Health Benefits of Quercetin

R. Kumar*, S. Vijayalakshmi, and S. Nadanasabapathi

Food Engineering and Packaging Division, Defence Food Research Laboratory, Mysuru – 570 011, India
*E-mail: kumardfrl@gmail.com

ABSTRACT

Flavonoids are natural antioxidants derived from plant pigments and commonly found in agricultural produce such as fruits, vegetables, and also in beverages like tea and wine. Quercetin is the most important flavonoid which belongs to the class of flavonol. Quercetin is a vital biologically active compound, which is present in many products, such as onion (Allium cepa), black tea (Camellia sinensis), Broccoli (Brassica oleracea var. italica), and also in red wine and green tea. It is widely used in medicine and pharmaceuticals. In particular, it is used for cancer treatment; as it restrains the growth of cancer cells. Earlier some of computational investigations of this molecule were reported in literature, but they were made at low theory level. Quercetin provided many health promoting benefits, like cardiovascular properties, cancer reducing agent, Anti-inflammatory, asthma and many more. That is why the further investigation of this molecule is important. The main important of this review is to understanding of the structure of quercetin and corresponding biological properties of quercetin expressed in vitro studies, absorption is critical, but in vivo studies, better absorbed antioxidant were observed like vitamin C, further reported studies on effect of food processing, health benefits, storage effects, and evaluate its safety and dosage.

Keywords: Quercetin; Flavonoids; Health benefits; Food processing; Safety

1. INTRODUCTION

Flavonoids involve an important group of naturally occurring, bioactive polyphenolics, popular in plants of higher generation. Currently, the interest and awareness on flavonoids have largely focused on two different beneficial aspects. First, for their biological activities, and second for its anti carcinogenic properties. The anti carcinogenic property of flavonoids is most frequently attributed to their anti oxidant activity.

Flavonoids are said to be highly effective as an anti-proliferative agent against lymphoid, colorectal, ovarian, and breast cancer cells. Similarly, they are identified to induce chromatin condensation and apoptosis in some cancer cells. The mechanisms of flavonoid induced cytotoxicity are not yet established, but it is said to influence the sequential occurrence of apoptosis.

Quercetin is a most abundant poly phenolic bioflavonoid or flavonoid, which is generally classified as a flavonol. Quercetin is also classified as water-soluble pigments, which cannot be produced by human. It is also known as a phytoestrogens. Quercetin, comprising 3 rings and 5 hydroxyl groups, has many health beneficial effects, including improvement of cardiovascular health and reducing the risk for cancer.

Quercetin, present in fruits and vegetables, is identified to occur in various forms of glycosides; although its skin is found to posses quercetin aglycone structure and are in higher concentration. It is also naturally present as glycone or carbohydrate conjugates in plants. It is one of the most profusely present dietary flavonoids that are present in apples (Malus domestica); black and green tea (Camellia sinensis) onions (Allium cepa) (predominantly in the outer rings); broccoli (Brassica oleracea).

Quercetin glycosides in the onion extracts were converted to quercetin and sugars by thermo-stable β-glucosidase enzyme. It is found to posses several beneficial biological activities, like antioxidant, anti-inflammatory, anti-cancer, and anti-viral properties. The beneficial effects of quercetin are limited due to its sparingly soluble nature in water, which makes its absorption limited.

2. CHEMISTRY OF QUERCETIN

2.1 Structure

The International Union of Pure and Applied Chemistry (IUPAC) nomenclature for quercetin is 3,3’,4’,5,7-pentahydroxyflavanone (or) 3,3’,4’,5,7-pentahydroxy-2-phenylchromen-4-one with a molecular formula C_{15}H_{10}O_{7}. The presence of five hydroxyl groups, at positions 3, 5, 7, 3’, and 4’ in quercetin molecule as shown in Fig. 1, leads to the formation of and pentamethyl derivatives. It is also commonly termed as quercetine, sophretin, meletin.

Quercetin is acts as a building block for other flavonoids. Quercetin is commonly present as an aglycone in food. On hydrolysis with acid, quercitrin is converted to quercetin and rhamnose as shown in Fig. 2.

2.2 Chemical and Physical Properties of Quercetin

Quercetin with its high molecular weight (302.24),
melting point (316.5 °C) and poor water-solubility makes it a big challenge for being available for biologically. The presence of five hydroxyl groups in the quercetin molecule makes it lipophilic nature. The Table 1 represents the physical properties of quercetin. Quercetin derivatives can be lipophilic or hydrophilic in nature based on the type of substituents in the molecule. In general, O-methyl, C-methyl and prenyl derivatives of quercetin are lipophilic in character. They are synthesised by the glands present on the surface of leaves, flowers and fruits. They can be easily isolated by immersing the plant tissue in acetone.

Table 1. Physical properties of quercetin

<table>
<thead>
<tr>
<th>Boiling point</th>
<th>Sublimes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting point</td>
<td>316.5 °C</td>
</tr>
<tr>
<td>Solubility</td>
<td>Very soluble: Ether, methanol</td>
</tr>
<tr>
<td></td>
<td>(a) Very soluble: Ether, methanol</td>
</tr>
<tr>
<td></td>
<td>(b) Soluble: Ethanol, acetone, pyridine, acetic acid</td>
</tr>
<tr>
<td></td>
<td>(c) Water: 60 mg/mL at 16 °C</td>
</tr>
</tbody>
</table>

2.3 Absorption and Metabolism of Quercetin

Initially it was assumed that quercetin is absorbed in the small intestine following the cleavage of ß-glucoside linkage by colonic micro flora found in humans, but later on it was concluded that its absorption was improved by conjugation with glucose as shown in Fig. 3. It is proposed that quercetin-3-glucoside on reacting with bacterial enzyme results in the formation quercetin, which further reacts with colon and tissues to give 3,4-diOH-phenylacetic acid and isorhamnetin. 3,4-diOH-phenylacetic acid which is produced, further interacts with colon and tissues to give 3-OH-phenylacetic acid and 4-OH-3-methoxy-phenylacetic acid; thereby finally quercetin formed is absorbed from the small intestine to colon.

From various studies it was found that 0.07 per cent to 17.4 per cent of the amount of quercetin consumed was excreted as quercetin or its conjugates. But the quercetin in form glycosides was reported to absorb in the rat stomach. Walgren et al., established from his study with invitro studies of Caco-2 cells, that lack of absorption of the quercetin glucosides, happens primarily due to the effective efflux by the multi-drug resistance protein 2 transporters. In succeeding studies conducted with human subjects, it was observed that the quercetin glucosides were hydrolysed by bacterial enzymes in the small intestine.

In another study, it was reported that the absorption of quercetin and quercetin aglycone ranged from 36 per cent to 53 per cent and 65-81 per cent respectively. It was found that absorption of quercetin in ileostomists, as quercetin glucosides, quercetin rutinoside and quercetin aglycone was 52±5%, 17±15% and 24±9%, respectively.

3. EFFECT OF FOOD PROCESSING OF QUERCETIN

3.1 Thermal Processes on Quercetin

Thermal processes have a great influence on the availability of flavonoid from foods, based on their magnitude and duration of exposure. Various thermal processes like drying, microwaving, heating by an autoclave, roasting, pasteurisation, blanching have been used and their respective impact on the flavanoid was analysed. The Table 2 listed a few studies where the effect of heat treatment on the degradation of quercetin in foods was reported. The authors have reported that...
that quercetin was labile to heat degradation.

Ranilla et al., reported that boiling and soaking of Brazilian beans at 100 °C along with or without draining, induced a loss percentage of 1-90 per cent of quercetin. Thermal pasteurisation of strawberry juices when performed at 90 °C for 60 s was reported to have no effect on detrimental effect on quercetin contents15, whereas it was proved to reduce quercetin content in grapefruit juices16,17. The flavonoids in aqueous solutions have showed to posses different degrees of sensitivity to heat treatment based on their structures. The degradation of flavonoids may also be influenced by other parameters such as pH, phytochemicals and their structure and also by the presence or absence of oxygen18.

3.2 Mechanical Processes on Quercetin

The commonly processes like peeling, trimming, and cutting has been studied for its effect on bioactive compounds in flavonoid-rich foods; which is expected to influence the content, activity and availability of those bioactive compounds19. High proportions of flavonoids are lost during the pre-processing step when undesired parts of the product was removed or cut off. For instance, during peeling and trimming of onions it said to result in 39 per cent of flavonoids to lose20 and great losses were noticed while peeling and dicing of tomatoes21. However, in another study, it was reported that cutting increased flavonol content in fresh-cut potatoes22 and onions23.

3.3 Domestic Processes on Quercetin

Several studies were investigated to find out the effects on flavonoid degradation under simulated home food preparation conditions as shown in Table 3. Common domestic processes methods like boiling, frying, baking, sautéing were performed. Boiling was reported to result in flavonoids losses of 43.9 per cent for asparagus spears and 20.5 per cent for onions, due to leaching of flavanoids into the cooking water24. Similarly, flavanoid losses in onions were reported25-27. Lombard et al., reported that sautéing resulted in a 25 per cent increase in the flavonoid content of onion. But the frying process was reported to decrease about 25-33 per cent of flavonoid content in onion25,27. Conversely, baking was found to increase the amount of quercetin conjugate and total flavonol content (7 per cent) in onions, due to the loss of water and other volatiles during cooking and thereby making these compounds concentrated in the tissues25,26.

### Table 3. Effects of domestic treatment on quercetin content

<table>
<thead>
<tr>
<th>Food product</th>
<th>Processing condition</th>
<th>Impact on flavonoid content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onions</td>
<td>Sautéing (5 min), baking (15 min, 176 °C)</td>
<td>Increase of quercetin conjugates</td>
</tr>
<tr>
<td>Brown skinned onions</td>
<td>Boiling (20 min)</td>
<td>A 14.3% loss of quercetin conjugates</td>
</tr>
<tr>
<td>Red skinned onions</td>
<td>Frying (5 min, 15 min)</td>
<td>23-29% Losses of quercetin conjugates</td>
</tr>
</tbody>
</table>

### Table 4. Effect of storage conditions on quercetin

<table>
<thead>
<tr>
<th>Food product/ flavonoids</th>
<th>Storage conditions</th>
<th>Impact on flavonoids content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh foods pomegranate</td>
<td>Storage (13 days, 1 °C)</td>
<td>No effect on antioxidant activity</td>
</tr>
<tr>
<td>Fresh-cut potatoes (flavonols) onions (quercetin conjugates)</td>
<td>Storage at 4 °C under light Long-term storage in darkness (6 months, 4 °C)</td>
<td>A 100% increase of flavonol content and no effect on quercetin conjugates</td>
</tr>
<tr>
<td>Enriched tea drink</td>
<td>Storage (6 months, 4 °C) Refrigeration in darkness (56 days, 4 °C)</td>
<td>Decrease of quercetin</td>
</tr>
<tr>
<td>Raspberry jams (quercetin 3-glycoside)</td>
<td>Storage (6 months, 20 °C)</td>
<td>40% loss of quercetin3-glycoside</td>
</tr>
</tbody>
</table>

### 4. EFFECT OF STORAGE ON QUERCETIN

The effect of storage conditions on the nutritional quality of food can be a limiting step28. The degradation of flavanoid is influenced by the storage duration, temperature and the presence and intensity of light. The influence of storage temperature and time need to be controlled to reduce the effect on the flavanoid degradation. The quality degradation has been found to vary with state of food (fresh or processed) when evaluated for the effect of storage temperature (0 °C and 20 °C) under dark or light exposure conditions as shown in Table 4.

The lower temperature storage of fresh has been reported to result in minimal effect on the flavanoid degradation. Price et al., reported that nil effect was acquired in onion quercetin conjugate content when stored under dark condition at 4°C temperature for 6 months. Lopez-Rubira et al., reported that the effect on the antioxidant activity was insignificant in the pomegranates stored at 1 °C for 13 days. In contrary to this, Vina and Chaves reported 47 per cent loss in total flavanoid content of pre-cut celery, when stored at 0 °C for 21 days. An increase in the flavanoid content was reported. The potato strips when stored at 4 °C and exposed to light, was reported to have a higher flavanoid accumulation rate22. Wang et al., reported that storage of raspberries 16 °C/24 °C for 4 days induced an increase in it’s the phenolic content.

The quercetin content of strawberry juices was found to decrease progressively on storage at 4 °C in darkness for 56 days15. In another study on raspberry jams, 40 per cent loss of quercetin 3-glycoside was reported when it was stored in dark at 20 °C for a period of 6 months22. Though the studies have proved the effect of storage conditions such as time,
temperature and lighting, on the degradation of the flavanoids, the effect cannot be generalised, as the degree or type of influence varies with the type of product and its nature, and with storage condition.

5. **EFFECT OF LIGHT ON QUERCETIN**

The photodegradation of flavanolid has been investigated earlier\textsuperscript{33-35}. The photodegradative effect on the flavanoids was reported to either increase or decrease, based on the state of the food (fresh or processed foods). The stress signal caused by the light exposure enhances the flavanols in fresh foods\textsuperscript{46} such as fresh-cut potatoes and onions\textsuperscript{22,23}. In a study on the effect of illumination on fresh cut onions, 8 per cent increase in the quercetin was reported. The exposure of the blueberries to UV-C increased the flavonoid content and the antioxidant activity as well. Wang\textsuperscript{31}, et al. reported an increase in the phenolic content of the raspberries when exposed light.

The effect of light, primarily on the photodegradation of phenols was reported to be dependent on various variables like wavelength of light, pH, concentration and its structure, based which positive or negative effects were obtained.

According to Tommasini\textsuperscript{36}, et al. structural rearrangement of 3-hydroxyflavone, occurred rapidly when irradiated at 254 nm than when it was exposed at 350 nm. It was also reported to be highly influenced by the physicochemical properties of the solvent, which played a vital in determination of the occurrence of a photo-oxidation or photo-induced molecular rearrangement.

6. **HEALTH BENEFITS OF QUERCETIN**

The versatile nature of quercetin contributes too many beneficial biological properties such as antioxidant action, canker sores, neurological effect, antiviral activity, anti-inflammatory, asthma, cardiovascular properties and as an anticancer agent.

6.1 **Antioxidant Action**

The antioxidant property of the flavanoids principally neutralises the free radicals by donating hydrogen atoms to it. Pietta\textsuperscript{37}, et al. observed that difficulty aroused on correlating the structure of flavonoids and their accountability for radical-scavenging.

The formation of reactive oxygen species (ROS) has been reported to contribute to the diabetes, atherosclerosis, hypertension, ischemic heart disease and heart failure. Quercetin acts as an antioxidant by preventing oxidative stress, the major cause for generation of ROS. The flavonoids comprising 3-OH and 3', 4'-catechol were known to be ten times more effective towards peroxynitrite than ebselen, a RNS scavenger\textsuperscript{38}.

Quercetin is widely known for its antioxidant property that is for its ability to scavenge free radicals and bind transition metal ions. The ultimate effects on the humans by quercetin for its antioxidant property need to streamline to obtain significant impact on the biomarkers/ indices to be measured. In a study, the consumption of a test meal of fried onions was reported to have significantly increased the plasma quercetin levels. Though an increase in the total antioxidant activity of the plasma was noted, not much difference occurred in the oxidation of the plasma or isolated low density lipoprotein (LDL) over the 48-h period following the consumption of the fried onions. The two weeks supplementation of quercetin in healthy subjects (150 mg/day) was reported to have minimal influence on the plasma, its antioxidant capacity, oxidised LDL, or alpha- or gamma-tocopherols.

6.2 **Neurological Effects**

Quercetin has been proved to be neuroprotective as well as neurotoxic. Joseph\textsuperscript{38}, et al. reported to be neuroprotector in rat brain when used in combination to fish oil, where it beneficial effects against neurodegenerative diseases (e.g. Alzheimer’s disease). Choi\textsuperscript{46}, et al. showed inhibitory effects against acetylcholinesterase. Quercetin was reported to have decreased the 6-hydroxydopamine induced oxidative stress in the neurons of brain striatum of rats\textsuperscript{31}. In another study, it was reported that the quercetin treatment affected the working of the nervous system by depleting the intracellular glutathione contents\textsuperscript{42}. On the other hand, whether the prolonged usage of antioxidant supplements can be considered safe for human health is still a big question.

6.3 **Antiviral Activity**

Quercetin has been reported to be effective against viruses i.e. it posses antiviral activity against enveloped viruses such as herpes simplex type I, parainfluenza type 3, respiratory syncitial, pseudorabies, and Sindbis. It was also proved to be protecting from the cardio virus\textsuperscript{42}. The antiviral activity of quercetin was due to its ability to bind to viral coat protein and polymerases and also to damage DNA. The mutagenic, carcinogenic, and anti carcinogenic activity of quercetin was found to be related to its ability to impose or prevent damage to DNA. It was reported that on stabilisation of Quercetin with ascorbate it enhances its antiviral activity, which was similar to the effect induced by ascorbate enhanced antiproliferative effect on squamous cell carcinoma\textsuperscript{43}. Quercetin was also proved to have enhance the antiviral activity of agents like interferon and 5°ethyl-2'-deoxyuridine.

6.4 **Anticancer Agent**

Quercetin and other flavonoids, derived from fruits and vegetables have been marked important compounds as it was considered to positively help in preventing cancer. Various studies has been performed to evaluate the anti-carcinogenic effect of quercetin on cell cultures, where it was found that slow the growth of cancer cells was effected and it also helped to foster apoptosis. The induction of apoptosis in cancer cells has been proved to be an vital step in the development of novel anticancer drug\textsuperscript{44}. Some animal studies conducted have shown that quercetin helps in the protecting form certain type of cancers, especially colon cancer\textsuperscript{45}.

6.5 **Canker Sores**

Small and shallow lesions known as the canker sores (aphthous ulcers), occur on the soft tissues in mouth or at the base of gums. Sharma\textsuperscript{46}, et al. proved that quercetin reduced the occurrence of mouth sores and also helps to induce mild symptomatic relief.
6.6 Cardiovascular Properties
Heart diseases have been identified to be the primary and leading cause of mortality in the developed countries. Though the exact reason for the cause and the mechanism involved in the occurrence of heart disease still remains a mystery, oxidative stress and inflammation has been identified to play a vital role. Quercetin has been investigated for its possible utilisation as a safe alternative to the antioxidant and anti-inflammatory drugs used for conditions like cardiovascular disease. The studies have revealed that, both preclinical and clinical study, quercetin positively reduced several of the risk factors related with heart disease, including blood pressure and cytokine-induced C-reactive protein (CRP) expression. It has also been identified as a potent vasodilatory agent.

6.7 Anti-inflammatory
The normal biological process in response to injuries, microbial infection or intoxication and chemical irritation was known as inflammation. Inflammation was generally considered to be initiated by the migration of immune cells from blood vessels to the infected/ injured area and discharge of mediators to combat the infection/injury.

Quercetin has been widely known for its anti-inflammatory activity. During a in vivo study conducted by Lin\textsuperscript{44}, \textit{et al.}, when the rats were treated with quercetin mixed with polysorbate 80, it resulted in the inhibition of edema in the paw of the rats. The applications of quercetin glycoside through the skin surface were found to be ineffective against inflammation due to low absorption value. The quercetin pentamethylether formulation was highly absorbed through the skin route in rat, and it was found to be effective against inflammation, thereby proving it to be a potent anti-inflammatory agent.

6.8 Asthma
Asthma is a chronic lung-disease that swells and narrows the airways, thereby causing difficulty in breathing. Quercetin was found to ease the symptoms of asthma. It was found to induce reduction in the inflammatory immune cells number and activation, cuts off the histamine level and also eases the airway smooth muscle. Rigolin\textsuperscript{31}, \textit{et al.} reported that even at the minimum concentration, quercetin was effective against asthma, in comparison to the standard asthma maintenance medications and steroid inhalers that reduces the resistance to air flow.

Quercetin was also reported to reduce pathologies of asthma, such as eosinophil and neutrophil enrollment, bronchial epithelial cell activation, mucus and collagen production and airway hyperactivity. The dietary intake levels of quercetin were reported to influence the asthma symptoms. The clinical studies performed revealed the possible application of quercetin to prevent or treat asthma in human patients.

7. NEGATIVE EFFECTS OF QUERCETIN
Quercetin which was generally considered to be safe was reported to result in few side effects like headache and discomfort of stomach. A preliminary study conducted, suggested that the byproduct of quercetin leads to the loss of protein function. It has also been reported that very high doses of quercetin may harm the kidneys and thereby it was suggested to take intermittent breaks during the consumption of quercetin. It was advised that pregnant and breastfeeding women and people with kidney disorder should avoid quercetin. Consumption of doses greater than 1 g per day, have been reported to have caused damage to the kidneys.

In a four-week rat study performed by Azuma\textsuperscript{48}, \textit{et al.}, an increase in the ratio of weight of liver and kidney to the body weight ratios was observed when fed with more than 314 mg and 157 mg quercetin/kg body weight/day, respectively. The consumption of doses above 157 mg quercetin/kg body weight/day resulted in a pro-oxidant effect.

In human studies, it was seen that the quercetin content has commonly been well tolerated. It was proved that consumption of doses up to 1,000 mg/day for several months have not induced any adverse effects on blood parameters of liver and kidney function, hematology, or serum electrolytes. At present, the principal concern for toxicity was the co-administration of high quercetin doses with digoxin. Though it has been proved to be toxic, until more studies pertaining to the safe dosage level determination, it suggested to avoid consumption of quercetin along with digoxin\textsuperscript{41}.

8. SAFETY AND DOSAGE OF QUERCETIN
Several studies, have shown that the higher doses of quercetin more than 200 μm reduced the cell viability\textsuperscript{99}, but low doses of quercetin (<200 μm) was reported to increase the cell viability and to be fixed as therapeutic dose. It was reported that a low dose of quercetin also resulted in the inhibition of the proliferation of breast cancer cells, mild cytotoxic effect, and also induce mild DNA damage. The fruit and vegetable consumption was reported to contribute to an average of 15 mg to 40 mg of quercetin per day from the diet. It was suggested that an increase in quercetin intake could be accomplished by increasing the consumption of more fruit and vegetables. Therapeutic dosages of quercetin intake were denoted to range from 250 mg to 500 mg three times per day. Quercetin was generally available, in the form of capsules or tablets ranging in doses from 50 mg to 500 mg, as dietary supplements. The dosage of quercetin has been recommended based on the health condition to be treated and no standard dose for quercetin has been suggested. According to Werbach\textsuperscript{50}, \textit{et al.}, for allergic conditions and for chronic hives, a dose of 250 mg - 600 mg per day and 200 mg - 400 mg has been recommended. It was reported that a low dose of quercetin was sufficient to inhibit the proliferation of breast cancer cells, mild cytotoxic effect, and to induce mild DNA damage\textsuperscript{51}.

9. DIETARY SOURCE OF QUERCETIN
Scientists have involved in the process of identification and quantification of quercetin from various food sources. It was reported that on comparing the quercetin content in onion peel with that in its flesh, the highest concentration was found in the peels of onion\textsuperscript{51}. It has been normally found in a variety of foods like onions, apples, berries, tea, tomatoes, grapes, shallots, brassica vegetables, many seeds, nuts, flowers, barks, leaves and also in some medical plants (ginkgo biloba, cranberries and St. John’s wort). The aglycone form
of quercetin was found in much lesser amounts in the diet generally consumed. Hollman, et al. analysed the glycoside and aglycone form of quercetin extracted from plants, and quantified using High-performance Liquid Chromatography (HPLC). The Table 5 represents the list of items and their quercetin content as reported by the United States Department of Agriculture.

Table 5. Quercetin content in foods

<table>
<thead>
<tr>
<th>Food source</th>
<th>Quercetin content (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw onions</td>
<td>13.27</td>
</tr>
<tr>
<td>Black tea</td>
<td>1.99</td>
</tr>
<tr>
<td>Apple, with skin</td>
<td>4.42</td>
</tr>
<tr>
<td>Green tea</td>
<td>2.69</td>
</tr>
<tr>
<td>Broccoli, raw</td>
<td>3.21</td>
</tr>
<tr>
<td>Red wine</td>
<td>0.84</td>
</tr>
<tr>
<td>Spinach, raw</td>
<td>4.86</td>
</tr>
<tr>
<td>Cocoa powder, unsweetened</td>
<td>20.10</td>
</tr>
<tr>
<td>Cranberries, raw</td>
<td>14.00</td>
</tr>
</tbody>
</table>

10. QUANTIFICATION METHODS

Extraction has been the critical and important step in the employment and development of analytical methods for analysis of plant extracts. Table represents the summary of optimised experimental conditions for various extraction protocols. In general, the basic unit operations of extraction involve drying and milling of source to acquire a homogenous powder and also to improve the extraction kinetic of the molecules. Methods such as ultrasonication, heating under reflux, extraction with Soxhlet apparatus were the most used techniques. However, these methods were time consuming and require large volumes of organic solvents like methanol, ethanol with low extraction rates. Molecules of interest can be of polar, non-polar or heat sensitive in nature; thus the selection of extraction method need to be done by considering all of these parameters. The various extraction and experimental methods for the extraction of quercetin has been represented in Table 6.

The Raman spectrum analysis of quercetin in the ethanol solution at a concentration of $1.0 \times 10^{-2}$ mol/L was observed. The bands obtained were at 600 cm$^{-1}$ and 1616 cm$^{-1}$, appeared without interference from the solvent peak. The quantitative measurement and confirmation of quercetin was done using with HPLC and UV-Vis absorption spectrometry. The HPLC analysis of quercetin was performed with a UV detector at 254 nm. The UV-Vis absorption spectra were determined by measuring the absorbance at 374 nm for quercetin molecule.

11. CONCLUSIONS

Quercetin, a flavonoid has been proved to be a powerful antioxidant which can be derived from raw foods such as fruit and vegetables, cocoa, tea, coffee, etc. Quercetin was also known to provide various beneficial properties for human health as a anti-oxidant, anti-inflammatory agent, antiviral activity, cardiovascular properties and anticancer properties. The health benefits of quercetin can be preserved in the processed foods by adapting less intense and non-aggressive processes. However, providing the consumers, antioxidants enriched food products may not be an easy task, despite the several studies conducted on the effect of food processes on the degradation of quercetin and their functional activities, it has been difficult to generalize the results and adapt. Many factors such as:

(i) The type of raw food
(ii) Standardisation of processing and analytical methods
(iii) The influence of the food matrix, affect the quercetin content extraction, analysis and it properties as well.

The usage of quercetin for its anti-oxidative and anti-inflammatory property has been well established. Interestingly, these were the two effects of quercetin which has been widely dealt to combat the oxidative stress and inflammation proving it to be a major source of supplementation for those who have been suffering from this problem.

The major toxicological work related to the quercetin and its by product has been widely studied with the in vitro studies. The formation of toxic compounds from quercetin upon oxidation, during its ROS scavenging activities were likely to occur. The primary oxidation product of quercetin formed was found to be orthoquinone, which has been proved to be toxic. As a result, the supplementation of quercetin during the in vivo studies has to be done with utmost care, considering the possibility of toxic compounds/ metabolite formation, especially in the treatment of chronic ailments.

REFERENCE


Table 6. Experimental conditions for the extraction of quercetin

<table>
<thead>
<tr>
<th>Extraction method</th>
<th>Solvents</th>
<th>Temperature (°C)</th>
<th>Pressure</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonication</td>
<td>CH$_3$OH, C$_2$H$_5$OH</td>
<td>Above room temperature</td>
<td>120 Watt</td>
<td>1 h</td>
</tr>
<tr>
<td>Microwave assisted extraction</td>
<td>CH$_3$OH, C$_2$H$_5$OH</td>
<td>60</td>
<td>15 Watt</td>
<td>2 min</td>
</tr>
<tr>
<td>Shaking-water bath</td>
<td>60% aqueous CH$_3$OH</td>
<td>30</td>
<td>60 min</td>
<td></td>
</tr>
<tr>
<td>Ultrasonication using a ultrasonic liquid processor</td>
<td>60% aqueous CH$_3$OH</td>
<td>Room temperature</td>
<td>10 Watt</td>
<td>30 s</td>
</tr>
<tr>
<td>Accelerated solvent extraction</td>
<td>60% aqueous CH$_3$OH</td>
<td>40</td>
<td>1500 psi</td>
<td>2 min</td>
</tr>
</tbody>
</table>


43. Pietta, P.G. Flavonoids as antioxidants. J. Natural Products, 2000, 63(7), 1035-1042. doi: 10.1021/np9904509

doi: 10.1021/jf9605916


doi: 10.1021/jf900527v

doi: 10.1016/0885-4505(88)90060-6


doi: 10.1016/j.foodres.2010.10.030


doi: 10.1021/jf0712503


doi: 10.1016/S0737-7085(03)00586-7

doi: 10.1021/jf020330y

doi: 10.1039/B608011A


doi: 10.1111/j.1365-2621.2006.01380.x


doi: 10.1016/j.lfs.2003.06.044

doi: 10.1021/jf1040977


doi: 10.1021/jf010192x

doi: 10.1016/j.lwt.2010.12.023

CONTRIBUTORS

Dr R. Kumar, obtained his MSc (Food Science & Nutrition) from Tamil Nadu Agricultural University, Coimbatore and PhD (Food Science) from Bharathiyar University, Coimbatore. Presently working as Scientist ‘F’ in DFRL, Mysuru. He has 65 research papers and 10 patents to his credit. He has received many awards including DRDO Performance Excellence Award and Thomson Edition Award. He has research experience in thermal, non-thermal food processing technologies and food packaging. Contribution in the current study, he did collection of relevant literature, preparation of manuscript and correction.
Ms S. Vijayalakshmi obtained her MSc (Food Science and Technology) from Pondicherry University. Presently she is working as Senior Research Fellow in DFRL, Mysuru. She has published more than 10 research and review papers. Her research interest includes: Reduction of Aflatoxin contamination by the use of pulsed electrical field (PEF) processing and combination processing. Contribution in the current study, she is involved in writing of manuscript.

Dr S. Nadanasabapathi obtained his MSc (Chemistry) from Annamalai University and PhD (Chemistry) from University of Mysuru. Presently working as Scientist ‘G’ and Head, Food Engineering & Packaging in DFRL, Mysuru. He has 95 research papers and 15 patents to his credit. He has received DRDO Performance Excellence Award, Thomson Edition Award, Technology Group Award, and Laboratory Scientist of the Year Award. He has research experience in the: Food packaging, thermal and non thermal food processing technologies. Contribution in the current study, he is involved in final correction and editing of the manuscript.