







Review

Nutritional Profile, Phytochemical Compounds, Biological Activities, and Utilisation of Onion Peel for Food Applications: A Review

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Abstract: The majority of the by products formed during onion processing remain unutilized, yet they are rich in bioactive compounds and phytochemicals. Onions are a very valuable vegetable. Onion chemical compounds are incredibly diverse, and they work through a variety of pharmacological mechanisms to prevent disease. Although the mechanism of the action of the chemicals found in onions has been studied, there is still room for further reformulating of nutrient supplements and pharmaceutical treatments thanks to a growing interest in sustainable resource utilisation and circular economy. This review focuses on the primary bioactive components found in onion peel and skin, particularly total phenolics, quercetin, total flavonoids, and their derivatives, as well as their therapeutic uses such as cardioprotective, anticancer, neuroprotective, antiobesity, antidiabetic, and antibacterial constituents. This review article noted that onion peel is a valuable agricultural byproduct that has a variety of biologically active compounds so it can be used as a health-regulating ingredient, particularly in the biomedical and pharmacological domains.

Keywords: onion peel; phytochemicals; therapeutic potential; sustainable valorisation

1. Introduction

In addition to basic human consumption, onion (*Allium cepa* L.) is a crop that is grown everywhere for its therapeutic and functional properties [1]. Globally the production of

onion has increased by 25% due to behavioural changes that resulted in the increased stipulation for freshly cut and prepared vegetables (onion), thus resulting in the generation of more waste. Onion processing waste mainly includes skin (peel) [2], comprising two outermost leathery layers, undersized and roots or deformed bulbs. In Europe, every year, more than 500,000 t of onion peel are generated, while in India, 300–500 kg of onion peel is generated every day. This peel decomposes in soil, causing odour and harm to the environment [3]. Despite being the potential source of biologically active components such as phenols and flavonoids, is still an underutilized product [4]. Peel also possesses numerous therapeutic effects, with antimutagenic, antibacterial, and antioxidant capabilities [5]. The multilayer tissue of onion bulbs contains a good number of bioactive compounds fitting two main chemical groups: the alk(en)yl cysteine sulfoxides and flavonoids. The first category of molecules is responsible for providing the distinctive aroma and taste of onion; therefore, the special flavours present in different varieties are because of these molecules [6]. Although several kinds of food waste are applied as animal feed, it was found that onions can cause harmful effects to animals. Because of its high-fibre content and good bioactivity, using onion waste as a component of food items may be advantageous [7]. Onion peel has been incorporated into many food commodities such as gluten-free bread, wheat bread, and meat patties in order to produce health benefits or to improve the storage life of the product [8]. The addition of onion to salads helps lower LDLs, prevents spontaneous preterm delivery, and decreases glycemia and other satiety problems [9].

Onion is thought to be a healthy food material because of the presence of trace metals such as zinc and it is considered to be one of the best sources of vitamin B₆ [10]. Onion extracts, which are antimicrobial in nature and kill the enterotoxigenic bacteria, show suppressing impacts on the expansion of cancerous cell lines and adipogenesis via impeding fatty acids (FAs). Additionally, these extracts have been found to improve insulin resistance and hyperglycaemia in diet and increase the fat content in streptozotocin-induced diabetic rats [11]. The aim of this study is to understand the composition, potential applications, and bioactive properties of onion peel.

1.1. Composition/Nutritional Profile of Onion Peel

Onion waste contains 8.3–15.6% dm (dry matter) of protein, 88.56% carbohydrates, and 169–750 mg/g dm (dry matter) of dietary fibre. In addition, the peel is also a rich source of calcium (1.8–16.5 mg/g), potassium (11.1–15.9 mg/g), zinc (0.0162–0.0538 mg/g), magnesium (0.6–1.5 mg/g), manganese (0.0065–0.0288 µg/g), iron (0.0196–0.8889 mg/g), selenium (0.00003–0.00093 µg/g), total phenolics (9.4–52.7 mg gallic acid equivalent (GAE)/g dm), and flavonoids.

The outer scales of onion contain 26.84% of crude fibre, 15.13% of crude fat, 2.64% of crude protein, 8.06% of ash, 8.02% of moisture, and 66.12% of carbohydrates. The fatty acid profile is primarily composed of 0.94% of lauric acid, 1.28% of myristic acid, 9.8% of palmitic acid, 2.84% of palmitoleic acid, 17.57% of oleic acid, 8.81% of stearic acid, 2.88% of linolenic acid, 52.87% of linoleic acid, 1.23% of behenic acid, 0.59% of arachidic acid, 0.63% of erucic acid, and 0.54% of lignoceric acid, demonstrating that the total USFA was 76.79% and total SFA content was 21.42%. However, the red onion cultivar had the most available flavonoids (20.22 mg/g), followed by the pearl onion (19.64 mg/g), while the white onion had the least (0.08 mg/g) [4].

Presence of nutritional compounds

Table 1 gives detailed information about the phytochemical profile of onion peel including the identified bioactive compounds with quantity yield.

Plant secondary metabolites

Onion peel is the best source of fructooligosaccharides, dietary fibres, polyphenols, and antioxidants [12]. Environment, type of cultivar, agricultural practices, ripening stage, and the period of preservation affect the onion's chemical composition. Onion peel contains significantly more flavonoids than its edible part. Anthocyanins, quercetin, and their derivatives are the two main subgroups of flavonoids present in onions which

give rise to the yellow and purple colour of onions. Major flavonoids present in onion comprise quercetin diglucoside, quercetin, quercetin aglycone, kaempferol, and quercetin 4-O-glucoside which is present in large amounts in the outer layer [2]. The *A. cepa* onion variety has numerous secondary metabolites, as mentioned in Table 2.

Table 1. Various types (region-wise) of onions, their suitable methods of extraction, and the bioactive compounds identified.

Variety (Region)	Extraction Method	Bioactive Components Identified	Yield	References
Yellow-coloured onion peel (Galati, Romania)	Ultrasound-assisted extraction at 40 kHz, 100 W; for 30 min, employing 70% ethanol	TPC, TFC	97.28 mg GAE/g dw 55.27 mg QE/g dw	[13]
Solid waste from onions	Ultrasound	Total polyphenols protocatechuic acid, protocatechuic acid derivative, 2-(3,4-dihydroxybenzoyl)—2,4,6 trihydroxybenzofuran-3(2 H)-one, quercetin 7,4'-O, cyanidin, O-diglucoside, 3-O-glucoside, cyanidin 3-O-malonylglucoside, quercetin 3,4'-O, O-diglucoside, quercetin 4'-O-glucoside, isorhamnetin 3-O-glucoside, quercetin, quercetin 4'-O-glucoside/quercetin adduct, quercetin 4'-O-glucoside/quercetin dehydrate adduct, and quercetin dehydrodimer	21.57–64.91 mg GAE/g dw	[14]
Onion peel (South Korea)	Ethanol	Total phenolic content, quercetin, and total flavonoid content	372.50 mg GAE/g 62.39 mg/g 183.95 mg QE/g dw	[15]
Onion peel (South Korea)	Subcritical water extraction: SWE (at 110 °C and 165 °C)	Total phenolic content, total flavonoid content quercetin	119.5 and 27.10 mg QE/g 44.4 and 12.26 mg/g dw	[15]
Onion peel (South Korea)	Hot water	Total phenolic content, Total flavonoid content, quercetin	120.6 mg GAE/g 54.50 mg QE/g 25.78 mg/g dw	[15]
Onion skin (South of Sweden)	50% ethanol containing 0.05 M ortho-phosphoric acid	Total phenols, quercetin-3, 7, 4-triglucoside, quercetin-7, p-hydroxybenzoic acid, 4-diglucoside, vanillic acid, quercetin-3, 4-diglucoside, quercetin-3-O-glucoside, ferulic acid, isorhamnetin-3-O-glucoside, kaempferol-3-O-glucoside, quercetin-4-O-glucoside quercetin, kaempferol	26.3 mg/g dw 366.4 mg/g dw 12.2 mg/g dw 20.0 mg/g dw 444.7 mg/g dw 301.8 mg/g dw Below detection levels 32.2 mg/g dw 1767.6 mg/g dw 10.7 mg/g dw 1779.8 mg/g dw 263.9 mg/g dw	[16]
Onion skin of pearl, red, white, and yellow onion (St. Johns, NL, Canada)	Ultrasonicated methanol–acetone–water mixture extract	Quercetin (free), quercetin (esterified), quercetin (bound), quercetin 3,40-diglucoside (free), quercetin 3,40-diglucoside (bound), quercetin 3,40-diglucoside (esterified), kaempferol (esterified), kaempferol (bound) kaempferol (free)	0.004–8.33 mg/g 0.007–0.03 mg/g 0.01–0.23 mg/g 0.004–9.59 mg/g 0.19–1.44 mg/g 0.16–2.54 mg/g 0.01 mg/g 0.006–0.01 mg/g 0.003–1.36 mg/g	[17]
Onion peel (south of Sweden)	50% ethanol consisting of ortho-phosphoric acid (0.05 M)	Total phenols quercetin-3,7,4-triglucoside, p-hydroxybenzoic acid, quercetin-7,4-diglucoside, quercetin-3,4-diglucoside, vanillic acid, quercetin-3-O-glucoside, ferulic acid, kaempferol kaempferol-3-O-glucoside, isorhamnetin-3-Oglucoside, quercetin-4-O-glucoside quercetin	173.5 mg/g dw 4.1 mg/g dw 416.2 mg/g dw 12.1 mg/g dw 729.5 mg/g dw 952.8 mg/g dw 30.7 mg/g dw 129.7 mg/g dw 93.2 mg/g dw 113.7 mg/g dw 1936.6 mg/g dw 623.8 mg/g dw	[16]
Onion waste (outer scales, top, bottom, brown skin) (Spain)	70% acidified methanol extract	Total phenolics, total flavonoids, total flavanols, quercetin, quercetin 3'-glucoside, quercetin 4'-glucoside, quercetin 3,4'-diglucoside, isorhamnetin 4'-glucoside, isorhamnetin 3,4'-diglucoside	19.7–52.7 mg GAE/ g dw 19.5–43.1 mg QE/g dw 7.89–19.27 mg/g dw 0.59–1.61 mg/g dw 0.32–1.03 mg/g dw 0.34–9.49 mg/g dw dw0.31–0.42 mg/g dw	[12]

Table 2. Various secondary metabolites found in *A. cepa* species.

Flavonols and Anthocyanins	Cepa (Yellow Variety) (tR, min)	Cepa (Red Variety) (tR, min)
Quercetin 3, 40-diglucoside	100.40 ± 0.05 (32.46)	331.93 ± 0.12 (32.50)
Quercetin 40-monoglucoside	140.43 ± 0.10 (40.42)	298.87 ± 0.13 (40.46)
Myricetin	8.63 ± 0.01 (42.31)	9.31 ± 0.02 (42.35)
Quercetin aglycone	60.51 ± 0.06 (47.09)	70.10 ± 0.08 (47.14)
Isorhamnetin	2.21 ± 0.01 (52.23)	13.73 ± 0.01 (52.28)
Peonidin 30-glucoside	1.11 ± 0.00 (12.38)	Nd
Peonidin 30-glucoside acetate	Nd	0.67 ± 0.3 (25.02)
Malvidin 30-glucoside	0.53 ± 0.00 (12.84)	0.24 ± 0.00 (13.28)
Cyanidin 30-glucoside	7.85 ± 0.11 (8.56)	0.11 ± 0.00 (8.06)
Cyanidin 30-glucoside acetate	0.76 ± 0.00 (22.43)	3.44 ± 0.03 (21.75)
Petunidin 30-glucoside	0.12 ± 0.00 (10.58)	Nd
Petunidin 30-glucoside acetate	Nd	0.17 ± 0.02 (23.25)

Concentration in mg/100 g dry weight; tR, retention time; Nd, not determined.

1.2. Bioactivities of Onion Peel

Onion peel can be used as a natural colourant ranging from orange to red and purple to blue in the food industry because of the presence of anthocyanins. The applications of these natural food colourants are increasing in comparison to synthetic colourants as they are nontoxic mutagens, possess numerous therapeutic properties, enhance the integrity of capillary blood vessels, and inhibit the aggregation of thrombosis, thereby reducing the risk of circulatory disease [18]. Bulbs of onion are considered a rich source of bioactive components (flavonoids). On the other hand, phytonutrients found in the onion's outer layer could be explored for sustainable "green" agricultural pest management, the preparation of intelligent packaging, or the creation of biologically active ingredients. Thus, the different applications of onion scraps could support the improvement of inexpensive, sustainable, and efficient techniques to decrease agrifood waste [6]. Onion skin ash water extract was used to produce bisphenol and its derivatives that possess different biological activities such as anticancer, antiviral (human immunodeficiency virus), antipyretic, and antimicrobial properties. The onion peel waste that is produced throughout the world has gained appeal because of its use in organic synthesis which in turn lessens its environmental impact [1]. Quercetin has been found to possess the capability to prompt the consumption of L6 myotubes when they are under oxidative stress. Quercetin and naringenin effectively suppress the impact on uterine contractions in mice [19].

2. Potential Food Applications of Onion Peel

Studies suggest that onion peel powder (OPP) is capable of prolonging the storage life of sausages manufactured with separated fish meat. The addition of onion peel powder considerably increased the antioxidant potential and total phenolic level and declined the pH. Hence, polyphenols from OPP significantly suppress lipid oxidation without deterioration of sensory properties [20]. It has been found that during the refrigerated storage of rainbow trout fillets, the use of OPE (onion peel extract) that has potent antimicrobial and antioxidant properties has enhanced the effectiveness of rainbow trout cutlets extending their shelf life to six days for 5% OPE treated groups and eight days for 10% treated groups [21].

2.1. Food Colourants

The outer skin and the epidermal layer of onions contain anthocyanins and phenolics. Cyaniding-3-glucoside is the main pigment in red onion with a low quantity of cyanidin-3-laminaribioside and several small unrevealed pelargonidin cyanidin peonidin glucosides. Before processing onions, the peel is removed as it is not edible. The peel contains a broad range of polyphenolic components and can be used as a natural antioxidant and colourant in the food industry. Onion peel is used as a food colourant in the confectionary industry

to manufacture jellies and gums, sugar-enrobed confectionery, foamed commodities, stiff-boiled candies, and fat-based coatings. Generally, it can be said that using natural food colourant as an ingredient is harmless, beneficial, and a good prospective food colourant for preparing hard candies and glazed jellies [18].

2.2. Baking Products

The applicable provenance of dietary and other beneficial materials for gluten-free commodities are the derivatives of fruit and vegetable manufacturing as they have the benefit of inexpensiveness. The infusion of onion scrap into gluten-free bread can enhance the possible therapeutic advantages with satisfactory sensory acceptance [20].

2.3. Safety

Acrylamide (AA) which is found in many thermally processed foods such as French fries is a human carcinogen that produces cytotoxicity and immunotoxicity in liver cells. This can be prevented by adding OPP as a natural food additive. Treatment of AA with OPP decreases cytotoxicity and immunotoxicity. The rate at which these effects decrease is directly proportional to the OPP concentration. Supplementation of OPP high in polyphenolic components may reduce AA-stimulated immunotoxin and cytotoxic effects because of its direct ROS (reactive oxygen species) scavenging activity [22]. The incorporation of methylene blue (MB), a cyclic cationic dye, might induce vomiting, nausea, and methemoglobinemia whilst its exposure causes damage to the skin and a fiery feeling in the eyes. The iron oxide nanoparticles (IONPs) achieved by mingling FeCl_3 salt with garlic and OPE help in the detachment of methylene blue (MB) dye from the water via the adsorbent process and thus offer a sustainable remedy for hazardous dyes. Utilising IONPs to convert FeCl_3 salt into iron oxide nanoparticles efficiently, garlic and onion skins serve as stabilizing, reducing, and anticaking agents [23].

3. Therapeutic Effects of Quercetin

The principal bioactive components found prevalent in onions are sulphur-containing components such as cysteine sulfoxides and onionin A, as well as phenolic components including quercetin, rutin, and quercetin glucosides. The concentration of bioactive compounds differs with varieties; for example, red onions contain the most anthocyanins and flavanols, followed by yellow onions, whereas white onions contain the least [24]. Moreover, the primary components differed between onion cuticles, with quercetin being the most abundant in red onion peel and quercetin-4-glucoside being the most abundant in the bulb. Table 3 elaborates on the amount of quercetin-3-O- β -D-glucuronide content in selected foods or fruit.

Table 3. Quercetin-3-O- β -D-glucuronide content in selected food.

Fruit Name	Type of Fruit Product	Amount of Quercetin-3-O- β -D-Glucuronide
Fruit and fruit products	black grapes,	2.15 mg/100 g
	raw strawberries,	1.74 mg/100 g
	green grapes,	1.50 mg/100 g
	cloudberries	0.79 mg/100 g
	raw red raspberries,	0.63 mg/100 g
Berry juices, Fruit juices	nonalcoholic beverages,	
	pure juice, red raspberry,	6.18 mg/100 mL
Herbal infusion	fennel, tea	3.26 mg/100 mL
	green grape, pure juice,	0.05 mg/100 mL
Leafy vegetables	vegetables	
	raw, red lettuce,	2.65 mg/100 mL
Pod vegetables	raw green lettuce	1.34 mg/100 mL
	raw green beans	g/100 mL

3.1. Antioxidant Activity (A.A.)

Onions are rich in natural antioxidants [25]. The antioxidant properties and the phenolic content in the onion bulb are also enhanced with the utilization of humic acids in mycorrhizal inoculate at increased atmospheric CO₂ levels [26]. The antioxidant constituents of onion seeds have been shown to be impacted by cultivating time and density [27], as well as the suitability and bioavailability of antioxidant activity and total phenolics of the floral shoot of the second-year onion resprout [28]. TPC (total phenolic content), TFC (total flavonoid content), and antioxidant capacity of the fresh-cut onions increased upon storage when they were washed with a blend of citric acid and nisin, in addition to onion sprouting [29]. The influence of the manufacturing of food on the antioxidant capability of onions was also explored, such as freezing, drying, sautéing, heating, and high-pressure processing [30]. For example, heating and freezing reduced the onion's antioxidant capability, although stir frying them did not. The antioxidant enzyme capability in African catfish and broiler chickens was found to increase with the dietary addition of O.E (onion extract), along with combining OPP (onion peel powder) and pawpaw seeds. Furthermore, it was discovered that the superoxide free radicals and total free radicals were reduced while glutathione and the total A.O. (antioxidant) content were increased in healthy beings for eight weeks upon drinking onion juice (100 mL) [31]. Researchers used the reaction engineering approach to describe a novel method for building a mechanistic model of the drying of an onion into thin layers (REA). To determine the activation energy, specific drying tests were run in a lab dryer. With respect to various product moisture contents, the observed activation energy is experimentally represented by a single polynomial function for all analysed temperatures. The features of energy by drying as indicated by the model are translated by this function. Having successfully fitted statistical parameters, the generated model is subsequently tested by simulating the moisture content profiles against the experimental data. With the use of an on-site solar dryer, this method enables modelling and determination of the interior features of onions for future research [32].

3.2. Anti-Inflammatory Properties

The scale extract of red onion (*A. cepa* Linn.) has been shown to produce immunomodulatory effects on Wistar mice which was practically incited by atypical prostatic hyperplasia [33]. The concentration of total flavonoids in manufactured onion had also been linked to hyaluronidase suppressing capabilities and radical scavenging capabilities. Rutin also exhibited a beneficial impact against ischemia-reperfusion-induced acute gastric mucosal lesions. Similarly, the aqueous extract of Welsh onion green leaves has demonstrated anti-inflammatory effects on mice. UV-B-induced skin inflammation was reduced by onion apigenin [33], in addition to lowering allergy and inflammation. Allium species include typheramide and alfrutamide, which affect COX (cyclooxygenases) and LOX (lipoxygenases) activity. The flavonoid quercetin prevents mice's hypothalamus from alterations in oxidative indicators caused by swimming stress, whereas dimethyl sulfone is indeed a nutritional indicator for onion consumption [34]. Onion inhibits cytokine production of human polymorphonuclear leukocytes with cepaenes and thiosulfates in living beings. It also has anti-inflammatory effects, which are employed to treat arthritis. The peroxide functioning cell-free extract of onion solid scrap showed biotransformation capabilities as well as a possible mechanism for ferulic acid oxidation.

3.3. Prevention of Cardiovascular Disease

Cardiovascular diseases and cancer can be prevented by the bioactive compounds (particularly flavonoids) present in onions, in addition to ceasing heartburn. Cancer suppression is achieved by the generation of bioactive equine IL (interleukin-12) via the expression of p40, p35, and IL-12 single-chain in mammals and baculovirus stimulation systems. Certain onion genotypes with elevated sulphur content were shown to have significant antiplatelet action. Furthermore, dimethyl- and diphenyl-thiosulfate decelerate

thrombocyte generation. Onion extract and onion soup have been proven to have a much more suppressing effect against platelet synthesis [35].

The leaves of onion (*A. cepa*) also exhibited A.O. action and cardioprotective in doxorubicin-induced cardiotoxicity in mice. They aid in the monitoring and control of circulating blood pressure and endothelium functioning in prehypertensive people who are overweight or obese.

Figure 1 shows some actual health benefits of quercetin found in onion peel. The strategy through which quercetin exhibits its cardioprotective impacts is unknown [36].

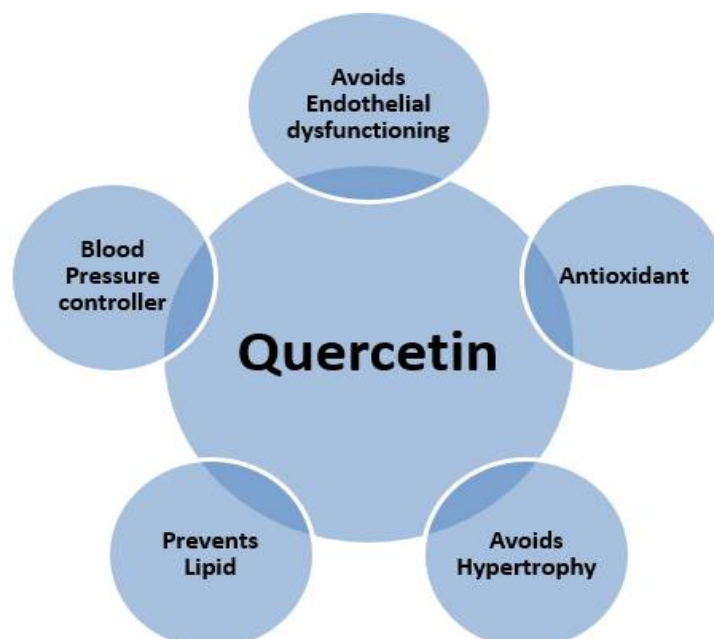


Figure 1. Schematic representation of health benefits of quercetin.

3.4. Antiobesity Properties

The most important strategy to prevent obesity is to promote the browning of white adipose tissue. Numerous clinical trials and animal studies have been shown onions to be helpful in the reduction and control of obesity [37]. Reduction in body weight and inhibition of fat aggregation in 3T3-L1 cells in rats with a diet of elevated fat content was achieved using OPE by decreasing the activation of genes linked to lipogenesis. Insulin resistance and overweightness were improved in high-fat rats with the supplementation of red onion extract and quercetin, in addition to the prevention of body weight gain upon oral ingestion of onion oil. Additionally, the OPE was typically observed to lower body mass, body fat distribution, and percentage body fat in Korean patients who were overweight and obese [38]. A positive change in metabolic disorders such as the reduction in total body fat, percentage of body fat, abdominal fat, and subcutaneous fat, and the decrease in triglyceride and C-peptide levels was achieved with the consumption of steamed onion. In addition to this, consumption of onion powder elevates subcutaneous fat in normal Japanese patients having significant lipoprotein cholesterol concentrations of 40 to 74 mg/dL [39].

3.5. Anticancer Properties

The proliferation of six different tumour cells was achieved by *A. cepa* containing organosulfur compounds. Cell death in human leukemia HL-60 cells or human tumour cell lines is induced by quercetin (3,5,7,3',4'-pentahydroxyflavone) [40]. Additionally, macrophage phagocytosis and the production of cytokines are also stimulated by quercetin. In onions, dihydroquercetin (taxifolin) is a potential prevalent flavonoid which shows stimulation of ARE and detoxifying phase two enzymes. Methanolic, aqueous, and ethanolic OPEs at various levels were shown to decline in intracellular oxidative damage, which

was caused by AAPH (2,2'-azobis (2-methylpropionamide) dihydrochloride) in cell lines of HepG2 (cell lines of liver tumours) owing to permeation of flavonoid and phenolic components (particularly, epicatechin quercetin 4'-glucoside quercetin and morin). They also help in reducing human leukocytes due to the transformation of hydrogen peroxide to water in the presence of phenolic A.O. [32]. The survival capability of human colorectal adenocarcinoma (HT-29) was reduced in a dose-dependent manner with OPE. OPE at a level of 250 mg/mL triggered apoptosis by causing cell damage. According to the lactate dehydrogenase experiments, lipopolysaccharide-induced tumour necrosis factor- α was reduced by 95.9–97.3% after 24 h of preincubation with OPE. Reduction in the activation of glutathione S-transferase detoxifying genes and heme oxygenase-1 (HO-1) such as GSTP1, GSTM1, interleukin (IL), and GSTT1 was observed with onion peel treatment. Quercetin present in OPE possesses A.O., cytotoxic, and anti-inflammatory properties, which help to prevent oxidative cell damage by decreasing the production of reactive oxygen species [41].

Choe and his coworkers (2020) [42] discovered that OPE has anticancer activities against breast cancer. The apoptosis system was defective, and there was unregulated growth in cancerous cells, while as in the case of malignant cells, cell proliferation was prevented by cell division with natural extracts. ROS-induced DNA damage inhibited cellular proliferation. Improved cell death, inhibition of angiogenic process, and cell cycle arrest is seen in the anticancer cellular mechanisms promoted by quercetin which has A.O. properties. *Allium* sp. demonstrated anticancer effects with the presence of DATS, which offers protection against oncogene-driven spontaneous cancer development and chemically-induced neoplasia [43]. Changes in carcinogen metabolizing enzymes, stimulation of cell apoptosis, inhibition of carcinogenic signalling pathways, and prevention of neoangiogenesis are all caused by natural compounds contained in onions. The ethanolic extract of onions is utilized to treat breast tumours. Apigenin is a flavonoid in onion that shows anticancerous effects that inhibit the expression of ultraviolet-B-influenced COX-2 (cyclooxygenase-2), which is a well-recognized promoter of chronic inflammatory diseases. Additionally, it causes the restoration of the level of an upstream modulatory factor in JB6 P+ cells [44]. Different types of cancers and their anticancer mechanisms are shown in Table 4 [45–56].

Table 4. Mechanism of various cancer types supporting the anticancer properties of onion peel.

Cancer Type	Mechanism	Reference
Bone cancer	Declines cyclin D1 activation in U2OSPt and SKOV3 cells	[45]
Bladder cancer	Suppresses cell development and colony creation of human bladder tumour cell lines by inciting DNA damage	[46]
Liver cancer	Induces apoptosis Reduces the activation of PKC, PI3K, ROS, and COX-2 Improves the stimulation of p53 and BAX Activates p53-ROS crosstalk and incites epigenetic alterations	[47–49]
Eye cancer	Minimizes the RPE in a concentration-dependent way, transformation, cell expansion, and secretion of VEGF Restricts the release of VEGF produced by CoCl ₂ -induced hypoxia	[50]
Blood cancer	Stimulates caspase-3, -8, and -9 and increases leukemic cell apoptosis. Minimizes stimulation of the antiapoptotic proteins B-cell, lymphoma (Bcl)-2. Improves stimulation of the proapoptotic proteins Bcl-2-interacting mediators of cell death	[51,52]
Skin cancer	In the hacat cell line, UVB irradiation causes COX2 upregulation and NF κ B stimulation. Decreases the size of tumours as well as the overall number of papillomas. Reduces glutamate oxalate glutamate pyruvate transaminase, alkaline phosphatase, and bilirubin concentration in the blood.	[53,54]
Thyroid cancer	Minimizes the cell development and improves apoptic rate by caspase activation Decreases the concentration of Hsp90. Reduces chymotrypsin-like proteasome activity.	[55,56]

Antimicrobial activity

It has been reported that *Salmonella enterica typhimurium* is inactivated when green onion extract is mixed in ozonated water, in addition to the inhibition of internalized and surface contaminated enteric viruses [57], and also stops the development of Gram-negative bacteria, Gram-positive and in vitro fungi. Chemical sterilizers and UV-C irradiation along with onions were also utilized for the inhibition of internalized *S. typhimurium*. To decontaminate the water from *E. coli* O157:H7, pulsed light, pulse light surfactant sanitizer treatment along with green onions were used. It has been reported that for decontaminating the top layer and penetrating *E. coli* O157:H7 on baby spinach and green onions, a moderate thermal treatment and UV acidified hypochlorite combination has been employed. The combination of clove bud oil and onion powder causes the suppression of *E. coli* O157:H7 on a concentration basis. Several *Allium cepa* white and red varieties have reported strong antioxidant and antimicrobial activities, in addition to the chemotypic variations. Anti-influenza A virus effects have been reported from the fructans present in the Welsh onion *Allium fistulosum* L. [58].

Aspergillus versicolor growth and sterigmatocystin production are inhibited by essential onion oil in addition to its antimicrobial activities [58]. Phenolic compounds and flavonoids present in *Allium flavum* (yellow onion) protect from oxidative stress and antioxidant impact. The flavonoids present in onions demonstrated neuroprotective effects and blood brain-barrier permeation. Antifungal activity has been reported from the saponins (antifungal) present in isolated bulbs [59].

Antibacterial activity has been reported towards four variants: *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus pneumoniae*, and *Staphylococcus pyogenes*, using *Allium cepa* cold water extract and fresh onion extract. In addition to this, antimicrobial actions toward the antibiotic susceptible bacteria such as *Staphylococcus aureus*, *Salmonellatyphi*, *Pseudomonas aeruginosa*, and *Escherichiacoli* has been reported using fresh red and white *Allium cepa* juices. All microbes excluding *Staphylococcus aureus* were sensitive to fresh red and white onion juices, with inhibitory activity varying from 15 to 35 mm in diameter [60].

Asthma

Asthma is an inflammatory condition which is categorized by symptoms such as inflammatory cell infiltration, airway hyper-responsiveness, mucus cell hyperplasia, and transitory bronchoconstriction that can contribute to airway fibrosis as well as an elevation in muscle fibres responsiveness. When allergic asthma patients come into touch with allergens, the T helper forms Th1 and Th2 reactions become unbalanced. Cytokines that are formed by the Th2-type CD4+T cells (interleukin (IL-4, IL-5, IL-13) in asthma play a significant part in coordinating chronic inflammation. The prevalence of asthma has grown exponentially worldwide, and its management has numerous obstacles, including access to care, diagnosis, ability to cope with asthma, healthcare professionals, patient education, healthcare providers, and the availability and accessibility of inhaled medication [58]. Asthma treatment with inhaled steroids and bronchodilators has shown to be effective. However, treating patients with significant asthma who have uncontrolled and frequent exacerbations is still a concern, so asthma motility across all age groups is still a problem. Efforts are made to identify novel alternative medicines justified by health struggles and issues for asthma patients. Herbal medicine has historically been widely utilized in the treatment of asthma. Additionally, inhaled corticosteroids, cromones, methylxanthines, anticholinergics, and sympathomimetics are also utilized in the treatment of asthma. Among the most often utilised herbs employed in the treatment of inflammatory illnesses such as asthma is *Allium cepa* L. The flavonoids contained in *Allium cepa* L. (quercetin) also have a soothing impact on the muscle tissue of isolated trachea but may have a bronchodilator influence [61].

Quercetin against COVID-19

Quercetin is a well-known flavonoid that is available in a broad range of therapeutic plants and nutritional supplements, including oranges, green teas, potatoes, onions, lettuces, and tomatoes. Quercetin is helpful in preventing the activity of coronaviruses which form

Middle East respiratory syndrome (MERS-CoV or **COVID-19**) and severe acute respiratory disorder (SARS-CoV or **COVID-19**). From various investigations, it was proven that the nephroprotective property of quercetin is effective in contradicting oxidative, obstructive, and inflammatory renal damage in a large spectrum of practical models of AKI. The main mechanism by which quercetin prevents renal damage is anti-inflammatory and antioxidant characteristics [62]. It has been found that quercetin possesses antiviral characteristics in both in vitro and in vivo experiments, especially on various members of the Coronaviridae family. The first report regarding its antiviral property was reported in 1990 where it was found that it diminished the pathogenicity of human and bovine coronaviruses such as NCD CV and OC43 by 50% at a level of 60 µg/mL. The in vivo experiment found that the oral treatment of quercetin exhibited a positive result in immuno-competent rats treated with the Mengo virus. Quercetin also established a concentration-dependent antiviral action towards HSV-1 and HSV-2, herpes simplex virus, in bioreactors. Quercetin prevents many respiratory viruses in cultured cells. Luteolin and quercetin have the capability to inhibit the approach of SARS-CoV or **COVID-19** into recipient cells. Quercetin shows great aptitude as a substantial treatment of SARS [63]. Figure 2 explains the process of kidney dysfunction, and Figure 3 explains the components of quercetin positively affecting it.

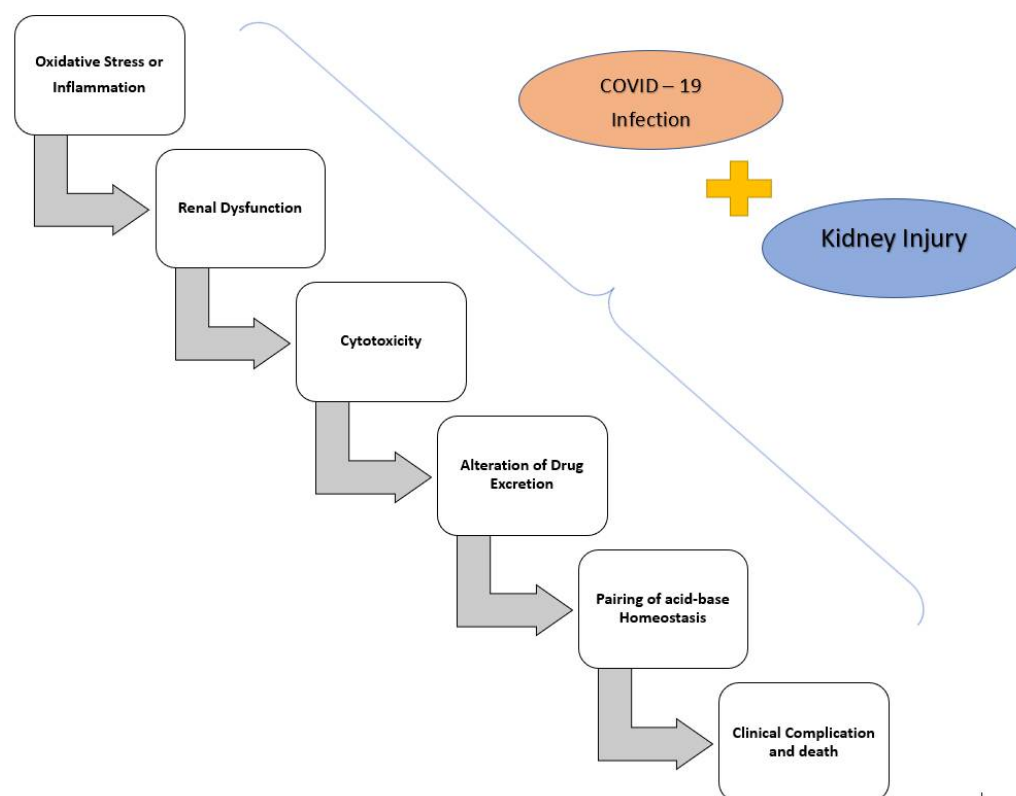


Figure 2. Quercetin as a beneficial health drug against COVID-19-linked with AKI (acute kidney injury).

Natural dietary sources and benefits

Flavonols usually occur in the form of glycosides in numerous food manufacturing industries, tubers, green vegetables, bulbs, several herbs, fruits, and spices, and also in tea and wine. Among all the flavonols, quercetin is the more prevalent molecule, and most of the dietary intake in quercetin comprises quercetin glycosides a type of conjugate wherein quercetin is associated through one or two glucose molecules (quercetin glucosides) or with rutinose (quercetin rutinose). Interestingly, the quercetin volume in food can be considerably impacted through expanding parameters, e.g., tomatoes that are grown organically display more elevated quercetin aglycone content than traditionally cultivated tomatoes [64].

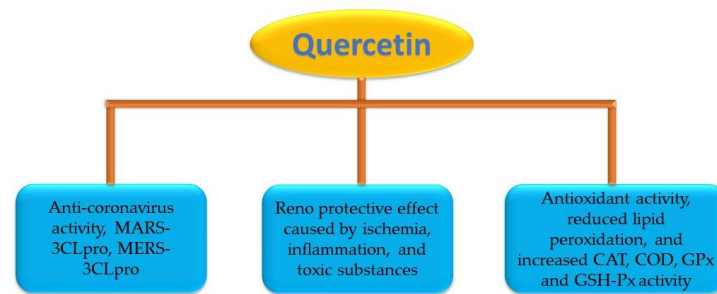


Figure 3. Elements of quercetin affecting kidney health.

Quercetin is used as an ergogenic substance and thus could reduce postexercise oxidative stress and inflammation, increase endurance performance and immune function, and decline the rate of diseases after vigorous exercise in athletes. However, the majority of the suggested benefits for athletes were not able to be confirmed, despite the fact that orally administered quercetin showed some effects in lowering illness rates and improving exercise capacity in athletes, notably in untrained ones. Quercetin is presently being utilized in conjunction with other bioactive constituents in the pursuit of gaining more stimulating effects, which is of specific importance to athletes. Quercetin as an aglycone is currently recommended as a component of nutritional supplements with a variety of benefits. Despite the fact that the EC has not provided approval for certain health claims, such as DNA protection of proteins and fats from oxidative damage for the general population, quercetin is allowed to be used in “Natural Health Products” in Canada, with two various declarations of health impacts: “an antioxidant” and “utilized in Herbal Medicine as a capillary and blood vessel protective agent” [65]. In western countries, regular quercetin consumption is expected to be 3–40 mg (expressed as aglycone equivalents). The usual consumption of quercetin aglycone that is advised is still between 1000 mg and 2000 mg (usually 500 mg). Therefore, it appears that quercetin consumption in the diet is much lower than quercetin intake via dietary supplementation [66]. A diagrammatic representation of the application of quercetin is shown in Figure 4 [64].

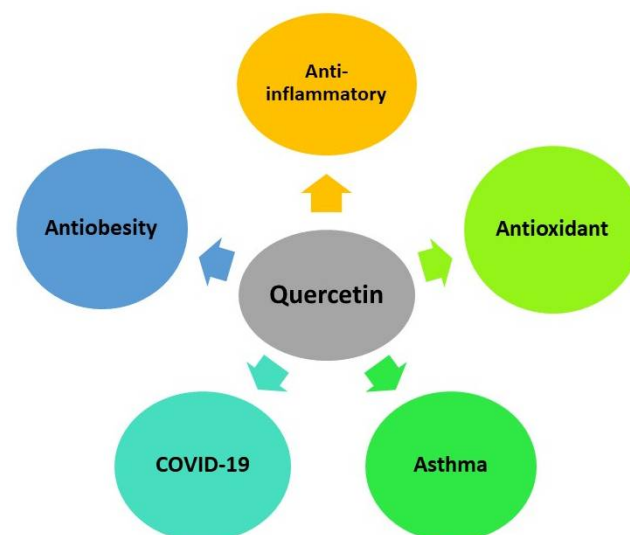


Figure 4. Prominent therapeutic applications of quercetin.

In addition to the above-mentioned dietary benefits, onion peel is considered a valuable lingo-cellulosic natural fibre source and a source of carbohydrates (pectin (42.4%), followed by hemicelluloses (36.6%), and cellulose (21%)). Cellulose microfibrils have been extracted using chlorite and alkaline extraction methods [67]. Because of its promising

properties, cellulose is the most abundant renewable resource in nature, with numerous industrial applications.

Pectin from onion peel can be recovered through hydrolysis (semicontinuous) of onion-peel waste with subcritical water treatment [32,68]. There is a growing demand that requires more sources of pectin, and onion peel is a sustainable source [69]. This is in line with the European Union's circular economy plan "Closing the loop—An EU action plan for the Circular Economy, COM (2015) 614", launched in 2015, aiming to valorise by products through the recovery of bioactive compounds.

4. Conclusions

Even though studies have shown that the onion peel, top, skin, outer layers, and bottom sections contain significant amounts of bioactive chemicals, they are nonetheless thrown away as garbage. The therapeutic benefits of bioactive compounds found in onion peel, for example the sulphur-containing components such as cysteine sulfoxide and the phenolic components such as quercetin glucosides and quercetin, have been extensively studied. These compounds also significantly contribute to a range of health attributes, including antimicrobial, anti-inflammatory, and immunomodulatory properties. Onion peel has the potential to be used as a viable alternative resource in the development of food supplements or functional foods for the treatment and prevention of conditions including nephropathy, obesity, cancer, neurodegenerative disease, diabetes, cardiovascular disease, and respiratory disorders.

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Abbreviations

LDL	Low density lipoprotein
FAs	Fatty acids
SFA	Saturated fatty acid
USFA	Unsaturated fatty acid
TFC	Total flavonoid content
TPC	Total phenolic content
OPP	Onion peel powder
OPE	Onion peel extract
AA	Acrylamide
IONPs	Iron oxide nanoparticles
A.A.	Antioxidant activity
A.O.	Antioxidant
REA	Reaction engineering approach
COX	Cyclooxygenases
LOX	Lipoxygenases
AKI	Acute kidney injury

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