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NUTRITIONAL AND MEDICINAL PROPERTIES OF BROCCOLI (*BASSICA OLERACEA*. L): A REVIEW

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ABSTRACT
Broccoli are vegetables consumed by human for their dietary fiber, vitamins, minerals, and non-nutritive phytochemicals. It is an annual crop that belongs to Brassicaceae family and is a relative of Brussels sprouts, cabbage, cauliflower, and kale. The study aimed to provide update information on the nutritional and medicinal efficacy of Broccoli. It is commercially cultivated for its large, leafy head that is rich in vitamin C. Broccoli is characterized by its thick stalk and a crown of densely-packed flower heads arranged in a tree-like fashion, both of which are edible. The plant has been widely used for the treatment of various diseases or ailment ranging from anti-cancer, antioxidant, anti-inflammatory, anti-diabetic, anti-microbial, antihypertensive and provide a wide range of glucosinalates. It is also enriched with calcium that is equivalent to milk and also a good source of phosphorus, calcium, manganese, iron, magnesium, selenium, zinc, and phosphorus. The major natural antioxidants in Brassica foods are vitamins C and E, carotenoids, and phenolic compounds, especially flavonoids. Broccoli contribute high levels of minerals, however, they are likely to be affected by cultivar, environment and type of inflorescence. It is generally believed to have originated from the wild, leafy, non-heading types of vegetable.

Keywords: Braccoli, Vitamins, Vegetables, Food, Cultivar, Nutrition

INTRODUCTION

Broccoli is a plant belonging to the family Brassicaceae previously referred to as Crucifereae. The plant has a vast history of being cultivated for their edible fleshy stem, roots, leaves, inflourescence, and oil extracted from its seeds. Plants are nature′s gift to humankind. They are considered as the most important resources of human nutrition and medicines. Plants have been the primary source of medicines for early drug discovery. In developing countries, due to economic factors, large population still depends on plant extracts as a source of medicine. In relation to this and due to increasing risk of chronic illness worldwide, the World Health Organization (WHO) advocate use traditional herbal medicines for the treatment of various chronic ailments in developing countries (Vasanthi *et al.*, 2012). In recent years, consumers began to change their eating habit with the growing interest in feeding and consumption of fresh vegetables for nourishment and healthy dietary. Previously in the "Western" diets are characterized by increased intake of calories, sugar, saturated fats and animal protein, and reduced consumption of vegetables and fruits, and this promote prevalence and frequency of diseases such as obesity, diabetes, and cardiovascular diseases (Septembre-Malaterreb *et al.*, 2018). Broccoli is rich in vitamin C, dietary fiber and also contain glucoraphin, sulforaphane, selenium and isothiocyanates. Broccoli is also an excellent source of indole-3-carbinol. These constituents present in broccoli are known to be very popular since they possess several anti-cancer properties and benefits. These anti-carcinogenic compounds have a wide variety of uses and benefits for the treatment of various diseases and disorders.

Broccoli is widely used in the treatment of several forms of cancer and also treats other neural disorders. The therapeutic potential of broccoli has been explained under its role in cancer, diabetes and other diseases (Juma *et al*., 2015).

Broccoli is an annual crop that belongs to Brassicaceae family and recognized among the important crop in the world (Petkowicz and Williams, 2020). It is native to the eastern Mediterranean region, and it was introduced to America and England in the 17th century and to China in the late 1900s (Li *et al*., 2019). Globally, production of broccoli was approximately 15.00 million tons in 1999 and that increased to approximately 26.92 million tons in 2019 (FAOSTAT, 2021).

Broccoli is a vegetable and highly important for human nutrition and bioactive nutrient molecules such as dietary fiber, vitamins and minerals, and non-nutritive phytochemicals (phenolic compounds, flavonoids, bioactive peptides). These nutrient and non-nutrient molecules reduce the risk of chronic diseases such as cardiovascular diseases, diabetes, certain cancers, and obesity (Septembre-Malaterreb *et al*., 2018). Broccoli hybrids, such as broccolini and brocco-flower, are commonly cultivated in the tropical regions. These hybrids fall within the same species and varietal as broccoli, and with similar nutrient compositions of other plants in the genus *Brassica* (Murray *et al*., 2015). Broccoli has a history of medicinal use. Ancient literature provides examples of broccoli-based treatments for gynecological disorders, later, it became a panacea for many different conditions, including gastric upset, tetanus, skin infections, and dropsy (Van Wyk, 2015). Broccoli cultivation (e.g., stalks and leaves) are being studied for their nutritive value and bioactive compounds, through extraction, these nutrients and bioactive compounds add value and supplement dietary or use as food additives (Dominguez-Perles *et al*., 2010). Broccoli sprouts and broccoli seed extract are also popular additives to nutritional beverages due to their high glucoraphanin concentrations (Daniells, 2016). The aim of the study is to provide an update on the nutritional and medicinal properties of Broccoli.

Origin of Broccoli

The name "broccoli" is a derivation of Italian "*broccolo*", which denotes the flowering top of a cabbage (Li *et al*., 2019). It is a cultivar of wild cabbage originated along the northern and western coasts of the Mediterranean Sea, where it became a domesticated food crop thousands of years ago. Over time, the wild cabbage was eventually bred by growers into distinctly different varieties or cultivars of *B. oleracea*, including broccoli, Brussels sprouts, cauliflower, collard greens, and kale (New World Encyclopedia, 2018), the specie (*B. oleracea)* hybridizes so easily. Broccoli is a fast-growing annual food crop that grows two to three feet tall and yields broccoli crowns, or florets, within 60 - 150 days growing time primarily depends on variety and climate conditions. The broccoli vegetable is usually eaten at the crown (inflorescence) stage. When the plants remain in the field past the crown stage and allowed to flower, they produce broccoli seeds. Sprouts are produced when broccoli seeds are grown with light and water for approximately 3 or 4 days (Van Wyk, 2015).

Description

The plant Braccoli is an annual vegetable belonging to the cabbage family (Brassicaceae) has about 338 genera with a total of 3700 species, among which some plants of commercial interest includes cabbage, cauliflower, Brussels sprouts and broccoli (Oronoz *et al*., 2013). Broccoli originated through a selection process of the wild cabbage in the Southern Europe and Asia Minor (Schery, 2016).

The plant develops an erect stem, pulpy and thick with limp and spaced leaves. Those stems emerge with leaf axils creating inflorescences of different colours from green, white, purple or yellow (Figure 1) and others laterals. The central inflorescence measure between 7.5 and 20 cm in diameter, and the height average is about 30 - 60 cm. Thick inflorescence has commercial interest which is formed by a group of flower buds with its pulpy stems, while in cauliflower, small size flower grow on the principal stem leaf axils (FAOSTAT, 2021).

Broccoli is a cold season crop that is sowed in a great diversity of soils. However, the best results are obtained on loamy, deep soils with a large content of organic matter and pH between 5.5 and 6.5. Broccoli seed can germinate between 4 and 35°C, but the optimal growth is reached when temperatures are between 16 and 18°C. The seedlings are usually transplanted between 30 and 45 days. In commercial sowings of broccoli under optimal conditions large and leafy plants are obtained that produce compact inflorescences with a large and branched stem (Lestrange *et al.*, 2013).

Figure 1: An image showing different colour (purple, yellow, green and white) of broccoli flower

Taxonomic hierarchy of Broccoli

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophyta
Class	Magnoliopsida
Superorder	Rosanae
Order	Brassicales
Family	Brassicaceae
Genus	*Brassica L.* – mustard
Species	*Brassica oleracea* L. – cabbage
Varieties	*Brassica oleracea* L. var. *italica* Plenck – sprouting broccoli

(ITIS, 2022)

Nutritional Properties of Broccoli

Brassica vegetables contain significant amounts of dietary fiber (Dias, 2021). Dietary fiber content of cauliflower was estimated to be around 5 % of fresh weight, 50 % of dry weight and 40 % non-starch polysaccharides.

Cellulose and lignin concentrations in Brussels sprouts were estimated to be 36 % and 14.5 %, while in cauliflower they were estimated to be around 16 % and 13 % of dry matter, respectively (Ogedegbe and Law-Ogbomo, 2013). Brassica vegetables are also rich in vitamins, including carotenes, tocopherols, vitamin C, and folic acid that have the potential to prevent and treat several diseases related to oxidative stress like cancerous and degenerative diseases (Dias, 2021).

Cao *et al.* (2016) study the antioxidant capacity among 22 common vegetables observed that green leafy kale rated as the second highest among the vegetables tested. Brussels sprouts and broccoli were also graded high in vitamin content comprising significant amounts of β-carotene and vitamins C and E (Kurilich, 2019). Evaluation of α and β-, α-, and γ-tocopherols, and vitamin C in broccoli, Brussels sprouts, cabbage, cauliflower, tronchuda, and kale, showed significant variations between and within the Brassicas. Vitamin C is the most abundant vitamin in all five Brassicas tested (Kurilich, 2019). Kale had the highest amount of these vitamins, followed by broccoli, Brussels sprouts, cabbage and cauliflower. Research indicated that 79 % of β-carotene, 82 % of α-tocopherol, and 55 % of vitamin C variability in broccoli were associated with genetic factors (Kurilich, 2019).

When 200 g of broccoli was consumed by healthy volunteers, significant modifications in the serum of both men and women were observed for lutein, γ-tocopherol in women only, whereas no changes were observed for α- tocopherol, β-carotene, and retinol (Granado *et al.*, 2016).

Carotenoids present in dark green leafy vegetables might be involved in the prevention of several diseases related to oxidative stress. Miyazawa (2015) found that carotenoids content in some *B. rapa* is two-fold higher than in spinach. Sixteen carotenoids were identified in pak-choi, choy-sum and Chinese cabbage, out of which lutein and β-carotene were the most abounding (Wills and Rangga, 2016). Lutein has also been isolated from extracts of fresh raw kale, and high levels of other carotenoids, mainly β-carotene, were also detected. Brussels sprouts and white cabbage, have been also described to contain significant amounts of trans- -β-carotene and cis-β-carotene (Lefsrud and Kopsell, 2016).

The main tocopherol in all Brassica vegetables is α-tocopherol with the exception of white cauliflower, which dominantly contains γ-tocopherol (Podsedek, 2017).

Brassica vegetables are also an excellent source of folic acid, a limited but important vitamin which deals as a coenzyme in many single carbon transfer reactions in the synthesis of DNA, RNA, and in protein contents (Dias, 2021). Folic acid reduces the risk of neural tube defects and may be associated with the reduced risk of vascular disease and cancer, while low folate intake has been identified as a main cause of anaemia (Bollheimer, 2015).

Brussels sprouts and broccoli were rated among the highest vegetable sources for folate, contributing about 110 to 135 and 70 to 90 µg/100g, respectively. Brassica vegetables are rich in many minerals (Dias, 2021). Among all the green leafy Brassica vegetables, kale is an outstanding source of minerals accumulating high levels of K, P, Ca, S, Fe, Cl, Sr, Cr, Mn, Se, and Zn (Tirasoglu, 2015).

Besides kales, different other Brassicas such as cauliflower, broccoli, white cabbage, Brussels sprouts and Chinese cabbage are reported to have high essential minerals and trace elements contents and excellent calcium bioavailability (Heaney, 2013).

Brassica are capable of accumulating considerable amounts of selenium (antioxidant) when cultivated and grown on high selenium soils content. Finley (2013) found that broccoli accumulates selenium in soil, which remarkably increase its health-promoting properties. Banuelos and Meek (2019) reported that broccoli grown on selenium enriched soil accumulated seven-fold more selenium than cabbage, collards and Swiss chard. Broccoli plants grown outdoors on a sphagnum, peatmoss, and vermiculite medium and fertilized with sodium-selenate and selenite accumulated 278 mg/g dry weight selenium, in the edible florets, compared to the non-fertilized control, which accumulated only 0.13 mg/g dry weight. In broccoli, selenium is stored as selenocysteine, which is immediately absorbed by human tissue. Selenium-enriched broccoli was found to reduce colon cancer and mammary tumors in animal models. Cabbage sprouts and fully developed heads also accumulated selenium and the accumulation was higher in the sprouts than in the mature heads (Dias, 2021).

Nutrient Density Index

Aggregate Nutrient Density Index (ANDI) is a scoring system based on nutrient content, rated on a 1 - 1,000 scale that was proposed by Fuhrman (2013). This index assigns scores to a variety of vegetables based on how many nutrients they deliver to our body in each calorie consumed. It is an index that estimates the nutritional quality of vegetables (Dias, 2021). It guides on increasing the nutrient density of the diet, the higher the ANDI score, and the greater percentage of diet, and the better our health (Dias, 2021).

A recent meta-analysis found that greater leafy green vegetables intake was associated with 14 % decrease in risk of type 2 diabetes (Carter, 2010). Another previous study reported that each daily serving of leafy green vegetables produces a 9 % decrease in risk of type 2 diabetes. Khan (2015) saw that oral feeding of *B. juncea* diet (10 % w/w) for 60 days to normal rats led to significant hypoglycemic effect and this was attributed to stimulation of glycogen synthetase which increase in hepatic glycogen content, suppression of glycogen phosphorylase and other gluconeogenic enzymes.

Medicinal Properties of Broccoli

Brassica vegetables contain about 50 different glucosinolates, a group of secondary plant metabolites found mainly in the *Brassicaceae* family. Glucosinolates are associated to disease protection. Epidemiological data show that a diet rich in Brassicas can reduce the risk from distinct and diverse forms of cancers and that the risk can be substantially reduced by an intake of at least 10 g per day (Dias, 2019). Epidemiological studies have reported that diets rich in broccoli, may reduce the risk of prostate cancer, and consumption of one or more portions of broccoli per week can reduce the incidence and the progression from localized to aggressive types of prostrate cancer (Traka, 2010). Mizrob (2022) reported that the auxin derivative Indole-3-carbinol (I3C) is a naturally occurring anti-carcinogenic compound found in high concentrations in broccoli and cabbage and has been shown to inhibit proliferation and induce apoptosis in various cancer cells, including breast cells, prostate, colon and leukemia. The I3C can prevent cardiac remodeling through activation of the

AMP kinase enzyme, resulting in improved myocardial function and modulation of the expression of genes responsible for the production of markers of hypertrophy and fibrosis with regeneration of damaged myocardium. tissue, which significantly reduces the activity of cardiac enzymes such as lactate dehydrogenase and creatine phosphokinase (Mizrob, 2022). 3,3'-diindolylmethane (DIM) is an acid-catalyzed dimer of idol-3-carbinol (I3C) found broccoli also inhibits angiogenesis and xenograft development of human mammary tumor cells in rodent models (Marques et al., 2014), and DIM strongly slowed down endothelial cell proliferation at a concentration as low as 5 μM (Mizrob, 2022). The evidence regarding the anticarcinogenic effect of phytochemicals in Brassicas are those from in vivo studies, mainly with broccoli, using human volunteers and animal models. In order to provide evidence of the relationship between whole broccoli and cancer prevention, Farnham (2020) investigated the diversity of induction of the phase II detoxification enzyme quinone reductase, in murine hepatoma cells, by 71 inbred and 5 hybrid lines of broccoli. They found that the rate of induction of quinone reductase in hepa 1c1c7 by the broccoli inbred lines ranged from 0 to 15,000 units and that the rate of induction was highly correlated (r = 0.85) to the concentration of glucoraphanin in each broccoli inbred. Besides broccoli, kale and Brussels sprouts, exhibited also protection against prostate cancer, breast cancer, lung cancer and chemically induced cancers (Dias, 2019).Clinical study showed that consumption of 250 g of broccoli and 250 g of Brussels sprouts per day significantly increased the urinary excretion of a potential carcinogen found in well-done meat (2-amino-1-methyl-6-phenylimidazo [4,5-b] pyridine (FIP) (Mizrob, 2022).

Among the effects that the consumption of Brassica vegetables and glucosinolates has on human health, they rank and rise for their anti-cancer, antioxidant, anti-inflammatory, anti-diabetic, anti-microbial, anti-parasiticidal, anti-mutagenicity, antiglycation, antifibrotic, antispasmodic, bone formation and cholinesterase inhibitory activities (Maina, 2020). Higher antioxidant potential of Brassica vegetables is also due to their higher content of phenolic bioactive compounds. This higher content of phenolics has been associated with beneficial health effects, such as reduced risk of age-related chronic diseases, and advantageous manipulation of gut microbiota (Bjorkman, 2011).

Broccoli in Cancer Prevention

Cancer is a multistep process that results in uncontrolled cell division. Broccoli has numerous quantities of sulforaphane that inhibit cancerous growth by induction. Isothiocyanates, which are the major active constituents of many cruciferous vegetables, suppress tumor growth by generating reactive oxygen species, or by inducing cycle arrest leading to apoptosis (Parul *et al.*, 2014). Broccoli sprouts are a rich source of several isothiocyanates (ITCs) that are well known class of cancer chemopreventive agents that inhibit the size, multiplicity and progression of bladder cancer when the extracts are delivered selectively to the bladder epithelium through urinary excretion (Munday, 2018). The ITCs are also known to prevent the process of prostate carcinogenesis. Erucin (ER) which is a dietary ITC, is considered to be a major cancer chemopreventive phytochemical which exhibited a lower potency in inhibiting the proliferation of prostate adenocarcinoma cells (PC3) (Melchini, 2013). Selenium-enriched broccoli sprouts, when compared to the normal broccoli sprouts are found to be superior and induces apoptosis of prostate cancer cells, inhibits cell proliferation and decreases prostate-specific antigen secretion and used as an alternative selenium source for prostate cancer prevention and therapy (Abdullah *et al.*, 2019).

The sprouts of high Se-broccoli are protective against chemically induced mammary or colon cancer, (Finlet *et al*., 2011). Sulforaphane along with another phytochemicals such as indole-3-carbinol and brassinin from broccoli have been useful for cancer chemoprevention (Gullett *et al*., 2010).

Broccoli in the Treatment of Diabetes

Broccoli is one among the few vegetables that possess antidiabetic potency and are commonly consumed. *Brassica oleracea* has beneficial hypoglycaemic influence in both experimental animals and humans (Platel and Srinivasan, 2017). The broccoli sprouts are known to improve insulin resistance in type 2 diabetic patients and lessens its complications due to its antioxidant components (Bahadoran *et al*., 2012). Broccoli is rich in flavonoids that have anti-inflammatory and antioxidant effects that protect against diabetes. Sulforaphane has the potential to induce some peroxisome proliferators-activated receptors that contributes to glucose homeostasis in hyperglycaemic and oxidative conditions, prevent nephropathy, diabetes-induced fibrosis, vascular complications and an excellent choice for supplementary treatment in type 2 diabetes (Bahadoran *et al*., 2013), prevents neurodegeneration, neuronal loss and oxidative stress (Andrea, 2013).

Phytochemical Properties of Broccoli

Phytochemicals are biologically active compounds found in plants in small amounts that could contribute significantly in protection mechanisms against some diseases. Many studies report a strong relationship between many ailments and health care potential of bioactive compounds (Hooper and Cassidy, 2016). In broccoli, chemopreventive bioactive compounds (i.e., isothiocyanates (ITCs), hydroxycinnamic acids, etc.) are effective against degenerative diseases over lifetime and certain types of cancer (Dreosti, 2020). For instance, cruciferous vegetables are an excellent dietary source of phytochemicals including glucosinolates, phenolic compounds and vitamins, as well as dietary essential minerals (Finley *et al.* 2011).

Glucosinolates

Brassica vegetables are the richest sources of glucosinolates in the human diet. Research studies of glucosinolate profiles reveal significant quantitative and qualitative differences among accessions within each Brassica group, developmental stages, plant parts, climatic conditions, and agronomic practices (Dias, 2019). Kushad*et al.* (2019) found in 65 cultivars of brocolli, that glucoraphanin was the main glucosinolate and that there was more than 27-fold difference between the highest concentration in 'Brigadier' and the lowest concentration in 'EV6-1'. Fahey (2017) evaluated glucosinolate content of broccoli sprouts and found that they have 20 to 50fold higher glucosinolates content than tissue from mature plants. In broccoli heads, the most significant glucosinolates are glucoraphanin, glucobrassicin, progoitrin, and gluconasturtiin (Vale, 2015).

Hansen *et al.* (2010) reported that there was a remarkable variation in the concentration of the individual glucosinolates between the cultivars 21 cultivars of red cabbage and 6 green-white cabbages. Red cabbage cultivars were found to have substantially higher concentrations of glucoraphanin in comparison to green-white ones. There were also significant differences within the red cabbage cultivars.

A great number of glucosinolates have been identified in green-white cabbages, namely glucoraphanin, glucoiberin, glucobrassicin, progoitrin, gluconasturtiin, sinigrin, epiprogoitrin, gluconapoleiferin, glucoalisin, gluconapin, 4-hydroxybrassicin, glucobrassicanapin, methoxyglucobrassicin, and neoglucobrassicin (Dias, 2021).

In cauliflowers, Brussels sprouts, kohlrabi, collards, kales and tronchudas the main glucosinolates are glucobrassicin, progoitrin and sinigrin (Kusznierewicz, 2018). Identical variations were also detected in turnips and rutabagas. Carlson, (2011) analyzed fourteen glucosinolates 29 cultivars of turnips and 12 rutabagas and found that the major glucosinolates in turnip roots were progoitrin, gluconasturtiin and glucobrassicin. In another study Carlson *et al*. (2017) compared the glucosinolates levels in tops and roots of 21 selected cultivars of turnip: 14 cultivars recommended for human consumption of either tops or tops and roots; 5 cultivars recommended for consumption of roots; and 2 cultivars used for animal feed. The research showed substantially lower levels of progoitrin and 1-methylpropyl glucosinolates in tops and roots of cultivars used as vegetables, comparing to those grown for animal feed. Contents of 1-methylpropyl, gluconapin, and glucobrassicanapin glucosinolates were higher in turnip tops than in roots; while progoitrin, glucoerucin, gluconapoleiferin, glucoalyssin, gluconasturtiin, glucobrassicin glucosinolates and total glucosinolates were all higher in the roots.

Antioxidants properties

The major natural antioxidants in Brassica foods are vitamins C and E, carotenoids, and phenolic compounds, especially flavonoids (Podsedek *et al.*, 2016). Vitamin E and carotenoids quench singlet oxygen (Choe and Min, 2015), and flavonoids as well as vitamin C show a protective activity to α-tocopherol in human LDL, and they can also regenerate vitamin E from the αchromanoxy radical (Davey *et al.*, 2010). Nutrient antioxidants may act together to reduce the level of reactive oxygen species (ROS) more effectively than single dietary antioxidants, because they can function as synergists (Trombino *et al.*, 2014). Kurilich (2012) found that broccoli extracts are protective against reactive oxygen species (ROS) apparently due to the presence of vitamin C, quercetin, kaempferol, lutein, zeaxanthin, α-tocopherol, γ-tocopherol, and β-carotene (Eberhard, 2015). In addition, a mixture containing both water-soluble and lipid-soluble antioxidants is capable of quenching free radicals in both aqueous and lipid phases. The significant variability in the concentration of the antioxidant phytochemicals of broccoli suggested that genotypes with enhanced content of dietary antioxidants can be developed through genetic manipulation and plant breeding as well as with the use of crop management strategies (Schreiner, 2015).

Vitamin C, which includes ascorbic acid (AA) and its oxidation product dehydroascorbic acid (DHA), has many biological activities in the human body. The biological function of L-ascorbic acid can be an enzyme cofactor, a radical scavenger, and a donor/acceptor in electron transport at the plasma membrane (Davey *et al*., 2010).

Dehydroascorbic acid (DHA), the oxidation product of AA, is unstable at physiological pH and it is spontaneously and enzymatically converted to 2,3-diketogulonic acid (Davey *et al*., 2010). Gokmen *et al.* (2010) reported that, DHA was the dominant form of vitamin C in cabbage accounting for 78.5 % of the total vitamin C content. In contrast, Vanderslice *et al.* (2010) observed that the contribution of DHA to the total vitamin C content was 14 % or 8 % in cauliflower and broccoli, respectively. Those values were in agreement with that reported for broccoli (Vallejo *et al*., 2013), i.e. the contribution of DHA to the total vitamin C content was ca. 11 %. The studies on antioxidants of Brassica vegetables have been focused mainly on broccoli florets (Jagdish *et al.*, 2016).

Mineral Contents

Humans require various mineral elements, some are required in large amounts (Na, Ca, K, Mg, Cl, N, P, S) and others are required in trace amounts (Fe, Zn, Cu, I, Se). All these mineral elements mainly enter the food chain through plants as soluble inorganic ions and as organic compounds or inorganic salts, in both soluble and insoluble forms (White and Broadley, 2015). Broccoli contribute high levels of minerals, however, they are likely to be affected by cultivar, environment and type of inflorescence. A wide number of plant-based foods contain calcium, but the amount of calcium, provided per 100 g or per serving, and its bioavailability vary considerably (Table 1). The bioavailability of calcium from a food is influenced by the presence of a number of other compounds within a food. As a result, calcium in plant foods is not generally readily absorbed, although there are exceptions such as broccoli, which contains lower concentrations of these interfering compounds (Fishbein, 2014). The bioavailability of calcium from milk and milk products is in the region of 30 % compared to 5 % from spinach. The number of servings of broccoli needed to equal 240 g milk is 71 g (Theobald, 2015).

Table 1. Chemical composition of Broccoli (100 g).

Nutrient	Florets	Leaves	Stalks
Proximates			
Water (g)	89.30	90.69	90.69
Energy (kcal)	34	28	28
Protein (g)	2.82	2.98	2.98
Total lipid (g)	0.37	0.35	0.35
Carbohydrated, by difference (g)	6.64	5.24	5.24
Fiber, total dietary (g)	2.6	-	-
Minerals			
Ca (mg)	47	48	48
Fe(mg)	0.73	0.88	0.88
Mg(mg)	21	25	25
P(mg)	66	66	66
K(mg)	316	325	325
Na(mg)	33	27	27
Zn(mg)	0.41	0.40	0.40
Vitamins			
Vitamin C (mg)	89.2	93.2	93.2
Vitamin C (mg)	0.071	0.065	0.065
Thiamin (mg)	0.071	0.065	0.065
Riboflavin (mg)	0.117	0.119	0.119
Niacin (mg)	0.639	0.638	0.638

Campas-Baypoli *et al.* (2016)

Pharmaceutical Importance of Broccoli

Cruciferous foods own a wealth of bioactive compounds (vitamins, carotenoids and other polyphenolics), although, the anticarcinogenic activity of the crucifers (i.e., broccoli) is attributable to their glucosinolate content. The glucosinolates are relatively inert but they can be hydrolysed to give a wide range of bioactive compounds such as isothiocyanates (ITCs) and indoles (Juge *et al*., 2017). In the absence of plant myrosinase, the glucosinolates-to-isothiocyanate conversion is mediated by bowel microflora (Shapiro *et al.,* 2011).

Isothiocyanates (ITCs) are potentially anticarcinogenic phytochemicals formed from the metabolism of glucosinolates and are found in cruciferous vegetables as well as a select number of other foods (Steck *et al*., 2017).

Indol-3-carbinol (I3C) is one of the major autolytic breakdown products of indole glucosinolates in Brassica plants. Several mechanisms have been suggested to contribute to the anticarcinogenic activities of I3C (Wu *et al*., 2005). The I3C may induce CYP1A2, as recently reported, in a small study involving five Jordanian men (5) and women (5) ingesting 500 g of broccoli per day, higher activity was found in men than in the women (gender effect), something that needs to be demonstrated in more ambitious epidemiological studies (Hakooz and Hamdan, 2017).

The gene CYP3A4 is responsible for the metabolism of many pro-toxicants, drugs, and endogenous sterols. SFN inhibits CYP3A4 gene expression mediated by the steroid and xenobiotic receptor (SXR, also called "hPXR") and it is the first described natural antagonist for SXR. The induction of CYP3A4 may result in adverse responses to certain drugs (lack of efficacy) that may result in a public health problem. This discovery is an important step in the design and development of new approaches from diet and therapeutics to reduce the frequency of non-desirable interactions of drugs (Zhou *et al*., 2007).

The SFN protect cells from oxidative damage by the addition of NF-E2 p45-related factor 2 (Nrf2), mediated by antioxidant enzymes, and also possesses *in-vitro* antibacterial activity against *Helicobacter pylori* (stomach ulcer). Broccoli sprouts are a rich source of sulforaphane-glucosinolate glucoraphanin, converted enzymatically to SF after ingestion of fresh sprouts, demonstrating a positive effect on infected mice and human subjects treated with a high-salt diet. Forty people infected by *H. pylori* were randomly assigned to diets containing a daily dosage of 100 g of broccoli (BS) and alfalfa sprouts (AS) for 2 months. The nutritive composition was almost identical, while only difference was the phytochemical density: BS contained 250 mg SFN/100 g portion size, while AS has neither SFN nor glucoraphanin. Therefore, the daily ingestion of BS rich in SFN suppresses the colonization of *H. pylori* in infected humans, so a diet rich in parental glucosinolate (glucoraphanin), may be useful for the chemoprevention of gastric cancer (Gamet-Payrastre, 2016).

Certain ITCs such as SFN, are potent monofunctional inducers of Phase-II enzymes although the majority of crucifers contain a range of glucosinolates exerting a variable range of modulator effect on detoxification enzymes. For example, broccoli is the main dietary source of SFN. The sulforaphane content (µg/g, fresh weight) in various tissues of broccoli decreased as follows: Edible florets 12.9 > stalks 5.1 > leaves 1.5 (Liang *et al*., 2016). The considerable levels of glucobrassicin (1.3-19.1 µmol/g d.w.), which can be hydrolyzed to indol-3-carbinol (I3C) is also of interest to improve health benefits from diet (Higdon *et al*., 2017). In the presence of an acidic environment in the stomach, I3C may suffer reactions of condensation to form dimers, trimers, tetramers, and oligomers. Totally opposite to SFN, I3C and its degradation products from acid condensation induce both Phase-I and Phase-II enzymes (Aggarwal and Ichikawa, 2015). *In- vivo*, I3C has been reported as a potent chemopreventive agent against hormone-dependent cancers (breast and cervical cancer) (Aggarwal and Ichikawa, 2015), Induction of apoptosis; inhibition of DNA adducts; suppression of the production of free radicals; stimulation of the 2-hydroxylation of stradiol; stimulation of angiogenesis; and hepato-protective (Wallig *et al*., 2015).

Industrial Importance of Broccoli

Broccoli is commercially cultivated for its large, leafy head that is rich in vitamin C. Global production of broccoli in 2019 was 27million tonnes, with China and India together accounting for 73 % while secondary producers United States, Spain, and Mexico each having about one million tonnes or less annually (FAOSTAT, 2021). The total production of broccoli and cauliflower was approximately 15.00 million tons worldwide in 1999, and increased to approximately 26.92 million tons in 2019. In Nigeria, production of this important vegetable is mostly carried out in the north (Ogedegbe and Law-Ogbomo, 2013).

The consumption of fresh broccoli implies a simple chain of cold or a fast freezing process. Industrially broccoli is used in the production of pickles (FAOSTAT, 2021). In some part of the world, the inflorescences with commercial quality are harvested manually off the field and packed in boxes, and then transported to the plant to make disinfection and fast cooling.

Broccoli by-products like leaf and stalk, constituting approximately 60 % – 75 % of broccoli production, are usually wasted during harvesting (Petkowicz and Williams, 2020). Wastage may also occur during processing, packing, dispatching, and retailing. The rampant need for plant-derived products from a booming global population depends on the limited arable land, so the utilization of agro-industrial by-products and wastes is necessary and contributes to the advance of sustainable agriculture. Understanding the nutritional values and beneficial effects of different broccoli parts provides a basis for further exploitation.

Cultivation

Cabbage is generally grown for its densely leaved heads, produced during the first year of its biennial cycle. Plants perform best when grown in well-drained soil in a location that receives full sun. Different varieties prefer different soil types, ranging from lighter sand to heavier clay, but all prefer fertile ground with a pH between 6.0 and 6.8. For optimal growth, there must be adequate levels of nitrogen in the soil, especially during the early head formation stage, and sufficient phosphorus and potassium during the early stages of expansion of the outer leaves (Thompson, 2013). Temperatures between 4 and 24 °C (39 and 75 °F) prompt the best growth, and extended periods of higher or lower temperatures may result in premature bolting (flowering). Flowering induced by periods of low temperatures (vernalization) which occurs if the plant is past the juvenile period. Vernalization allows the plant to grow to an adequate size before flowering. In certain climates, cabbage can be planted at the beginning of the cold period and survive until a later warm period without being induced to flower (Bradley *et al*., 2009).

Seedlings typically emerge in about 4 – 6 days from seeds planted 13 mm deep at a soil temperature between 20 and 30 °C (68 and 86 °F). Growers normally place plants 30 to 61 cm apart. Closer spacing reduces the resources available to each plant (especially the amount of light) and increases the time taken to reach maturity (Wien and Wurr, 2017). Cabbages are mature when they are firm and solid to the touch. They are harvested by cutting the stalk just below the bottom leaves with a blade. The outer leaves are trimmed, and any diseased, damaged, or necrotic leaves are removed (Thompson, 2013). Delays in harvest can result in the head splitting as a result of expansion of the inner leaves and continued stem growth (Wien and Wurr, 2017).

Broccoli heads are usually harvested with about 15 cm of the stem attached. After they have been cut off, part of the foliage is removed from the harvested shoots. Broccoli intended for fresh consumption is often sold in bunches weighing about 450 to 600 g.

Broccoli heads mature at different times, resulting in two or three cuts needed to harvest a field (OMAFRA, 2003). Broccoli can be sown on ridges or on flat bed, prefer sowing on ridges in case of heavy soils. Application of organic manure or vermicompost improves plant growth, productivity and improves water holding capacity of field soil. The sterilization of soil by drenching, nursery beds with formalin, about 15 - 20 days before seed sowing is beneficial for preventing the attack of the fungal diseases. After drenching, seed beds should be covered with polythene for a week. Then beds are again dug and left open for 5 - 6 days to avoid injurious effect of formalin on seeds.

The nursery beds should be covered with a proper mulching material before watering. Apply water over the grass mulch during initial stage about 15 - 20 days of sowing, while during later stage watering should be done through furrows. The mulch should be removed as soon the emergence of seed sprouts. The beds should be provided with roof for shading against hot sunshine and rains (Singh *et al*., 2014).

Preservation

Broccoli is highly perishable and should be cooled immediately following harvest. In addition to icing, hydro cooling and forced-air cooling can also be used, but good temperature management must be maintained following cooling (OMAFRA, 2005). If preserved at 0°C and near 100 % relative humidity, broccoli can be stored for 3 to 4 weeks. Exposure to ethylene (from apples, other ethylene producing fruit or engine exhaust) will accelerate the yellowing of flower buds and reduce storage life Crushed ice or slurry ice is usually added to packed cartons to keep produce fresh during shipping, especially when adequate refrigeration is not available (OMAFRA, 2005).

CONCLUSION

Vegetables are important for human nutrition in terms of bioactive nutrient molecules as dietary fiber, vitamins and minerals, and non-nutritive phytochemicals (phenolic compounds, flavonoids, bioactive peptides, etc.). Broccoli is an annual crop that belongs to Brassicaceae family and is a relative of Brussels sprouts, cabbage, cauliflower, and kale. Increasing knowledge on vegetable plants has brought in revolution in nutritional therapy. Broccoli is a widely used as food in many countries due to its high nutritional value, unique flavor and good taste. The major natural antioxidants in Brassica foods are vitamins C and E, carotenoids, and phenolic compounds, especially flavonoids. Broccoli contribute high levels of minerals, however, they are likely to be affected by cultivar, environment and type of inflorescence. The plant is fundamental in nutrition and therapeutics for balanced diets good sources of dietary fiber, vitamin C, vitamin B6, vitamin K, minerals, glucosinolates, flavonoids, and selenium. Consumption of broccoli is advice for better improve nutritional and health benefits.

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