g extract		[67]
		70% methanol, phosphoric acid	20–29 mg/100 g fw		18–35 mg/100 g fw	[35]
	Terminal leaf buds	Water	43.87 mg/g			[68]
B. oleracea Capitata F. Rubra	Leaves	70% methanol	134–171 mg/100 g fw			[24]

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	Floret	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]
	Inflore-scence	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, 6.37 mM/100 g		62.27 mg/100 g fw	[53]
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			
	Inflore-scence	Water	30.4 mg/g			[68]

Species/ subspecies	Parts used	Extracting solvent	TPC (GAE)	TFC	AAC	References
	Florets, leaves	Methanol	350–1345 μg/100 g	90–780 mg CE/100 g		[47]
		phosphoric acid			396–649 mg/100 g	[47]
B. oleracea Sabauda	Leaves	70% methanol, phosphoric acid	47–59 mg/100 g fw		49–51 mg/100 g fw	[35]
B. oleracea Capitata	Leaves	Methanol	102.71 mg/100 g fw			[60]
B. juncea L. Czern.	Leaves	Water			0.1 mg/g fw	[70]
	Leaf, stem	Hexane methanol water	3.01–3.85 mg/100 g sample			[58]
B. juncea L. Coss Sareptana	Leaf, stem	Hexane methanol water	14.12–19.78 mg/100 g sample			[58]
B. rapa Rapifera L.	Root	70% ethanol	0.21–2.59 g/100 g dw			[61]
		Water	5.640 mg/g			[68]
	Root, Shoot, Leaves	Methanol	30–78 mg/100 g fw	4.1–8.5 mg RE/g fw	0.13–0.25 mg/g	[71]
B. rapa Pekinensis L.	Leaves	75% Methanol	150–347 mg/100 g	61.9–328.70	7.04–13.68	[63]
B. rapa Parachinesis	Leaves	Ethanol	42.32–42.92 mg/g extract	49–133 mg QE/g extract		[9]
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.

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*, *B. rapa* are high in phenolics, flavonoids and carotenoids.

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]
	Inflore-scence	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. aabuada	Leaves	Methanol	195.22 μM/100 g fw			[7]
B. oleracea Gongylodes	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 routs by capturing free radicals [26]. Polyphenols are used for the treatment of hypertension, vascular fragility, allergies and hypercholesterolemia due to their antimicrobials, antiulcer, antidiarrheal, 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			[41]
	Flower buds	80% methanol		15.37 μM TE/g dw		[37]
B. oleracea Italica	Sprouts		74.48–93.2%	35–75 g Fe^{2+}E/kg dw		[29]
	Inflore-scence	Water		0.998 mM $FeSO_4$/g fw		[48]
B. juncea L. Czern.	Seed oil	Ethanol, hexane			55.15%	[13]
	Leaf, stem	Hexane methanol water		2.25–3.12 mM $FeSO_4$/100 g sample		[58]
B. juncea L. Coss	Leaf, stem	Hexane methanol water	3.23–7.75 mM $FeSO_4$/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.			87–714.5 μM TE			[63]
B. napus Napobrassica	Leaves, root			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 Capitata F. Alba		Ethanol, methanol, acetone	IC_{50}: 1.01–1.40 mg/ml			[67]
		70% methanol	0.77–1.0 μM AAE/g fw	IC_{50}: 4.35–10.07 mg/ml	1.34–1.8 μM TE/g fw	[35]
B. oleracea Capitata F. Rubra		70% methanol	6.76–9.19 μM AAE/g fw	IC_{50}: 2.73–2.80 mg/ml	9.8–12.6 μM TE/g fw	[35]
B. oleracea Capitata L.	Leaves	80% methanol	14.94 μM TE/g dw		24.78 μM TE/g dw	[37]
		Series of solvents	IC_{50}: 0.006–0.16 mg/ml			[41]
		Series of solvents	59.18–75.65% IC_{50}: 4.2–8.7 μg/ml			[6]
	Flower buds	80% Methanol	12.51 μM TE/g dw		25.16 μM TE/g dw	[37]
	Leaves	Ethanol	7.316 μM AAE/g fw			[39]
		water	15.14 M AAE/g fw			[39]
B. oleracea Italica	Floret	Ethanol, methanol, acetone	IC_{50}: 0.71–1.35 mg/ml			[67]
		Water	47.93–85.40%			[46]
	Florets leaves	Methanol	IC_{50}: 2.27 mg/ml			[47]
	Inflore-scence	Water	EC_{50}: 0.25 mg/ml			[48]
B. oleracea Gemmifera		Ethanol, methanol, acetone	IC_{50}: 0.8–1.22 mg/ml			[67]
		70% methanol	3.90–5.98 μM AAE/g fw	IC_{50}: 2.31–2.60 mg/ml	5.85–7.04 μM TE/g fw	[35]

Species/subspecies	Parts used	Extracting solvent	DPPH·	SOA·	ABTS·	References
B. oleracea Alboglabra	Leaves	Water	IC_{50}: 18 μg/ml			[52]
		Ethanol	1.26–2.72% IC_{50}: 0.90–0.99 mg/ml			[9]
B. oleracea Botrytis	Florets	80% ethanol	68.91%			[69]
	Seed	DCM	IC_{50}: 1.51–2.75 mg/ml	IC_{50}: 0.17–0.26 mg/ml		[54]
B. oleracea Botrytis Cimosa	Edible portion	Ethanol	EC_{50}: 6.51 mg/l			[8]
B. oleracea Sabauda		70% methanol	1.38–1.68 μM AAE/g fw	IC_{50}: 5.55–6.25 mg/ml	2.89–3.74 μM TE/g fw	[35]
B. oleracea Acephala	Edible leaves	Ethanol	IC_{50}: 1.53 mg/ml		33.22 μM TE/g fw	[8, 53]
B. juncea L. Czern	Seed	Hexane	40.2–70.2%			[13]
		DCM	IC_{50}: 2.76–5.79 mg/ml	IC_{50}: 0.059–0.46 mg/ml		[54]
		Hexane methanol water	4.23–6.41 mM TE/100 g sample			[58]
B. juncea L. Coss		Hexane methanol water	6.86–8.18 mM TE/100 g sample			[58]
B. rapa Rapifera L.	Root	70% ethanol	IC_{50}: 0.23–2.00 mg/ml			[61]
	Root Shoot Leaves	Methanol	13–26%			[71]
	Root aerial parts	70% ethanol	11.11–86.3%			[62]
	Seed	DCM	IC_{50}: 2.78–5.92 mg/ml	IC_{50}: 0.003–0.03 mg/ml		[54]
B. rapa Pekinensis L.	Leaves	75% methanol	92–239 μM TE		175–393 μM TE	[63]
B. rapa Parachinesis	Leaves	Ethanol	5.5–6.26% IC_{50}: 0.55–1.01 mg/ml			[9]
B. nigra L.	Oilseed	Ethanol	89.25%			[64]
	Leaves	Ethanol	5.09–68.08%			[22]

AAE: Ascorbic acid equivalent, ABTS·: DPPH: EC_{50}: Effective concentration required for 50% inhibition, IC_{50}: Inhibitory concentration required for 50% inhibition, SOA: Superoxide anion radical, TE: Trolox equivalent.

Table 5. Free radical scavenging potential of commonly used ***Brassica*** species.

Species/subspecies	GPx	SOD	CAT	HO	APx	References
B. oleracea 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)			[21]
B. juncea L. Czern.	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.

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.

Factors	Effects	References
Solvent polarity	Antioxidant activity increases with increasing the polarity of extracting solvent.	[61]
Extraction/ treatment Time	Increase in extraction time resulted in an increase in phytochemical content and antioxidant activity.	[41]
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 activity of antioxidant enzymes.	[33]

Table 7. Factors affecting the phytochemical composition and antioxidant activity of some 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.

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