Leek (*Allium ampeloprasum* L.)

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Abstract

Leek (*Allium ampeloprasum L.*) is one of the most popular vegetables cultivated all over the world, and it belongs to the family Amaryllidaceae/Alliaceae. The *Allium ampeloprasum L.* is categorized into wild leek, cultivated leek, kurrat, pearl onion, taree and great-headed garlic based on their diverse cytogenetic and morphological characters. Leeks are known for their characteristic flavours and medicinal value. Leeks have excellent nutritional properties and are a rich source of bioactive compounds and phytochemicals. Leeks are rich in indietary fibres; fructans; PUFA, predominantly linoleic acid; various amino acids, mainly glutamine, glutamic acid, aspartic acid, arginine and alanine; and organic acids like ascorbic acid and malic acid. The bioactive compounds and phytochemicals like S-alkyl-L-cysteine sulphoxides, polyphenols, saponins, kaempferol glycosides, β-carotene, pectic polysaccharides and tocopherols are responsible for various health benefits. These phytochemicals have excellent antioxidant and potent anticarcinogenic properties which help in the reduction of colorectal, stomach and breast cancers. Consumption of leeks causes a reduction of the risk of hypercholesterolemia, blood pressure, arteriosclerosis and platelet aggregation which helps in the prevention of cardiovascular diseases. Besides these, the leeks have antimicrobial activity against various bacteria and fungi and viruses.

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Keywords

Leek · Nutritional properties · Bioactive compounds · Processing effect · Health benefits

16.1 Introduction

Leek (*Allium ampeloprasum L.*) is categorized under the genus *Allium*. It is the most important ancient vegetable crop cultivated worldwide. It belongs to the family Amaryllidaceae/Alliaceae of monocotyledonous species. A complex of different cyto- and morpho-types of leek form an *Allium ampeloprasum L.* species complex and is widely distributed all over the world. The complex includes groups of cultivated leek, kurrat, pearl onion, taree and great-headed garlic. After cooking leek is eaten as in soups, fried or mixed with other ingredients, but leek can also be consumed in raw as a fresh state in salads. It is also used as an ingredient in many food preparations and preservation and for improvement of flavour and nutritional quality of many food dishes. It is mainly grown for its leaves and blanched stem. The mature leek contains some starch and appreciable quantities of dietary fibres, carbohydrates, proteins, minerals, bioactive phytochemicals, antioxidants and vitamins A, B and C. The leek has been used for a wide range of diseases. The literature of leek shows that leek has some pharmacological activities such as antidiabetic, anti-inflammatory, hypolipidaemic, anticarcinogenic, antimicrobial, free radical scavenging, antihelmintic, diuretic, antihypertensive and digestive properties. Processing of leeks such as post-harvest processing, cutting, blanching, tampering, cooking, fermentation and storage is significantly affecting the nutritional component, biologically active compound and ultimately biofunctional properties of leek (Dogan Dogan 2012; Dey and Khaled 2015; García-Herrera et al. 2014).

16.1.1 History

The leek is known to be originated from *Allium ampeloprasum L.* which is widely spread from Portugal to western Iran of the Mediterranean Basin. Its minor crops are locally cultivated from Asia to Iran and the Caucasus and infrequently in California and other areas of Europe and America. Leeks are cultivated since very early times with ancient popularity when the Egyptians built pyramids. It is also believed to be a chief vegetable of the Greeks and Romans that spread subsequently throughout middle-age Europe. Leeks have a long and affluent history and are appreciated mostly by ancient Egyptians, Greeks and Romans due to the valuable health effects. The Roman emperor Nero used to eat leeks as a daily diet to make his voice tougher, while the Greek philosopher Aristotle has also credited the strong voice upon eating of leek diet. The Romans have introduced leeks to the United Kingdom where it grew due to the ability to withstand cold weather. Nowadays, leeks are grown up in many European nations as an important crop and as part of northern European cuisines (Aedo 2013).

16.1.2 Production

Leeks are the most important vegetable crop cultivated in the world, especially in Western Europe, and mainly grown in a home garden, greenhouse as well as in open field on a big farm. It can easily adapt to different ecological conditions, and thus the cultivation spreads all over the world. Worldwide production and cultivation area of leeks and other alliaceous vegetables are given in Table 16.1. According to the most recent data given by the United Nations Food and Agriculture Organization, the leek is produced worldwide, and its production is approximately 2,179,050 tonnes, and it is cultivated on area of 137,791 ha in 2017. Leeks are mostly cultivated in Europe and Asia and less often in southern Asian country group (India, Pakistan Sri Lanka, Bhutan, Nepal and Bangladesh) having very less production as well as cultivation area. In India and Sri Lanka, it grows well at higher altitudes, but humid conditions are not good for its production. In India commercial cultivation of leek is not followed, and it grows mainly in the kitchen garden (FAOSTAT 2018; Swamy and Gowda 2006).

16.1.3 Botanical Description

The genus *Allium* includes about 750 species and is in fair agreement with a record of the World Checklist of Selected Plant Families (Kew Science 2020), which classifies 860 species of *Allium*. The modern intrageneric classification splits the genus *Allium* into 15 subgenera and 72 sections. The subgenus *Allium* is the largest, including around 280 species, 114 of which comprise its main section, *Allium*. An informal classification of this subgenus into different groups; the species complex group of *Allium ampeloprasum L.* and garlic. A species complex of *Allium ampeloprasum L.* formed due to the difference in cyto- and morpho-types in leeks and is widely distributed either in the wild or domesticated range adjacent to the Mediterranean Sea, Mediterranean islands, and across from North Africa and South-west Asia to South England. *Allium ampeloprasum* complex includes groups of wild leek, cultivated leek, kurrat, pearl onion, taree and great-headed garlic (elephant garlic). The great-headed garlic forms bulbs and cloves similar to garlic, but size,

Table 16.1 Production and cultivated area of leeks and other alliaceous vegetables

Region	Tonnes	Area, ha
Worldwide	2,179,050	137,791
Europe	807,061	30,006
Western Europe	558,765	15,372
Southern Europe	157,394	6334
Eastern Europe	112,556	6712
Asia	1,314,426	90,079
Southern Asia	66,078	2614

Source: FAOSTAT (2018)

number of cloves per bulb and flavour are markedly different. The species complex is categorized by their ploidy levels, and the polyploid series are 2n = 24, 32, 40, 48 or 56. However, tetraploids and hexaploids are predominant in wild populations. The species complex is surrounded by arguments concerning atypical meiotic behaviour and genome makeup, features that make it very exciting to study (Friesen et al. 2006; Guenaoui et al. 2013). The taxonomical classification of the leek is given below. It is variously classified as *Allium ampeloprasum*, *Allium porrum*, *Allium ampeloprasum* var. *porrum*, *Allium ampeloprasumporrum* or *Allium ampeloprasum* (GRIN 2008).

Kingdom: Plantae
Clade: Angiosperms
Clade: Monocots
Order: Asparagales
Family: Amaryllidaceae
Subfamily: Allioideae
Genus: *Allium*
Species: *Allium ampeloprasum*

The most public names of leeks in various languages are leek in English; jiucongin in Chinese; poireau and porreau in French; porreein in German; porro and porrettain in Italian; liikiin in Japanese; lukporejin in Russian; and ajoporro and apuerro in Spanish (Swamy and Gowda 2006).

16.1.4 Nutritional Properties

Leek is a good source of carbohydrates, proteins, fat, dietary fibre and K, Ca, Mg, Na and Cu mineral components (Table 16.2). The total available carbohydrate composition is 0.5 to 16.60 g/100 g. The wild leek variety has higher carbohydrates than other wild leafy vegetables. The average protein content is 1.5 to 2.1 g/100 g. Among the amino acids of leek, glutamine, glutamic acid, aspartic acid, arginine and alanine are present in a higher amount (Najda et al. 2016). More than 20 distinct fatty acids are found in edible parts of the leek. The fatty acids, namely, linoleic, palmitic, oleic and α-linolenic acid, are reported to be 46–53, 20–23, 4–13 and 3–7%, respectively, and they make up to 80% of the total lipids present. Saturated fatty acids are 38.23 to 40.0% of total fatty acids, and palmitic acid is the major one, i.e. 26.42%. PUFA is around 54.16 to 79.04% of total fatty acids. Leek is a good source of potassium, iron and selenium. Leek contains 30.24 to 81.7 mg/100 g of Ca and 0.20 to 2.1 mg/100 g of Fe. In addition to that, Mg, Na, P and Cu are 10–28, 5–54.6, 35 and 0.06–0.30 per 100 gm of leek (García-Herrera et al. 2014; Koca and Tasci 2015).

Table 16.2 The nutritional profile of leek

Proximate composition	Leek (*Allium ampeloprasum* var. *porrum*)			
	Van der Meer and Hanelt (1990)	Souci et al. (2000)	García-Herrera et al. (2014)	USDA (2018)
Moisture (%)	90	86	78.32	83
Total available carbohydrates (%)	5	6.75	16.6	14.2
Proteins (%)	2	2.1	1.67	1.5
Lipids (%)	0.3	0.1	0.18	0.3
Fibre (%)	Nd	2.9	4.23	1.8
Energy (kcal/100 g)	Nd	Nd	78.92	61
Ashes (%)	1.5	Nd	0.79	Nd
Minerals (mg/100 g)				
K	250	Nd	309.37	180
Na	5	Nd	54.6	20
Ca	60	63	70.16	59
Mg	Nd	Nd	14.03	28
Mn	Nd	Nd	0.11	Nd
Fe	1	0.81	0.6	2.1
Zn	Nd	Nd	0.75	0.1
Cu	Nd	Nd	0.11	Nd
P	Nd	Nd	Nd	35
Vitamins (mg/100 g)				
Total vitamin C	25	Nd	6.69	12
Thiamin	Nd	Nd	Nd	0.060
Riboflavin	Nd	Nd	Nd	0.030
Niacin	Nd	Nd	Nd	0.400
Vitamin B6	Nd	Nd	Nd	0.233
Folate, DFE (μg/ 100 g)	Nd	Nd	Nd	64
Vitamin A, RAE (μg/ 100 g)	Nd	Nd	Nd	83
Vitamin A, (IU/ 100 g)	Nd	Nd	Nd	1667.0
Vitamin E	Nd	Nd	0.05	0.9
Vitamin K (phylloquinone) (μg/ 100 g)	Nd	Nd	Nd	47.0

16.2 Bioactive Components of Leeks

Allium genus is known as a rich source of bioactive compounds, which have interesting health encouraging properties and biological activity. These are additional nutritional elements and include organosulphur compounds like isoalliin, methiin and S-alk(en)yl-L-cysteine sulphoxides (ACSOs) and compounds such as fructans, lutein, β-carotene, ascorbic acid, tocopherols, steroidal saponins,

phytosterols and polyphenols like flavonol glycosides and ferulic acid (Muir et al. 2007; Nishimura et al. 2016).

16.2.1 Organosulphur Compounds

Allium species are well known to produce organic sulphur compounds also known as S-alk(en)yl-L-cysteine sulphoxides (ACSOs). In *Allium* species about 75% of the sulphur present in the storage form γ-glutamyl-ACSOs (γ-glutamyl peptides). In leeks, four different ACSOs have been found which are MCSO or methiin, 1-PECSO or isoalliin, PCSO or propiin and 2-PECSO or alliin, but only methiin and isoalliin are present in significant quantity, while propiin and alliin are present in trace quantity (Table 16.3). Plenty of volatile compounds of distinct odour like that of garlic are formed instantly after crushing the tissues of leek due to degradation of the S-alk(en)yl-L-cysteine sulphoxides by the action of alliinase enzyme (Bernaert et al. 2012b; Lundegardh et al. 2008).

16.2.2 Polyphenols

In leeks, the different polyphenolic compounds are present such as propyl gallate, ferulic acid, caffeic acid, sinapinic acid, luteolin, kaempferol, kaempferol 3-O-glucoside, quercetin, quercetin 3-O-galactoside and naringenin. The total phenols, flavonoids and flavanols of the whole leek, body parts of leek and essential oils (EO) of the leek are reported in Table 16.4 (Bernaert et al. 2012a, 2013b; Mnayer et al. 2014; USDA 2010; Vandekinderen et al. 2009).

The concentration of polyphenolic compounds of the leek body parts is presented in Table 16.5, among them kaempferol 3-O-glucoside, quercetin 3-O-galactoside and ferulic acid which are the main phenolic components of leeks.

16.2.3 Ascorbic Acid

The *Allium* species contain good amount of ascorbic acid, which is present in both the forms L-ascorbic acid (AA) and L-dehydroascorbic acid (DHAA). The L-ascorbic acid form is the biologically active form of vitamin C, but along with

Table 16.3 The chemical structure of ACSOs of leek species

Chemical name	Chemical formula	Common name
S-methyl-L-cysteine sulphoxide	R = CH3	Methiin
S-propyl-L-cysteine sulphoxide	R = CH2CH2CH3	Propiin
S-(2-propenyl)-L-cysteine sulphoxide	R = CH2CH = CH2	Alliin
Trans-S-1-propenyl-L-cysteine sulphoxide	R = CH = CHCH3	Isoalliin

Source: Bernaert et al. (2012b)

Table 16.4 Polyphenol content of the different types of leek and its body parts

Leek body part	Total phenols mg GAE 100 g^{-1})	Flavonoids (mg CE 100 g^{-1})	Flavanols (mg 100 g^{-1})	References
Whole leek (fw basis)	41.6 ± 4.0	10.10 ± 1.02	1.01 ± 0.09	Ninfali et al. (2005)
	47	Nd	Nd	USDA (2010)
	22	Nd	Nd	Proteggente et al. (2002)
	38–56	Nd	Nd	Vandekinderen et al. (2009)
Wild leek (fw basis)	57.7	0.86	Nd	García-Herrera et al. (2014)
Green leaves (dw basis)	50–140	Nd	Nd	Bernaert et al. (2012a)
White shaft (dw basis)	50–150	Nd	Nd	Bernaert et al. (2012a)
EO of leek	107.9 ± 0.53	Nd	Nd	Mnayer et al. (2014)
GHG-L leaves	10.73	6.5	Nd	Najda et al. (2016)
GHG-L bulb	20.21	2.64	Nd	

Table 16.5 Polyphenolic compounds found in green leaves and white shaft of leek

Polyphenol	Green leaves	White shaft
Propyl gallate	2.09 ± 0.02	2.11 ± 0.01
Ferulic acid	27.07 ± 1.43	29.71 ± 0.39
Caffeic acid	0.93 ± 0.03	1.03 ± 0.06
Sinapinic acid	3.76 ± 0.20	Nd
Luteolin	0.74 ± 0.02	0.71 ± 0.01
Kaempferol	0.85 ± 0.05	0.77 ± 0.01
Kaempferol 3-O-glucoside	31.92 ± 2.66	3.50 ± 0.12
Quercetin	2.67 ± 0.04	2.63 ± 0.02
Quercetin 3-O-galactoside	21.73 ± 0.1	23.23 ± 0.13
Naringenin	Nd	0.16 ± 0.00

Bernaert et al. (2013b)

this DHAA also shows biological activity. DHAA is easily transformed into AA in the human body. The ascorbic acid readily neutralizes nitrogen species (RNS), reactive oxygen species (ROS), singlet oxygen and hypochlorite and helps to reactivate tocopherols and glutathione. Leek contains 2.37–12 mg/100 g of vitamin C. In leek, the AA level varies according to the different body parts, and the green leaves have higher AA content than the white shaft. The AA of white shaft varies from 0.89 to 3.55 mg AA g^{-1}dw, and that of green leaves varies from 2.77 to 8.52 mg AA g^{-1}dw (Bernaert et al. 2012a; García-Herrera et al. 2014).

16.2.4 Saponins

Saponins have attracted increasing attention because of their anti-inflammatory, antimicrobial, antidiabetic, platelet aggregation, inhibitor and gastroprotective property, antitumour effects and antitussive actions (Fang et al. 2015; Sadeghi et al. 2013a). Different steroidal saponins, spirostane glycosides and cinnamic acid derivatives are isolated from a different variant of leek. From *Allium porrum* steroidal saponins neoporrigenins A and B are isolated; the three new steroidal saponins named yayoisaponins A–C are found composed with agigenin, diosgenin, β-chlorogenin and 24-ethylcholesta-(6-acyl)-3-O-β-D-glucoside. From the bulbs of *Allium ampeloprasum* var. *porrum*, a new steroidal saponin is isolated, and its structure is established using NMR spectroscopy (Adão et al. 2011; Uchida et al. 2009).

16.2.5 Organic Acids

The total organic acid content of leeks is 310 mg/100 g. The malic acid is major organic acid of wild leek, and it is present at about 132.86 mg/100 g, followed by oxalic acid, glutamic acid, citric acid and succinic acid present at nearly 91.65, 51.67, 38.86 and 2.14 mg/100 g, respectively (García-Herrera et al. 2014; Kirk-Othmer 2007).

16.2.6 Polysaccharides

Leek contains 3 to 10% fructans (based on fresh mass), and apart from fructooligosaccharides, α-galacto-oligosaccharides, in the form of raffinose and stachyose, are present, and they are about 0.96% and 0.24% of the fresh mass of leek, respectively. *Allium* are rich in pectic polysaccharide (1 → 4)-linked galacturonic acid. Leeks contain glucuronic acid (1.1 to 37.5 mol%), galactose (13.3–26 mol%) and rhamnose (2.77–14.13 mol%). A novel glucofructan having a gastroprotective property is identified using Sephacryl S-300 HR high-resolution chromatography (Malafaia et al. 2015; Peshev and Van den Ende 2014).

16.2.7 Linoleic Acid

In leek lipids, PUFA is the major fraction present around 54.16 to 79.04%, and the ratio of PUFA and SFA is more than 0.45, which is assumed as beneficial for health (García-Herrera et al. 2014; USDA 2018).

16.3 Bioactive Properties

Leek like other *Allium* provides interesting nutrients, phytochemicals and other bioactive compounds to the human diet. Nutritional composition of leeks varies according to species, temperature, rainfall, sunlight, soil properties, growing conditions and the contact of other plants or animals in the system. The composition of leek also varies according to the crop's body part such as leaves and pseudostem, and these parts are mainly consumed and used in many food preparations (Bernaert et al. 2012a; García-Herrera et al. 2014).

16.3.1 Antioxidant Activity

Plant and vegetable origin bioactive compound acts as antioxidants due to their free radical scavenging and metal chelating activities or singlet oxygen quenching. Because of antioxidant compound present in fruits and vegetables, the increased amount can minimize the risk of chronic degenerative diseases such as cardiovascular diseases, cancers and others. Methods like DPPH, FRAP and ORAC are used to determine the antioxidant activity in vitro because the total antioxidant capacity cannot be determined precisely by any single procedure due to the variety of phytochemicals present and the related chemical moiety diversity (Boffetta et al. 2010; Chu et al. 2000; Gandini et al. 2000; Perez-Jimenez et al. 2008; Prior et al. 2005; Van Duijnhoven et al. 2009).

Leek has abundant antioxidants. The associated advantageous effects have been attributed mainly for phenolics, ACSOs, ascorbic acid, carotenoids and tocopherols. The antioxidant capacity of the leek is in the same range as raw cabbage, raw pumpkin and celery, higher than the raw cucumber, raw tomatoes and iceberg lettuce but less than the raw broccoli, raw garlic, onion and raw spinach. The antioxidant capacity of leek with a different body part is reported in Table 16.6. Generally, the white shaft and green leaves of leek contain approximately 8 and 9 mg GAE g^{-1}dw and 2 and 5 mg L-ascorbic acid $^{-1}$dw antioxidants, respectively. The antioxidant

Table 16.6 Antioxidant capacity of the different types of leek and its body parts

Leek type/ body part	DPPH (μmol TE g^{-1}dw)	ORAC (μmol TE 100 g^{-1}dw)	FRAP (μmol Fe_2SO_4 g^{-1}dw)	References
Leek	Nd	569	Nd	USDA (2010)
	Nd	490	Nd	Ninfali et al. (2005)
Leeks white shaft	2–11	379–1242	3–18	Bernaert et al. (2012a)
Leeks green leaves	5–14	1150–1904	14–37	
GHG-L leaves	17.65	Nd	Nd	Najda et al. (2016)
GHG-L bulb	81.14	Nd	Nd	

activity of leek is dependent on phenolics and ascorbic acid. White shaft of the leek has low AA content as compared to green leaves, hence white shaft showing lower antioxidant activity than green leaves in terms of the FRAP and ORAC. Green leek leaves usually have more antioxidant capacity than those of the white stem, but green leaves of leek mostly not used are removed during harvesting and processing, and the lactic acid fermentation of leek can provide an alternative to the effective utilization of the green leaf portion (Bernaert et al. 2012a; Huxley and Neil 2003; Seabra et al. 2006; USDA 2010;Wouters et al. 2013).

The antioxidant activity of methanolic extract of wild leek is assessed by DPPH and ferric reducing power assays, and its EC_{50} values range between 15.12 and 0.70 $mgmL^{-1}$ of a sample of methanolic extract, respectively. The IC_{50} value for DPPH inhibition of leek is 4.49 mg ml^{-1}, which is more than shallot and less than chive, garlic, Chinese chive and onion (García-Herrera et al. 2014; Mnayer et al. 2014).

16.3.2 Antimicrobial Activity

Allium species are characterized by their rich content in volatile allicin, other OSC, flavonoids and saponin that are responsible for the antibacterial, antifungal and antiviral activities. As compared with other OSC, allicin has strong antimicrobial action against a varied range of microbes. Allicin instantly entered through artificial and normal phospholipid membranes. Regarding the antibiotic effectiveness against gram-positive and gram-negative bacteria, authentic allicin had approximately 1–2% of the effectiveness of streptomycin (vs *S. aureus*), 8% of vancomycin (vs *S. aureus*), and 0.2% of colistin (vs *E. coli*). The oxygen in the structure (-S (=O)-S-) of allicin helps to release the S-allyl moiety, which has antimicrobial activity (Cushnie and Lamb 2005; Fujisawa et al. 2009; Miron et al. 2000; Mnayer et al. 2014; Putnik et al. 2019).

Leek essential oil (EO) contains verity of OSCs such as dipropyl disulphide (DPDS), dipropyl trisulphide and dipropyl tetrasulphide. The allyl group of OSC is accountable for the antimicrobial activity. The DADS, PTSO and dipropyl sulphide are recognized as toxicologically harmless for ordinary human consumption and food processing. Sulphides and thiosulphinates are antimicrobial against *Helicobacter pylori* and *Escherichia coli*. The antimicrobial activity of leek EO has in the order of most resistant to the most sensitive action on strains of *Pseudomonas aeruginosa* > *Escherichia coli* > *Bacillus cereus* > *Staphylococcus aureus* > *Bacillus subtilis* > *Candida albicans* > *Streptococcus pyogenes* (Behbahani and Fooladi 2018; Casella et al. 2013; Llana-Ruiz-Cabello et al. 2015a, b; Mellado-García et al. 2017; Seo et al. 2001). Antimicrobial activity of leek essential oil is mainly attributed to propyl derivatives (mainly to dipropyl trisulphide); it demonstrated antimicrobial activity against *Staphylococcus aureus*. Compound N-feruloyl tyramine and N-caffeoyl tyramine showed antifungal activity against *Botrytis cinerea* at the lowest concentration, while both *Penicillium italicum* and *Aspergillus niger* are inhibited only by N-caffeoyl tyramine at lowest doses. Cinnamic acid derivatives based on thymol and carvacrol show the antimicrobial activity by inhibiting the ergosterol

synthesis in bacterial cells and destroying the membrane integrity. However, ferulic and caffeic acids are the most lethal against the microbes (Ahmad et al. 2011; Barile et al. 2007; Lanzotti et al. 2012; Mnayer et al. 2014; Puupponen-Pimiä et al. 2001; Sadeghi et al. 2013a, b).

16.4 Health Benefits of Leek

Leek is proven to provide many health benefits such as antiosteoporotic, antidiabetic, hypoglycemic, hypolipidaemic, antihypercholesterolemic, platelet aggregation inhibitory, free radical scavenging, anticarcinogenic, hepatoprotective, spasmolytic, gastroprotective, anti-inflammatory and immunomodulating activities (Dey and Khaled 2015; Lanzotti 2006; Lim 2015).

16.4.1 Immunomodulatory Activity

Leek is a rich source of water-extractable pectic polysaccharides having high molecular weight and high galacturonic and glucuronic acid and galactose content and having good immunomodulatory activity. Its immunomodulating effect is due to the presence of (1 → 3,6)-β-galactan side chains and of glucuronic acid of pectic polysaccharides. The water-extractable pectic polysaccharides have the potential to increase the activity of peritoneal macrophages and killing activity against *Salmonella enteritidis*. Pectic oligosaccharides hinder bacterial toxin receptor binding and attachment of bacterial pathogens to gut epithelial cells. Steroidal saponin isolated from leek bulbs showed immunological adjuvant activity on the cellular immune response against ovalbumin antigen and haemolytic activity in the in vitro assays. Pre- and post-topical treatment of leek volatile oil is effective against trichothecene toxin-induced epidermal injury in the mouse footpad rich in epidermal Langerhans cells. Langerhans cells show a critical role in cutaneous immunological responses (Adão et al. 2012; Ganan et al. 2010; Kratchanova et al. 2010; Nguansangiam et al. 2003; Paulsen and Barsett 2005; Rhoades et al. 2008).

16.4.2 Anticarcinogenic Activity

Epidemiological studies and meta-analysis indicated that the high levels of *Allium* vegetables in the diet decrease the risk of cancer, mainly cancers of the gastrointestinal tract. The OSC has been reported to prevent the growth of many types of tumours. The allyl derivatives of OSC from *Allium* are inhibiting carcinogen formation in the forestomach, oesophagus, colon, mammary glands, and lungs. This may be due to the inhibition of carcinogenic nitrosamines and heterocyclic amines which exist in the foods. Diallyl mono-, di- and tri-sulphides obtained from *Allium* are responsible to introduce apoptosis in malignant tumour cells (Chope et al. 2011; Goncharov et al. 2016; Nicastro et al. 2015; Ramirez et al. 2017; Zhou et al. 2011).

Polyphenolic compounds, such as quercetin, kaempferol and isorhamnetin, are the three main flavonoid aglycones and have aninflammatory effect on activated macrophages. Flavonoids are thought to have the strong anticarcinogenic effect that prevents cancer cell development and angiogenesis encouraging cancer cell apoptosis. The flavonoid kaempferol is protecting normal body cell functioning, neutralizing the toxic characteristics of 7-beta-hydroxycholesterol in muscle cells and avoiding programmed death in healthy cells. Besides, quercetin and kaempferol show chemopreventive effect in brain tumours and synergistically suppress cell spread in human gut cancer lines (Ackland et al. 2005; Hamalainen et al. 2007; Kim et al. 2008; Labbé et al. 2009; Ruiz et al. 2006; Sengupta et al. 2004).

Sapogenin isolated from *Allium porrum*, 12-keto-porrigenin, 2,3-seco-porrigenin, agigenin and porrigenins A, B and C, displayed cytotoxicity and high antiproliferative action on four tumour cell lines WEHI 164 (murine fibrosarcoma), J-774 (murine monocyte/macrophage), IGR-1 (human melanoma) and P-388 (murine leukaemia) cell lines in vitro. Sapogenin, namely, porrigenin C, showed a considerable antiproliferative activity on four tumour cell lines in vitro. Steroidal saponins from leek bulb, i.e. diosgenin and a spirostanol saponin derivative, showed considerable cytostatic action on human promyelocytic leukaemia HL-60 cells with IC_{50} values of 2.1 and 3.2 ug/mL, respectively. Fructooligosaccharides also help in the inhibition of tumour growth and reduce the risk of cancer. Elephant garlic extracts depressed osteosarcoma cell (U2OS) viability and proliferation and affected their morphology. It does not only hinder cancer cells directly via antiproliferation but also reduces the cancer cells by delaying the metastasis process by 66.7%. It prevents the evolution from G1 phase to S phase (Irkin and Korukluoglu 2009; Huang and Ren 2013; Ly et al. 2005; Magra et al. 2006).

16.4.3 Prevention of Cardiovascular Diseases

Allium vegetable eating has substantial effects on dropping blood pressure, inhibition of atherosclerosis, decreasing serum cholesterol, triglycerides, platelet aggregation, and enhancing fibrinolytic activity. Rabbits fed with *Allium porrum L.* extract showed that plasma total cholesterol and LDL decreased significantly concerning the hypercholesterolemic group of rabbits. Polyphenolic compounds reduce vascularization and stimulate vasodilation. Kaempferol acts as a thromboxane receptor antagonist and acted as an active agent in the inhibition of atherosclerosis and acute platelet aggregation (IC_{50} 20 mM) and reduces the risk of coronary heart disease (Bayan et al. 2014; Fattorusso et al. 2001; Haminiuk et al. 2012; Lin et al. 2007;Movahedian et al. 2006; Supakul et al. 2014).

16.4.4 Anti-inflammatory Effect

Inflammation leads to the release of histamine, bradykinin and prostaglandins (PGs). Production of pro-inflammatory cytokines during inflammation progression induced

by phagocytic cells stimulates cellular activities via enhancing PGs and ROS and RNS production, and they are responsible for the development of cardiovascular and neurodegenerative disorders, such as Alzheimer's disease, atherosclerosis, cataracts, inflammation, and cancer. Organosulphur compounds such as allicin are helped in the inhibition of inflammatory processes. The anti-inflammatory activity of allicin is associated with the prevention of secretion of TNF-α-initiated pro-inflammatory cytokines from digestive epithelial cells. OSC can control the production of the Th cytokines and encouraged immune response by hindering signalling pathways and decreasing the production of inflammatory lipopolysaccharide. A bioactive compound like allyl methyl disulphide positively suppressed IL-8/IP-10 development by the TNF-α in intestinal cells. Allyl methyl disulfide also acted as a suppressor of the IL-8 mRNA in HT-29 cells and causes IκBα degradation and NF-κB p65 translocation. Leek is a rich source of PUFA, predominantly linoleic acid. The high linoleic acid composition inhibits the activity of pro-inflammatory cytokines like IL-1β, IL-6, IL-13, and TNF-α. Also, some newly isolated steroidal saponins from leek show anti-inflammatory and haemolytic effects and antiulcerogenic activities (Adão et al. 2011; Khayyal et al. 2014; Liao et al. 2012; Pan et al. 2015; Zhang et al. 2015).

16.4.5 Antidiabetic Property

Polyphenolic and OSC compounds and other antioxidants of *Allium* vegetables are reported to responsibly improve insulin secretion. Polyphenolic compounds help in control as well as reduction of blood glucose level by inhibiting α-amylase and α-glucosidase enzyme, shielding β-cell from glucotoxicity, triggering 5-adenosine monophosphate-activated protein kinase (AMPK), enhancing insulin-dependent glucose uptake or acting as antioxidative and anti-inflammatory to protect β-cell (Del Rio et al. 2010; Ferguson et al. 2004; Haminiuk et al. 2012; Lin et al. 2016; Melino et al. 2019; Silva et al. 2008).

Diallyl trisulphide, richly present in *Allium*, helps in control or reduction in the glucose. The in vivo study of induced diabetes model shows the reduction of intestinal absorption of glucose or increase of insulin secretion from residual B-cells in Langerhans islets. OSCs help in chelating hydroxyl radicals and superoxide which induces diabetic interfering function of alloxan, and chelating these compounds prevents diabetes. Supplementation of hydroalcoholic and ethanolic extract of leek (*Allium ampeloprasum*) extract to diabetic rats showed hypoglycemic, hypolipidemic and antioxidative properties. Leek contains high levels of ROS scavenging compound which prevents the oxidative DNA damage and necrosis of pancreatic B-cells by chelating compounds of hydroxyl radicals and performed a vital role in sustaining the viability of pancreatic B-cells. The ethanolic extract also improved serum insulin in diabetic mice. *Allium porrum* are shown to inhibit the active transport and absorption of D-glucose throughout the rat enterocytes in the rat everted intestinal sac testing. Leek consumption helps in the reduction of blood glucose level. Leeks are rich in fructooligosaccharides and other α-galacto-oligosaccharides, i.e. raffinose and stachyose, and these α-galactosides are not

converted to monosaccharides due to absence of specific degrading enzyme. They passed down to the large intestine and get hydrolysed by microbiological enzymes and metabolized by colon microflora (Belemkar et al. 2013; Liu et al. 2005; Montezano et al. 2015; Rahimi-Madiseh et al. 2017; Roghani and Aghaie 2007; Selvan et al. 2008).

16.4.6 Other Health Benefits

The powder obtained from jumbo leek (*Allium ampeloprasum*) bulb showed the hepatoprotective activity. It decreases the initiation of hepatocyte necrosis in D-galactosamine hydrochloride (GalN)-induced acute fulminant hepatitis and forbids the incidence of ethanol-dependant chronic liver disorders in rats by stopping the absorption of alcohol from the stomach (Uchida et al. 2009).

Allium porrum has a significant protective effect against osteoporosis. Oral feeding of leek extract leads to restore bone mineral density in osteoporosis rats. It also decreases the ethanol-dependant elevation of alkaline phosphatase and malondialdehyde levels in serum (El-Shenawy et al. 2013).

Allium ampeloprasum improves reproductive functions in male rat due to its antioxidant and androgenic activities. It has a promising effect in enhancing healthy sperm parameters. Oral feeding of *Allium ampeloprasum* aids to improve male fertility and secretion of testosterone and gonadotropin levels in normal rats. *Allium ampeloprasum* extract increases the mass of testes, seminal vesicles and prostate glands, improves sperm superiority and quantity, and improved testosterone, luteinizing hormone and follicle-stimulating hormone levels in serum of testicular toxicity-tempted male rats and helps in curing sexual impotence (Jaffat et al. 2014; Morakino et al. 2008). Leek leaves ointment helps in the reduction of bleeding, anal discomfort, excretion discomfort and anal burning of all haemorrhoid patients (Mosavat et al. 2015).

16.5 Effect of Processing on Bioactive Compounds

Vegetables are generally treated before consumption or storage (blanching, canning and fermentation), which enhances the flavour and digestibility of foods. Before eating the *Allium* are typically processed such as blanching, boiling, steaming or stewing. Leek is the main ingredient of salads, soups, sauces, oven dishes, stewed, etc. Thermal processing tends to reduce the ACSO, polyphenol, ascorbic acid, tocopherol and carotenoid contents and also impact the antioxidant activity (Gabrić et al. 2018; Granato et al. 2018). The degradation of antioxidants and BACs during processing is subjected to its sensitivity, modification, time of exposure to processing technique and type of processing technique. Antioxidant activity of *Allium* is reduced due to heat-induced decay of some polyphenolic and OSC compounds (Wangcharoen and Morasuk 2009).

The food processing techniques like steaming, frying and microwaving are responsible for enhancing the ACSO content, while blanching had the reverse effect, maybe due to γ-glutamyl peptidase and oxidase catalysis. The synthesis of OSC in *Allium* is avoided by inactivating allinase enzymes. The ideal temperature for allinase action is 37.5 ± 5 °C, but allinase is completely inactivated by raising the temperature and time of holding (e.g. 60 °C for 105 min), while for reduction of 50% of its activity, there is a need to expose it at the same temperature for 15 min (Chen et al. 2017; Kim et al. 2016; Poojary et al. 2017; Rose et al. 2005; Shen et al. 2002).

In general, food processing steps such as fermentation, tampering, cutting and cooking (blanching, boiling and steaming) prolonged shelf-life of fresh vegetables, develops typical sensory properties and enhanced nutritional properties of the end product. Processing such as fermentation, blanching and steaming of leek results in an increase in antioxidant activity and no effect on the total phenolics, while boiling harms antioxidants and the total phenolic content. ACSO content of leeks such as methiin and isoalliin decreases due to fermentation, tampering and thermal processing like boiling and steaming, but blanching results in an increase in ACSOs, and it is found that methiin is less susceptible to heat treatment than isoalliin. Fermentation causes the enhancement of endogenous polyphenolic compounds like ferulic acid, astragalin, luteolin and naringenin, but sinapinic acid degraded after fermentation of the green leaves. It also encouraged the production of polyphenolic compounds that are not naturally occurring in the fresh leek, and these compounds are hydroferulic acid quercetin-3-O-rutinoside, quercetin-3-O-arabinoside, naringenin and dihydroquercetin (Bernaert et al. 2013a, b; Gorny 2006; Josephsen and Jespersen 2004; Hutkins 2006; Van Boekel et al. 2010; Wouters et al. 2013).

Frozen storage of leek has some effect on aroma compounds, lipoxygenase activity, carbohydrate content, antioxidant, total phenolics and ACSOs. The aroma components of leek slices undertake a notable change throughout 12 months of freezing as compared to fresh-cut leeks. OSCs such as dipropyl disulphide vary from 0.197 to 0.0409 mgL^{-1} and propyl (E)-propenyl disulphide from 0.0437 to 0.00452 mg^{-1}. During the end of the storage, aroma profile of leek is characterized by several saturated and unsaturated aldehydes, like hexanal (1.53 to 3.63 mgL^{-1}), (E,E)-2,4-nonadienal (0.000 to 0.0647 mgL^{-1}) and (E,E)-2,4-decadienal (0.129 to 0.594 mgL^{-1}). The action of lipoxygenase enzyme decreases throughout the freezing period, and decrease is ∼25% of the original activity of fresh leek. The carbohydrate content of leek tends to increase during 150 days of refrigerated storage period. Among studied carbohydrates degradation increases throughout storage and is responsible for increasing glucose from 4.4 to 16.2 g/100 g of DM, fructose from 4.7 to 23.8 g/100 g of DM and saccharose from 5.1 to 18.7 g/100 g of DM, and it depends on the cultivar and the storage duration. A slight increase in kestose, nystose and raffinose content is found later on the period of storage, and it varied from 0.3 to 0.9, 0.5 to 1.8 and 0.8 to 1.8 g/100 g of DM, respectively, while stachyose composition remained at a constant level during the storage period. Antioxidant activity and phenolic compound of green leaves and white shaft of leek are very lowly influenced by refrigerated storage, but significant increase in isoalliin is

observed in the white shaft during refrigerated storage (Bernaert et al. 2013b; Bernaert et al. 2014; Grzelak-Biaszczyk et al. 2011; Nielsen et al. 2004).

16.6 Uses of Leek in the Food Industry/Processing

The leaves and white blanched stems are generally cooked, and in the cooking process, the strong flavour of leeks frequently vanishes during boiling and remains a very mild, pleasant taste to the product. These are also chopped into tiny slices and added to salads which give a slight onion flavour along with a pleasant sweetness. The dense leaf bases and slightly mature bulb are consumed with or without attached leaves. The green leaves are palatable and have a strong odour and powerful taste. They are generally used for flavouring in salads and dishes. These are used mainly for flavouring soups and stews in place of onions as a favourite leek soup dish for many gardeners. Leek has also been used extensively in the cuisines of Wales as a symbolism for the country (Anonymous 2005).

16.7 Conclusion

Leek is famous worldwide and consumed mostly as a vegetable, a salad and in soups. Leek has higher or same range antioxidant activity compared to other *Allium*, and it is attributed to polyphenolics, ACSOs, saponins, ascorbic acid, carotenoids and tocopherols. In leek variety of polyphenolic compounds are present, among them kaempferol 3-O-glucoside, quercetin 3-O-galactoside and ferulic acid which are present in higher quantity. Flavonoid glycosides of the leek are mono-hexose, dihexose and coumaroyl, feruloyl and caffeoyl acylated di-hexose derivatives of kaempferol. Saponins such as steroidal, spirostane, furostane, cholestane and sapogenin are present in leek, but spirostane-based saponins exhibited higher antimicrobial activity. Water-extractable pectic polysaccharides of the leek are high (1 → 4)-linked glucuronic acid, galactose and rhamnose which show immunomodulatory activity. It has been found that the processing such as fermentation, steaming, blanching and refrigerated storage appeared to be accountable for better retaining of the BACs present in leek. These processes are responsible for enhancing the antioxidant activity without affecting total phenolics, while only blanching enhances the ACSOs. Leek is considered as folk medicine since ancient times. Bioactive compounds of the leek are believed to be responsible for the health-promoting properties such as antiosteoporotic, antidiabetic, hypoglycemic, hypolipidaemic, antihypercholesterolemic, platelet aggregation inhibitory, free radical scavenging, anticarcinogenic, hepatoprotective, spasmolytic, gastroprotective, antimicrobial, anti-inflammatory and immunomodulating activities.

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