Chapter

Antioxidant-Rich Vegetables: Impact on Human Health

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Abstract

Antioxidants are valuable ingredients present in vegetables. Vegetables are essential and crucial in human's health and diet because of their minerals, antioxidant vitamins, phytochemical compounds, and dietary fibre content. This is the reason why an adequate consumption of vegetables has been linked with reduced risk and protection against various chronic diseases. Notably, each vegetable belongs to a group that contains a unique quantity of phytochemical compounds, which distinguish them from other groups and even within their group. The exact mechanisms by which the consumption of vegetables protects against human diseases are yet to be fully understood. However, the phytochemicals present in vegetables could be responsible for attenuating some of them. These phytochemicals are strong antioxidants that reduce the risk of chronic diseases by mounting resistance against the generation of free radicals and their damage. They are also involved in the modification of metabolic activation, detoxification of carcinogenic compounds, or attack of tumour formation in cells. This review highlights the inherent antioxidant potentials of vegetables, their roles as an excellent source of antioxidants and their impact on human health and diseases. Information provided in this review will provide more insight into the roles of antioxidants present in vegetables.

Keywords: antioxidant, vegetable, phytochemical, disease, free radical

1. Introduction

These days, the new trend of consumption of foods in our society is for the "natural and healthy," which includes vegetables and fruits in the diet. "Western" type diets involve a high intake of food with much calories and animal protein with low consumption of vegetables. The resultant effect of this type of diet with physical inactivity is the development of diseases such as diabetes, obesity and cancer [1]. Therefore, the search for vegetables continues to gain attention as they are known to contain bioactive compounds with medicinal values that can offer healthy diet, build up the body's defences and help to prevent diseases [2].

Vegetables are large class of plants serving numerous purposes in the medicine, food and beverage industry. Their leaves, stems, seeds and flowers are useful for feeding, as flavours and colourants. They are plants of great importance in our diet. They are protective foods that are of great benefit in maintaining good health, building and repairing the body and preventing diseases because of the large number of essential nutrients they contain. They are rich in antioxidants like

carotenoids, ascorbic acid, flavonoids, folic acid and minerals like calcium, iron, phosphorus, phenolic compounds, proanthocyanidins, vitamins and saponins [3]. These phytochemicals exhibit multiple biological effects such as antioxidant, anti-inflammatory, antimicrobial and anti-cancer activities. Particularly, the antioxidative activity of phenolic compounds is highly recognised and this is attributed to their chain-breaking and free radical scavenging abilities, which remove free radical intermediates, thereby offering protection against the production of reactive oxygen species [3]. Excessive production of reactive oxygen species (ROS) can cause oxidative damage to biological macromolecules such as nucleic acids and proteins [4].

In rural areas, vegetables form an integral component of the food and nutrition of the local population as they are traditionally reckoned for their medicinal, therapeutic and nutritional values since time immemorial. They are either consumed as raw or cooked as traditional delicacies and the sales from the surplus of these vegetables serve as an additional income to many families. Moreover, to this set of population, vegetable consumption gives variety to their food and add flavours to the diet. It is rich in various nutritive elements and can make up for the dietary shortfalls of vitamins and minerals necessary for the human diet. Generally, malnutrition and food shortages are prevalent among the rural population. Thus, the cultivation of vegetables will contribute to increased food production, balanced nutrition, food and health security and poverty eradication for them.

Study revealed that before the nineteenth century, there has been a particular interest in vegetables and herbs because of the beneficial effects of phytochemicals present in them [5]. They were being used for therapeutic purposes until synthetic drugs were developed. Their consumption has drawn great attention due to the discovery of the fact that, their regular intake has an alliance with declined rates of heart diseases, cancers, diabetes, and other degenerative diseases. Protection that vegetable offer has been ascribed to the presence of antioxidative compounds such as α- tocopherol, ascorbic acid [6] and phytochemicals like carotenoids, flavonoids, lycopene, phenolics and β-carotene [7–9]. These compounds are free radical scavengers, hydrogen-donating compounds, metal ion chelators with ability to inhibit generation of free radicals and reactive oxygen species (ROS) [10].

Thus, this review draws attention to the bioactive compounds present in our vegetables, their biological importance and elucidation of their roles in disease prevention and health.

2. Antioxidant potential of vegetables

Antioxidants are defined as substances which when present at low concentration compared to those of an oxidizable substrate [11], significantly delay or prevent the oxidation of that substrate. Some of the mechanisms of action of antioxidants involve prevention of lipid peroxidation, oxidative damage to membranes, glycation of proteins and inactivation of enzymes caused by free radicals. Oxidative stress can arise due to the generation of ROS including free radicals and non-free radicals. Evidences have shown that they have roles in the development of several diseased conditions such as lipid peroxidation, protein oxidation, DNA damage and cellular degeneration [12, 13].

Normally, during cellular metabolism, free radicals and other reactive oxygen species are continuously released in the body. They can also be produced from sources such as drugs, food, exhausts and other pollution from the environment. Organisms are endued with endogenous and exogenous antioxidant defence systems against free radical generation. However, when free radical produced in

the body overwhelms the antioxidant system, oxidative stress ensues. This has implications in the aetiology of several pathological conditions [14]. This is the reason for the special attention being given to the use of antioxidants especially of natural origin.

Antioxidant phytochemicals have been recognised for the role they play in the prevention and management of chronic diseases [15]. Phytochemicals are proven to have antioxidant capacities in humans. Consumption of vegetables with high contents of these compounds is liable to raise the antioxidant capacity of the body system. For instance, serum total antioxidant capacity was found to be elevated significantly following the consumption of spinach in elderly women [16]. Further, a study has also supported a significant increase in antioxidant capacity caused by the daily consumption of 10 servings of fruit and vegetables for a period of 15 days [17].

Given the growing prospect observed in these phytochemicals, there is a need to identify and quantify them, elucidate their mechanisms of action and assess their potential health benefits. This information could serve as a basis for intervention strategies.

The phytochemical content of some vegetables like Broccoli, Brussels sprout, green cabbage have been revealed [18]. α- and β-carotene are richly present in broccoli (1 and 779 mg/100 FW), carrot (4.6 and 8.8 mg/100 FW), tomato (112 and 393 mg/100 FW), pea (19 and 485 mg/100 FW), and sweet pepper (59 mg/100 FW). However, some factors such as level of growth, handling during post harvesting, and processing could contribute to the significant variation that sometimes occur in structure and function of phytochemicals from vegetable to vegetable [19]. Vegetables such as beans, broccoli, cabbage, cauliflower, cress, pea, spinach, spring onion, and sweet peppers are reported to be rich in ascorbic acid [20]. Asparagus, Brussels sprout, cabbage, carrot, cauliflower, kale, lettuce, spinach, sweet potato, and turnip are abundant in vitamin E [18] while red pepper is high in vitamin C content (144 mg/100 g) [21].

Furthermore, the structure can influence the antioxidant capability of a phytochemical in vegetables. For instance, the antioxidant properties of flavonoids depend on their C-ring structure. Flavonoids like rutin and luteolin with full substituted C-ring and an ether bonded with three oxygen display superior free radical scavenging capacity and higher reaction rate when compared to flavonoids that lack one or more C ring structural elements. Also, individual phenolic units in vegetables have been found to show better antioxidant activity than total phenolics. Generally, the high scavenging property of vegetables with phenolic content may be as a result of hydroxyl groups existing in the phenolic compounds' chemical structure that can provide the needed component for radical scavenging activity (**Figure 1**). The hydrogen atoms of the adjacent hydroxyl groups, situated in various positions of the rings A, B and C, the double bonds of the benzene ring, and the double bond of the oxo functional group (-C=O) of some flavonoids, offer them their high antioxidant activity. These structural features are shown in the

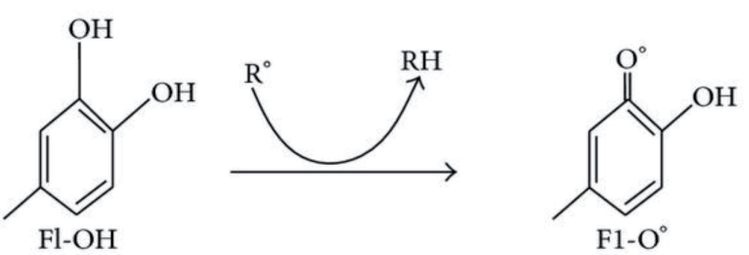

Figure 1.
Free radical scavenging of flavonoids where R is the radical and Fl-OH is the flavonoid.

benzene rings of flavonoids as shown in **Figure 2**. The antioxidant ability centre of phenolic acids is in the phenolic hydroxyl group, such that the positioning of phenolic hydroxyls is directly related to their antioxidant activity [22].

The impartation of colours is also an important factor in the antioxidative activity of phytochemicals in vegetables (**Table 1**). It is said to be directly related to the pigment content such as carotene, phytoene, chlorophyll, lycopene and anthocyanin, and their relative quantities at different maturity stages. It is an important trait that largely reflects quality, type of phytochemical as well as antioxidant activity [30]. Jaganath and Crozier [31] inferred that colour difference as observed in vegetables and fruits is an indication of accumulation of phytochemicals such as flavonoids and carotenoids. Red pigment conferred on red bell peppers is linked to a large content of lycopene, a member of the carotenoid family, localised in the prostate gland. Lycopene is a powerful antioxidant that has a connection with lessened risk of some cancers, especially prostate cancer [23], and protection against heart attacks. The yellow or orange colouration noticed in vegetables such as spinach, sweet potatoes and carrots represents produce rich in both α and β-carotene. They are also members of the carotenoid family where β-carotene can be converted to vitamin A in the body, a nutrient that plays a crucial role in vision. The mechanism involves the cleavage of β-carotene into two molecules of vitamin A which is then

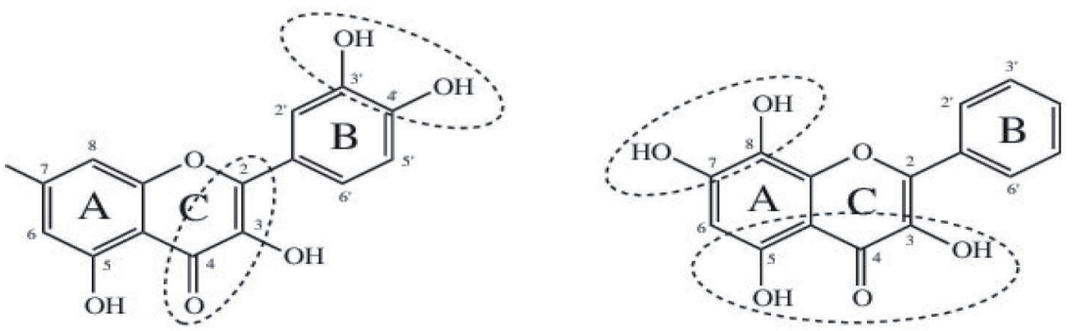

Figure 2.
Structural characteristics of flavonoids with high antioxidant activity; presence of hydroxyl groups and double bonds (circled) in the benzene rings.

Vegetable colour	Pigment/Phytochemical content	Health benefits	References
Red (in red bell peppers)	Lycopene anthocyanin	Reduced risk of some cancers, especially prostate cancer delays many diseases associated with ageing	[23]
Yellow or orange (in spinach, sweet potatoes and carrots)	α and β-carotene, flavonoids	plays a crucial role in vision, improves immune function, improves skin and bone health, prevents cancer	[24, 25]
Green (as in spinach, parsley)	Lutein	Maintains good vision	[26]
Blue/purple (as in eggplant)	Anthocyanin and phenolics	Reduced risk of ageing, cancers and heart disease	[27, 28]
White, tan or brown (as in onion, garlic, potato)	Thiosulphides,	Lowers blood pressure, regulate cholesterol levels and lower the risk of some types of cancers	[29]

Table 1.
Impartation of colours in vegetables and their health benefits.

converted to II-cis-retinal and thereafter combines with opsin to form a protein called rhodopsin. When light hits the rods, metarhodopsin is produced [24]. Beta-carotenes in vegetables are also involved in improving immune function, skin and bone health as well as prevention of cancer [25].

3. Mechanisms of antioxidative action of vegetable phytochemicals

Generally, the protective effect of vegetables has been credited to their antioxidant components. Antioxidants prolong the onset of free radical generation due to their capacity to supply hydrogen atoms or chelate metals implicated in ROS formation [18]. The mode of operation by which antioxidants negate the influence of free radicals involves various mechanisms among which is the termination of the free radicals [32] and post-modification of resultant bioactive compounds during metabolism [33].

Cells can respond to the effect of antioxidant phytochemicals by interacting with receptors and enzymes involved in signal transduction, or through modification of gene expressions that may affect the redox status of the cell and subsequent induction of series of redox-dependent reactions [34]. Reference [34] also presented an evolving evidence that phytochemicals like flavonoids may participate in the modulation of intracellular signalling cascades. Intracellular signalling pathways serve as major avenues of connection between the plasma membrane and regulatory targets in various intracellular compartments [35]. This signalling process also leads to the activation of protein kinases by phosphorylation, and then affects the activity of transcription factors that regulates gene expression [36]. Ruiz et al. [37] showed that the signalling cascades enable the cells to regulate processes such as growth, proliferation, and apoptosis. Phytochemicals can modulate effects in cells through selective actions on different components of the signalling cascades.

One of the mechanisms utilised by carotenoids is inhibition of the oxidation initiated by singlet oxygen. Flavonoids possess antioxidant, anti-inflammatory, antimutagenic and anti-carcinogenic properties. Apigenin is a flavone found in parsley and celery. It prevents inflammation by hampering the production of proinflammatory cytokines and cyclooxygenase 2 (COX-2) expression through the inhibition of nuclear factor-κB (NF-κB) (**Figure 3**), phosphoinositide-3-kinase (PI3K/Akt) and activating transcription factor-3/cyclic adenosine monophosphate (ATF/cyclic AMP) responsive element signalling pathways [38]. Kaempferol, a flavonol present in broccoli suppresses the inflammatory activities of inducible nitric oxide synthase (iNOS) and COX-2 by blocking signal transducer and activator of transcription 1 (STAT-1), NF-κB, and activator protein 1 (AP-1) signalling pathways as observed in activated macrophages and human endothelial cells [39]. Quercetin, known to be present in green leafy vegetables, onions and broccoli, exerts its potent antioxidant and anti-inflammatory activities by inhibiting the expression of pro-inflammatory cytokines [40] and suppressing (tumour necrosis factor) TNF-induced NF-κB (**Figure 3**) [41]. Furthermore, it can also regulate lipid profile thereby reducing glycaemia through the inhibition of 11β-hydroxysteroid dehydrogenase type 1 [42].

Lycopene, a carotenoid present in tomatoes, diminishes inflammatory response by reducing the gene expressions of iNOS and COX-2 [43] as well as IL-12 production. This is achieved by obstructing mitogen-activated protein kinase (MAPK) signalling and the activation of NF-κB [44]. Moreover, β-carotene in green-coloured leafy vegetables prevents the genetic expressions of LPS-induced iNOS, COX-2, and TNF-α by reducing phosphorylation and degradation of I-kappa B-related protein (IκBR) and nuclear translocation of NF-κB in macrophages [45]. Lutein, known for its yellow pigmentation in leafy vegetables such as spinach was discovered to have

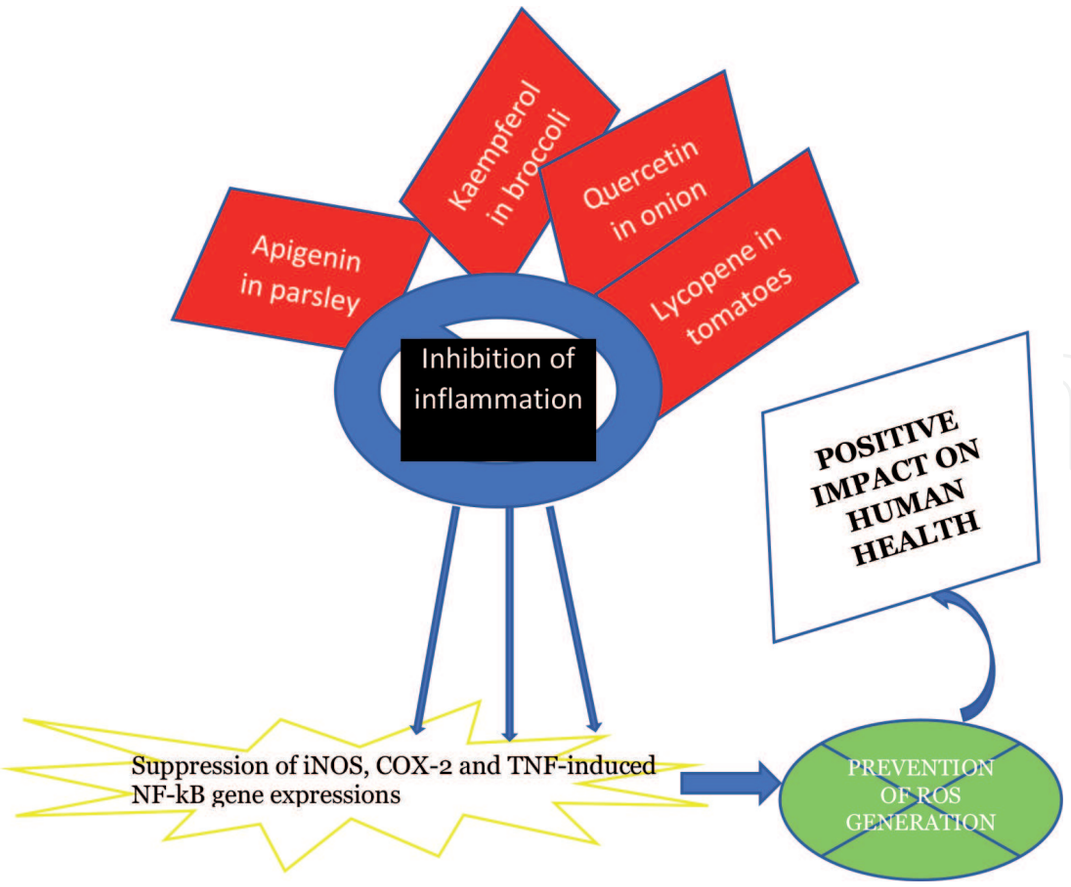

Figure 3.
Mechanism of inhibition of inflammation and oxidative stress by phytochemicals in vegetables.

the ability to repress LPS- and hydrogen peroxide-induced pro-inflammatory gene expression by diminishing the activities of PI3K and NF-κB inducing kinase (NIK) and phosphorylation of Akt [46].

4. Classification of vegetables

There are thousands of species of plants used as vegetables globally. Classification of these species can be done by taking into considerations some common features such as the part of the plant used for nutrition and the specific nutritional value. A summary of the health benefits of vegetables described below and their antioxidants content are displayed in **Table 2**.

4.1 Leafy vegetables

4.1.1 Lettuce

Lettuce (Lactuca sativa L.) is from the Asteraceae (Compositae) family. It is a vegetable that is extensively cultivated globally, commonly consumed fresh and as one of the salad ingredients owing to its health-promoting effects [68]. It comes in different textures, colours, leaf shapes and in a wide variety of head formations. According to Mou [69], it is classified into six major types which are butterhead, Cos or Romaine, Crisphead, Leaf or Cutting, Stalk or Stem, and Latin. lettuce is known to be a great source of flavonoids and vitamin B9. [70, 71] reported in their studies that, its vitamin B9 and flavonoid contents were higher compared to spinach, which is another popular green leafy vegetable that is widely consumed.

Vegetables	Antioxidants Content	Health Functions	References
Lettuce	Vitamins C and E, carotene, lutein	reduction in the occurrence of cancers like lung, prostate, and colon, heart disease and vision impairment, reduction in total cholesterol and LDL levels	[47, 48]
Watercress	Vitamins C and E, quercetin, lutein, β-carotene, anthocyanins	prevention of various liver diseases, reduction in susceptibility to cancer of the colon and oxidative stress, prevention against type 2 diabetes and cardiovascular diseases	[49, 50]
Vernonia Amygdalina (Bitter Leaf)	Luteolin	Treatment of malaria, fever and cough, management of postpartum haemorrhage, Reduction of plasma glucose and triglyceride/ cholesterol levels, inhibition of human breast cancer cells' growth.	[51–53]
*Telfairia Occidentalis (*Fluted Pumpkin)	ascorbic acid	Treatment of anaemia, malaria convulsion and gastrointestinal disorders, lowering of blood glucose level, elevation of haematological parameters, improvement of sperm quality, management of infertility	[54–56]
Corchorus olitorius (Jute Mallow)	Vitamins C and E, Carotenoids, quercetin	Treatment of folic acid, iron shortage and anaemia, blood purification	[57, 58]
Onion	kaempferol, quercetin	Regulation of fasting blood glucose levels, improvement of glucose tolerance, support of growth of beneficial bacteria, decreased incidence of stomach and intestine cancers	[59–61]
Carrot	Vitamins C and E, carotenoid	Inhibition of mutagenesis, lowering of blood glucose level, function as immune enhancer, anticarcinogen and antioxidant	[62]
Tomato	Lycopene, carotene, tocopherols, lutein, ascorbic acid	Reduction in the development of stomach and rectal cancers, reduction in vulnerability to lipid peroxidation, reduction in prostate cancer risk and an increased apoptotic cell death in carcinomas, elevation of antioxidant defence system	[63–65]
Eggplant	lycopene, lutein, α-carotene, myricetin and kaempferol	control of the level of high blood cholesterol inhibition of type 2 diabetes and hypertension	[66, 67]

Table 2.
Summary of the vegetables and their health functions.

Variation with regards to quality/quantity of vitamins and phytochemicals depends on some pre-harvest factors such as agricultural practices, maturity, genotype, maturity and environmental circumstances [72].

However, genetic composition has a great influence on the determination of synthesis and bioaccumulation of carotenoids, chlorophylls, vitamin E, phenolic compounds, vitamin C and antioxidant molecules [73]. Vitamins are vital micronutrients present in lettuce and have been implicated in the reduction of certain diseases such as cardiovascular and degenerative diseases [74]. Variations in the amount of vitamins found in lettuce may depend on leaf type, colouration and butterhead. Romaine lettuces have been particularly found to be good sources of folate [70], with green lettuce having the highest vitamin C concentration [75].

Also, the content of carotenoids such as carotene and lutein and colours across the 52 genotypes of lettuce was discovered to vary as assessed by [76] and

categorised in the following order: Romaine and green leaf > red leaf > butterhead > crisphead. Report given about these two carotenoids that they were remarkably and positively correlated with chlorophyll a and b as well as with total chlorophyll content was found to be quite contrary to the findings of [77] who argued that the content of these carotenoids may not correlate with leaf green pigmentation, since the contents of carotenoids seemed to be lower in green compared to red-pigmented lettuce. This contradictory opinion may suggest that the content in carotenoids may not be consistently and outrightly related to leaf pigmentation [78]. Nevertheless, the frequent consumption of carotenoids-rich lettuce has been linked with a reduction in the occurrence of chronic diseases such as certain types of cancer (lung, prostate, and colon), heart disease and vision impairment [47].

Further, many researchers also reported variation in the content of the secondary metabolites present in lettuce with respect to the genotypes and leaf colours [79]. According to [80], red lettuce contains just a single anthocyanin, called cyanidin-3-O-(6″-malonyl-_-glucopyranoside) which is further converted to two cyanidin derivatives named as (cyanidin-3-O-(6″-malonyl-_-glucopyranoside methyl ester) and cyanidin-3-O--glucopyranoside). These cyanidin derivatives possess antioxidant activities against lipid peroxidation and cyclooxygenase activity.

The significance of leaf pigmentation was further accentuated by [78] in their study where leaf pigmentation was found to correlate with the concentration of phenolic compounds such as flavonoids, and anthocyanins. For instance, the total phenolic content in red butterhead, red leaf and red romaine lettuces was higher than the green counterparts [81, 82]. The red colour of lettuce has been associated with a high level of total phenolics, popular for imparting a higher antioxidant activity than vitamins C and E [83]. The health benefits of red-pigmented lettuce have been highlighted in an *in vivo* study done by Lee et al. [48] on mice fed with a high-fat diet and supplemented with red lettuce. The results indicated that total cholesterol and low-density lipoprotein (LDL) were reduced, thus underscoring the prospects of red-pigmented lettuce consumption against cardiovascular disease. Similarly, a study carried out by [84] demonstrated that rats fed with red oak-leaf lettuce reduced appreciably LDL and cholesterol levels. Also, the new cultivar B-2 of red-pigmented lettuce, characterised by a high concentration of flavones, anthocyanins and phenolic acids has been reported by [80] to contribute to decline in diseases caused by oxidative stress, leading to anti-tumour activities against some cancer cell lines.

Based on the above considerations, clinical studies have validated the inherent benefits of frequent consumption of fresh lettuce, in particular the red-pigmented varieties.

4.1.2 Brassica leafy vegetables

This category of vegetable was formerly referred to as cruciferous vegetables and it includes a broad range of species with promising health-benefitting properties. These species include kale, pack Choi, mizuna, watercress, wild and salad rocket DC and Eruca vesicaria [L.] Cav. Database has shown that, about 12% of the vegetables grown globally belong to the Brassicaceae family. They are rich sources of phytochemicals [49], vitamins C, E and K, carotenoids, and phenolic compounds.

Genetic factor has been considered as a factor that influences and modulates the biosynthesis and accumulation of phytochemicals in Brassica leafy vegetables [49]. Variations in the amount of phytochemicals have been observed in a comparative study of antioxidant molecules involving four Brassica leafy vegetables [85]. Watercress showed the highest polyphenol and vitamin C content, while salad and wild rocket showed high concentrations of kaempferol and quercetin derivatives.

Mizuna displayed remarkable concentrations of isorhamnetin and sinapic acid [85]. The potential value of salad Brassica leafy vegetables as dietary sources of antioxidants has been highlighted. Its positive effects against type 2 diabetes and cardiovascular diseases have been affirmed.

Brassica leafy vegetables, in particular kale, are considered as a valuable source of carotenoids such as lutein and β-carotene as well as chlorophyll a and b. During the analysis to determine the concentrations of carotenoid of 33 kale cultivars, zeaxanthin was the most abundant carotenoid in 21 cultivars. American and hybrid cultivars were shown to have high concentrations of zeaxanthin, while German landraces, German commercial varieties, Italian, and red-coloured kale varieties exhibited high concentrations of chlorophyll a and b [86].

Coloured Brassica leafy vegetables like violet kale or pack Choi containing anthocyanins have taken the attention of nutritionists and horticulturists. The anthocyanins content could serve as a marker for differentiating between varieties/cultivars. The phytochemical concentrations in pack Choi are dependent on the particular colour. Aiyeloja and Bello [87] observed that red pack Choi produced higher concentrations of total flavonoids, total phenolic compounds, glucosinolates, carotenoids and anthocyanins than its green counterpart. Regular intake of leafy vegetables containing anthocyanin could contribute to prevention of various liver diseases, reduction in susceptibility to cancer of the colon and oxidative stress [50].

4.1.3 Bitter leaf (VA)

Vernonia amygdalina from *Asteraceae* family is popularly known as the bitter leaf in English. Its petiolate leaves of are about 6 mm in diameter and elliptic in shape. The green leaves have a characteristic bitter taste [88]. They are well distributed in tropical Africa and Asia. The leaves of VA serve as condiments in soup after being washed or boiled to remove the bitter taste. In folk medicine. It has a long history of being used in the treatment of malaria fever and cough [51].

In traditional medicine, many practitioners make use of the different parts of the plants for the treatment of antihelminth, antimalaria [89]. Many others use the aqueous extract got from the leaves as a tonic, an appetiser and for wound healing [90]. Traditional birth attendants from Malawia and Uganda find it useful in aiding removal of the placenta after birth, post-pertum uterine contraction, induction of breast milk production and management of postpartum haemorrhage.

The local use of VA in various parts of Africa for treatment of several ailments and general well-being has been backed up scientifically. Antidiabetic potential of the aqueous extract of VA in streptozotocin-induced diabetic rats has been reported [52]. The finding showed that VA was capable of diminishing plasma glucose, levels of triglyceride/LDL-cholesterol and malondialdehyde (an index of lipid peroxidation). This can occur via scavenging of the reactive oxygen species or by promoting the synthesis of antioxidant enzymes [91] which can subsequently lead to reduction in oxidative stress.

Reference [88] described the antidiabetic effect of VA when combined with another vegetable named *Gongronema latifolium*, on the pancreatic β – cells of rats induced with streptozotocin. The animals administered with the extracts were observed to gain body weight as compared to weight loss experienced in the diabetic group. Further, blood glucose level significantly declined after 28 days of treatment with the combined extracts. Regeneration of islets cells was believed to be the explanation as this would induce a rise in insulin production and secretion [92]. Active ingredients such as flavonoids are believed to be present in VA [44] which may be responsible for their potentials in altering pancreatic damage initiated by streptozotocin or alloxan in experimental animals. In addition, the bitter principle of VA

may also be responsible for insulin production, stimulation and release of pancreatic islets from the beta-cells [93]. Likewise, tannin, flavonoids glycosides and phytosterols of this plant could also inhibit the action of alpha-glucosidase inhibitor which may have contributed to the hypoglycemic effect being exhibited by this plant.

VA is increasingly becoming a powerful and strong challenger for cancer management as coumarins, flavonoids, sesquiterpene lactones have been implicated as the active principles in VA that may be responsible for its anticancer activity [94]. Aqueous extracts of VA was found to exhibit a cytostatic action on cultured human breast tumour cells (MCF-7) growth *in vitro* implying its tumour stabilisation and protective effects *in vivo* [94]. Its potential effects in inhibiting DNA synthesis even at physiological concentrations have been demonstrated in cancer cells [95]. Its hexane, chloroform, butanol and ethylacetate fractions were found to be capable of inhibiting the growth of human breast cancer cells even at concentrations as low as 0.1 mg/ml to 1 mg/ml, with an inhibition rate as high as 98% [53].

Other findings have established the usefulness of VA and its biopeptides (derived from the aqueous extracts of its leaves) against cancer via apoptotic mitogen-activated protein kinases and signal transduction pathways [96].

4.1.4 Fluted pumpkin (Telfairia occidentalis)

T. occidentalis (TO) commonly called fluted pumpkin is from the family: Cucurbitaceae. It is a popular vegetable that occurs in the forest zone of West and Central Africa. It is a perennial vine, growing to 10 m or more in length with its stems having branching tendrils and the leaves divided into 3–5 leaflets. The leaf is widely consumed due to its diverse benefits. The young succulent shoots and leaves are consumed as vegetables in the eastern part of Nigeria. Its herbal preparation has been applied in treating anaemia, malaria convulsion, gastrointestinal disorders [54]. Also, in addition to its nutritional value, this vegetable has agricultural and industrial importance [97].

Some scientific researchers have discovered its free radical scavenging and antioxidant properties. The leaves are rich in ascorbic acid and phenols [97]. Utilisation of the leaves in folk medicine in the treatment of some diseases in which the involvement of generation of free radicals have been implicated could be as a result of the antioxidative and radical scavenging ability [98].

Kim et al. [55] reported that aqueous extract of TO leaves lowers blood glucose level and elevates haematological parameters in rats. The chemical composition of TO shows vitamin A and C as part of its constituents which are well-known antioxidants and capable of scavenging free radicals [99]. They are well-established haemopoietic factors that have a direct impact on blood production in the bone marrow. Amino acids are also derived from TO and could also be useful in production of the globin component of the haemoglobin, contributing to elevation in haemoglobin concentration.

The leaf extract has also been documented to have the ability to improve sperm parameters which can assist in improving sperm quality [56]. Some of its active ingredients possess spermatogenic activities. Therefore, the leaves may be very applicable in the treatment and management of infertility especially those linked with a reduction in sperm performance.

The anti-anaemic potentials of the aqueous extract of leaves against phenyl hydrazine-induced anaemia in rabbits have been investigated [100]. The finding revealed that the leaves are notably rich in iron and play a major role in curing anaemia.

4.1.5 Basil (Ocimum)

Ocimum basilicum and *Ocimum gratissimum* are known for the management of different diseases in Africa. They belong to the Lamiaceae family. The leaves can be

petiolate or sessile and most times toothed at the margin. The presence of volatile oil which contain up to 75% of thymol, gives them a characteristic pleasant aroma. The leaf of *O. gratissimum* or even the whole plant is a well-known remedy for diarrhoea and other diseases [101].

In folklore medicine, *O. basilicum* (basil) is a medicinal plant used for various ailments, such as cough, diarrhoea, headaches, constipation and kidney malfunction. Its oil commonly referred to as basil oil contains camphor with antibacterial properties. The vapour of the boiling leaves can be inhaled by people with catarrh and colds while the leaves may be rubbed between the palms and sniffed for treatment of a cold.

4.1.6 Jute mallow (Corchorus olitorius)

C. olitorius (Linn) is a leafy vegetable belonging to the family Tiliaceae. It is commonly called jute mallow in English and "ewedu" in south western Nigeria. The plant is characterised by the viscosity of its leaves which usually forms a thick viscous soup after being cooked and can be added to stew or soup. The leaves are rich sources of vitamin and minerals.

In folklore medicine, the leaf extract is employed in the treatment of pain, fever, gonorrhoea and tumour. It is rich in minerals, vitamins B1, B2, C and E, carotenoids, [57]. In some parts of Nigeria, the leaves' decoction is used to treat shortage of folic acid and iron, as well as anaemia. The leaves are also used as a blood purifier [58] while the cold leaf extract infusion is consumed to restore appetite and strength and the leaves are used for treating fever, tumours, gonorrhoea and piles [102].

The hepatoprotective effect of the ethanolic extracts against carbontetrachloride-induced hepatotoxicity in rats has been studied [103]. The extracts produced a significant hepatoprotective effect by reducing the levels of liver function enzymes and lipid peroxidation. Some of the phenolic antioxidants in the leaves are 3, 5-dicaffeoylquinic acid, quercetin 3-galactoside, phenolic [5-caffeoylquinic acid (chlorogenic acid), quercetin 3-(6-malonylglucoside), quercetin 3-glucoside, and quercetin 3-(6-malonylgalactoside).

4.1.7 Amaranth globe (Gongronema latifolium)

Gongronema latifolium commonly known as the amaranth globe is from Asclepiadaceae family. It is a tropical rainforest plant in Nigeria, used as spice and vegetable in traditional folk medicine [104]. It has a sharp-bitter, sweet taste. Useful in making sauces, preparation of salads and soup. In West Africa, it is widely used for nutritional and medicinal purposes. The aerial parts can be prepared as an infusion to treat malaria, intestinal worms, cough and dysentery. It can be taken as a tonic to address the loss of appetite. The decoction made from its stem with lime juice is taken to treat stomach-ache, diabetes and high blood pressure. Senegal and Ghana believed that the leaves when rubbed on the joints of small children could assist them to walk. The latex is applied to teeth affected by caries, used in weight loss in lactating women and for general health management. A decoction of the roots, combined with other plant species, is utilised in the treatment of sickle cell anaemia. The leaves, when macerated in alcohol is used to treat bilharzia and hepatitis [105].

Screening of Gongronema latifolium vegetable revealed the presence of phytochemicals such as alkaloids, tannins, glycosides, polyphenols, saponins and flavonoids [106]. Its antidiabetic properties have been revealed in streptozotocin-induced diabetic rats during the oral administration of its aqueous and ethanolic

extracts [104]. Its antibacterial activity and ability to maintain healthy blood glucose level has been documented.

Gongronema latifolium is a vegetable with pool of antioxidants with capability to prevent and treat many diseases.

4.2 Root, bulb and tuber vegetables

4.2.1 Alliums

Alliums vegetables belong to the ***Alliaceae family*** and they include garlic, onion, leek, chive, welsh onion, among others. Alliums are very rich in thiosulphides, which have an association with the reduction of various chronic diseases. Variations in the total thiosulphide content among alliums, even when grown under identical conditions have been reported [107]. The report revealed that, the total thiosulphide contents in green onion leaves, chive, and onion bulbs were found to be 0.2, 0.72, and 1.02 g/kg fresh weight, respectively. Even, the type of thiosulphides in these vegetables were found to also vary. For instance, onion bulbs contain 34% methiin, 5% ethiin, 6% propiin, 5% alliin, and 49% isoalliin [107], while garlic cloves contained about 92% alliin, 8% methiin, and trace amounts of ethiin, propiin, and isoalliin [108]. Flavonoids such as anthocyanins and flavonols like quercetin and kaempferol are found to be present in red onions and yellow fresh cultivars respectively.

Onion and garlic are rich and abundant sources of calcium, potassium and manganese providing close to 10% of their daily requirements in humans. Onion and garlic can acquire selenium if they are cultivated in soils rich in selenium, in the form of selenocysteine and seleno-proteins. This led to the proposal by [109] that selenium-enriched garlic and onion could provide a safe efficient delivery system of selenium into the body for cancer prevention [110]. Onions are also good source of chromium relevant in diabetes prevention. The mechanism appears to be through the potentiation of insulin receptor kinases [29]. A lot of clinical studies have demonstrated the ability of chromium to regulate fasting blood glucose levels, which can lead to improved glucose tolerance, decreased insulin levels and improved lipid profile levels in diabetic patients.

Onions are also rich source of dietary fibres like inulin with varying degrees of health benefits [111]. Its prebiotic properties are reflected in its preference fermentation by beneficial bowel bacteria like *Lactobacilli* and *Bifidobacteria*, thereby changing the bacterial microflora of the intestine to make pathogenic, or disease-causing bacteria less abundant [59]. Fructans are abundant in onions and they are excellent supporters of the growth of beneficial bacteria [60]. In addition, fructans facilitate absorption of calcium and this could serve a useful purpose in the prevention of osteoporosis [112]. Diets high in fructans have also been associated with a decrease in the levels of lipid and blood glucose profiles glucose [113]. Antidiabetic potentials and antihyperglycemic effects of onions have been demonstrated [114].

The therapeutic merit and positive impact of onions, garlic and other *Allium* vegetables have been further confirmed in various epidemiological studies carried out where their consumption has been found to delay the growth of a broad spectrum of cancers. Consumption of onions has been linked to reduced incidence of stomach and intestine cancers [61] and reduction in mortality due to prostate cancer [115].

Routine intake of garlic has been linked with a decline in the occurrence of preneoplastic lesions in individuals infected by *Helicobacter pylori* [116]. It is also involved in reduction in the risk for colorectal and prostate cancers. Presumably, some garlic constituents can inhibit tumour initiation through deactivation and elimination of pro-carcinogens [117]. Some studies presented the ability of onion extracts to inhibit mutation [118], reduce multiplication process of cancer cells [119]

Vegetable	Phytochemicals present	Antioxidant	References
Broccoli	Flavonoids: anthocyanins, flavanols, flavonols Tetrapenoids: carotenoids, quinones	α carotene, β carotene, α tocopherols, Sitosterol, β-sitosterol, sitostanol, campesterol, brassicasterol, stigmasterol, cyanidin, catechin, luteolin, quercetin, procyanidin A1, procyanidin B2	[121–127]
Brussels sprout	Tetrapenoids: Carotenoids, triterpenoids: tocopherols, tocotrienols, sterols	α carotene, β carotene, α tocopherols, campesterol, β sitosterol	[122, 123, 128, 129]
Eggplant	Phenolic acids: hydrocinnamic acid Flavonoids: anthocyanin, carotenoids	Quercetin, apigenin, rutin, lutein, zeaxanthin, nasunin	[1, 130]
Onion	Triterpenoids: sterols Sulphur compounds: thiosulfinates Flavonoids: anthocyanins, flavonols Lignans	β-sitosterol, allicin, cyanidin, quercetin, kaempferol	[131]
Spinach	Triterpenoids: Phenolic terpenes Tetrapenoids: Carotenoids	Vitamin E, α carotene, β carotene, lycopene	[131]
Cabbage	Glucosinolates: Aromatic glucosinolates, aliphatic glucosinolates Phenolic acids: Hydrocinnamic acids Lignans Tetrapenoids: carotenoids	Glucobrassicin, ferulic acid, chlorogenic acid	[131]

Table 3.
List of selected vegetables and their antioxidant-richness.

and risks for cardiovascular diseases [120], which are effects being attributed to the presence of bioactive molecules such as quercetin (**Table 3**).

Carrot is an important root vegetable belonging to the family Apiaceae, rich in flavonoids, carotenoids, vitamin C and vitamin E. It is a coloured vegetable with a gold mine of antioxidants such as carotenoids, polyphenols and vitamins which can function as antioxidants, anticarcinogens and immune enhancers. Carotenoids especially the ones present in orange carrots, are potent antioxidants with capacity to neutralise the toxic effect of free radicals, inhibit mutagenesis to decrease the risk of some cancers. The importance of carotenoids in lowering blood glucose level has been identified in a study where high blood glucose levels were observed in some participants with low level of carotenoids. Carotenoid level can decrease in response to severity of glucose intolerance. This suggests the impact that carrot and vitamin A-rich carotenoids could have on diabetics in the management of their condition [62].

4.3 Solanaceous vegetables

4.3.1 Tomato

Tomato is a widely grown vegetable that is globally consumed. It can be consumed fresh or in its processed forms. The phytochemical constituents in tomatoes are carotenoids, lycopene, phytoene, neurosporene, and carotenes [132].

Assessment of lycopene content based on fresh weight shows that tomato (on average) contains about 35 mg/kg of lycopene, the red cultivars have an average of 90 mg/kg of lycopene while the yellow ones have just 5 mg/kg [133].

It has been revealed that tomatoes and tomato-enriched foods are the richest sources of lycopene in the world. Dietary intake of lycopene shows that, about 25 mg is taken each day and 85% is obtained from fresh and processed products of tomatoes [134]. Also, an appreciable amount of α-, β-, γ-, δ-carotene is found in tomatoes [135]. Tomato is also a remarkable source of ascorbic acid, potassium [67], lutein, tocopherols and flavonoids [63].

The cultivar and culture have been proved to have a great influence on the flavonoid content. For instance, cherry tomatoes notably have a flavonoid content that is higher than standard tomato cultivars while the field-grown have higher flavonoid content than the greenhouse-grown [136].

Several research investigations have been ongoing to determine the relationship between dietary intake of tomato/lycopene and the risk of having cancer. Findings on different cancers relative to lycopene and tomato intake showed a great reduction in prostate cancer risk and an increased apoptotic cell death in carcinomas [64]. People subjected to diets rich in tomato and tomato-based products with high lycopene content, were found to unlikely develop stomach and rectal cancers when compared to those who consumed a lower amount of lycopene-rich vegetables [65].

The antioxidant properties of tomatoes have been described. Its daily consumption for an average of 2–4 weeks elevates the antioxidant defence system and reduces susceptibility to lipid peroxidation [137] as oxidative modification of low-density lipoproteins is key to developing atherosclerosis. Comparative studies [138] in healthy individuals and people with type 2 diabetes, showed reduced vulnerability to lipid peroxidation [139] after daily intake of tomatoes or tomato juice.

Possible anti-inflammatory, anti-thrombotic and lipid-lowering effects of tomatoes and their products have also been investigated where an aqueous extract from tomatoes demonstrated antiplatelet activity *in vitro* [140]. In humans, research shows remarkable deductions in *ex vivo* platelet aggregation a few hours after supplementation with tomato extract [140].

4.3.2 Sweet and hot peppers

Peppers are always available in a beautiful array of colours and shapes. They contribute to the flavour and colourful appearances of our dishes. Fresh peppers are excellent sources of vitamins (in form of C, K), carotenoids and flavonoids (quercetin and luteolin) [141]. Vitamins A and C are involved in the prevention of cancer, age-related diseases, reduction of inflammation and they support immune function. Vitamin K improves blood clotting, bone formation, and protects the cells against oxidative damage. Red peppers are rich in lycopene, a phytochemical commonly known for preventing prostate cancer and cancers of the bladder, cervix, and pancreas.

The nutrient content of bell peppers varies with colour as studies have shown that red coloured bell peppers have significantly higher amount of nutrients than the green counterpart. Their role in prevention of blood clot formation and reduction in the risk of heart attacks and strokes could probably be due to vitamin C, capsaicin, and flavonoids content.

Hot peppers are known for their spiciness. The major phytochemicals identified in hot peppers are capsaicinoids. Capsaicin releases about 70% of the pungent flavour in hot pepper, while dihydrocapsaicin constitutes the remaining 30% [142]. The hotness or heat experienced in the taste bud from hot peppers comes from capsaicin. It relays this sensation by acting on pain receptors in the mouth.

Predominantly, capsaicin is located in the white membranes of peppers, imparting its "heat" to seeds as well. It can lower blood cholesterol and triglycerides levels, boost immunity, and reduce the risk of stomach ulcer. Capsaicin also possesses analgesic, anti-bacterial, and anti- diabetic properties. Capsaicin is included in many commercial formulations for the treatment of painful diabetic neuropathy, rheumatoid-arthritis, muscle pains, aches in the tooth and gastric ulceration [143].

The levels of vitamins and minerals present in chilli hot peppers are amazingly high. 100 g of chilli hot peppers provides 240% of vitamin C, 39% of vitamin B6 (pyridoxine), 32% of vitamin A, 13% of iron, 14% of copper and 7% of potassium [144]. They are rich in vitamins such as niacin, pyridoxine (vitamin B6), riboflavin and thiamin (vitamin B1) and minerals like manganese, iron, potassium, and magnesium. It is pertinent to note that, potassium is an important component of cell and body fluids, useful in controlling heart rate and blood pressure. Manganese serves as a co-factor for superoxide dismutase.

Hot and sweet peppers contain substances that can stimulate the body's heat production and oxygen utilisation for about 20 minutes after eating. This experience can contribute to losing extra calories and weight loss.

4.3.3 Eggplant

Eggplant is a very common and popular vegetable grown in many countries. It is grown in the subtropics, tropics and Mediterranean areas because of its demand for a long season of warm weather to produce good yields. Eggplant contains phenolic compounds such as caffeic, chlorogenic acid and flavonoids. Chlorogenic acid is a notable phenolic compound found in all eggplant cultivars with potent free radical scavenging activity [145]. Some of the benefits attributed to chlorogenic acid include antimicrobial, antiviral and anticancer activities. In addition to their nutritional potentials, these phenolic acids found in eggplant are accountable for the bitter taste that comes from the flesh when cut. Breeders have already started working on the development of eggplant cultivars that will give and ensure a balance of optimal nutritional value and pleasant taste.

There are other antioxidants such as lycopene, lutein, α-carotene, myricetin and kaempferol present in eggplant [146]. This is also depicted in **Tables 2** and **3**.

Eggplant is a good source of dietary fibre and bone-building manganese and vitamin K that can support digestion and bone-building respectively. It is also an excellent source of molybdenum and potassium, copper, vitamin C, vitamin B6, folate, and niacin [147]. Studies have demonstrated the effectiveness of eggplant in controlling the level of high blood cholesterol [66]. This was shown in a clinical study, where volunteers were fed with eggplant powder and a significant decrease in blood-lipid profile levels was observed [148]. Its relevance in inhibition of invasion of human fibrosarcoma HT-180 cell, type 2 diabetes and hypertension has been revealed [67].

5. Conclusion

Chronic diseases are the principal causes of death. Excessive production of reactive oxygen species has been identified to be responsible for the pathogenesis of many of these chronic diseases. Thus, antioxidant phytochemicals are considered as potential agents for the prevention/management of these diseases due to their biological activities and health benefits such as free radical scavenging abilities, anti-inflammatory action, anticancer and protective action against numerous diseases.

Regular intake of diet rich in vegetables has a favourable impact and indisputable positive effects on human health and offers the human body protection from different chronic diseases. This review contributed to the body of evidence that supported the biomedical importance of regular consumption of antioxidant-rich vegetables. This antioxidant property of vegetables has been linked to the presence of phytochemical compounds contained in them. Therefore, the antioxidant constituents may be responsible for the mechanism by which vegetables decrease the risk of diseases by directly quenching free radicals, altering gene expressions or indirectly participating in cellular signalling involved in redox balance. In order to get all the health benefits inherent in diet-rich vegetables, it is recommended to consume a great diversity of vegetables to ensure the delivery of a unique blend of health-promoting phytonutriceuticals.

Conflict of interest

There is no conflict of interest.

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