



Antioxidant Compounds and Health Benefits of Citrus Fruits

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Authors' contributions

This work was carried out in collaboration between both authors. Author OA designed the study, wrote the first draft and obtained the figures and the plates. Author GOA wrote the Abstract, edited and built up the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Citrus fruits are spread worldwide, grown across the globe and are well- appreciated for their refreshing juice and health benefits. This review aimed at investigating the applied health therapeutic uses of some citrus fruits exploited in the treatment of several health challenges as antitumor, anti-inflammatory, anticancer, antiviral, antimicrobial activities against cardiovascular diseases and macular degeneration. Citrus fruits abilities on the exploited benefits are not far from their rich bioactive compounds and phytochemical contents such as minerals, vitamins, flavonoids and carotenoids. These phytochemicals may act as antioxidants, boosting the action of protective enzymes in the liver, reverse lipid for oxidation of genetic material and improve immune system. We reviewed literature for the antioxidant compounds and health benefits of some citrus fruits (namely, oranges, lime, lemon and grapefruits) from electronic database search obtaining information from research studies and reports. We recommend more research into more varieties of citrus predominantly in the tropics.

Keywords: *Bioactive compounds; Citrus fruits; health benefits; phytochemicals; Vitamin C.*

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1. INTRODUCTION

Antioxidants compounds are substances with biological activity and are able to modulate metabolic processes resulting in the promotion of better health conditions. The benefits exhibited by these compounds in addition to their antioxidant activity include inhibition or induction of enzymes, inhibition of receptor activities, and induction and inhibition of gene expression. They are strongly associated with therapeutic properties including antiallergenic, antiatherogenic, anti-inflammatory, antimicrobial, anticarcinogenic, antithrombotic, cardioprotective, and vasodilatory effects. The growing interest for natural antioxidant and antimicrobial compounds has led to research on plants as a source of such bioactive compounds [1,2] These compounds can then be defined as secondary plant metabolites eliciting pharmacological or toxicological effects in humans and animal [3].

Citrus is the largest genus in the family Rutaceae and is the most traded horticultural product in the world [4] Citrus fruits contain an array of potential bioactive compounds in their peels, pulp, seeds and juice [5]. They are also among the most commonly grown and consumed fruits around the world [6]. Citrus fruits have been cultivated in an ever-widening area since ancient times; the best-known examples are the oranges, lemons, grapefruits, and limes. Citrus fruits are among the most accepted and well preferred fruits in the world, not only due to their flavour, but also for their taste and benefits in general health. Citrus is one of the most important commercial fruit crops grown in all continents of the world [7]. Citrus contained nutrients and phytochemicals that are beneficial for health. Citrus fruits and juices contain a wide range of substances including carbohydrates, fibre, vitamin C, potassium, folate, calcium, thiamine, niacin, vitamin B6, vitamin A, phosphorus, magnesium, copper, riboflavin, pantothenic acid and a variety of phytochemicals. These substances are necessary for proper functioning of the body but some confer additional protection against chronic diseases over and basic nutrition Pectin, a water soluble fiber is also present in citrus. Although pectin occurs in a majority of plant cell walls, it is most abundant in citrus (lime, lemon, grapefruit, and orange) fruits [8]. Citrus fruits are the precious resource of phytochemicals which are beneficial for the human body as vital bioactive medicines [9]. Since ancient times citrus has been used not only as food but also in folk

medicine to treat some complaints such as bronchitis, tuberculosis, cough, cold, menstrual disorder, hypertension, anxiety, depression and stress [10] The contribution of Citrus species in deterrence of life threatening diseases have been assessed and it has been reported that citrus fruits exhibit a wide range of promising biological properties due to their phenolic profile and antioxidant properties. In addition to this, it provides an ample supply of vitamins, minerals, dietary fibers, essential oils and carotenoids content which makes citrus a health-benefit promoting fruit [11].

It has been reported that there is dearth of knowledge about the nutrient content, bioavailability and potential health benefits of citrus varieties grown in tropical areas [4], of which Nigeria is one. This work aimed to review the antioxidant compounds and health benefits of citrus fruits.

2. CITRUS FRUITS: BIOACTIVE COMPOUNDS AND HEALTH BENEFITS

Citrus fruits contain a number of secondary metabolites, such as flavonoids, alkaloids, coumarins, limonoids, carotenoids, phenol acids, essential oils amongst several others. These active secondary metabolites show several biological activities of importance to human health, including anti-oxidative, anti inflammatory, anti-cancer, as well as cardiovascular protective effects, neuroprotective effects, etc. In addition, *Citrus* fruits have been used as traditional medicinal herbs in several Asian countries, such as China, Japan and Korea [12]. The different cultivated species of citrus are a valuable source of nutrients and bioactive compounds, such as vitamins B and C, carotenoids, flavonoids and their glycosides, essential oils, coumarins, phenylpropanoids, limonoids, minerals, fiber and high water contents that have effects positive for human health [13].

2.1 Flavonoids

Flavonoids (the term is derived from the Latin word "flavus," meaning yellow) are phenolic substances which exhibit biological activities including antiallergenic, antiviral, anti-inflammatory, and vasodilation actions [14]. Flavonoids are mostly found in fruits, vegetables, and certain beverages that have versatile beneficial antioxidant effects. Flavonoids have aroused particular interest recently because of their potential beneficial effect on human health

reported to have antiviral, anti-allergic, antiplatelet, anti-inflammatory, antitumor, antioxidant, and treatment of neurodegenerative disorders. Flavonoids are categorized into six classes according to the chemical structure into flavanols, flavones, flavanones, flavanols, isoflavones, and anthocyanidins [15]. Flavonoids have been ascribed positive effects on human and animal health and the current interest is for disease therapy and chemoprevention. They have been found to carry out a number of protective functions in the human body. Many flavonoids have evolved as bioactive compounds that interfere with nucleic acid or proteins and show antimicrobial or insecticidal and pharmacological properties. Flavonoids are therefore of interest in medicine as therapeutics and at the same instance in agriculture as pesticides [16]. Several experiments have shown a wide range of biochemical activities of flavonoids; however their ability to act as antioxidants is the best-described resource. It is well known that the antioxidant activity of flavonoids depends on the atomic structure arrangement of functional groups [17]. Flavonoids can prevent cell injury through the direct scavenging of free radicals and hence prevent their deleterious effects [18].

2.2 Alkaloids

Alkaloids are naturally occurring compounds containing carbon, hydrogen, nitrogen, and usually oxygen and are primarily found in plants, especially in certain flowering plants [20]. Alkaloids are secondary plant metabolites that have been shown to possess potent pharmacological activities. They are the most biologically active compounds found in natural herbs and the source of some important drugs currently marketed; these include some anticancer agents [21].

Alkaloids have influential and multiple actions. They possess a variety of pharmacological potentials in modern medicine and the effects includes analgesic (e.g., morphine), anti-hyperglycemic (e.g., piperine), anticancer (e.g., berberine), antiarrhythmic (e.g., quinidine), antibacterial (e.g., ciprofloxacin). Some other alkaloids exhibit stimulant effects to central nervous system (e.g., cocaine, caffeine, and nicotine) as well as psychotropic effects (e.g., psilocin). Although alkaloids have an extensive history and numerous applications but only a few are promoted as active medicine exert numerous neuro-protective activities in numerous diseases

such as epilepsy, psychological disorders, cerebral ischemia, dementia and memory impairment, depression, anxiety, many others [20]. Some alkaloids are used as antiseptics due to their antibiotic activity e.g. berberine in ophthalmics and sanguinarine in toothpastes [22].

2.3 Coumarins

Coumarin is a natural product with aromatic and fragrant characteristics, widespread in the entire plant kingdom. It is found in different plant sources such as vegetables, spices, fruits, and medicinal plants including all parts of the plants—fruits, roots, stem and leaves [23]. Among the polyphenolic compounds in citrus, coumarins have attracted attention. In plants, coumarins display important allelochemical functions such as defense against pathogens. Many studies have also focused on their beneficial effect on human health. For example, antitumor activities have been reported for prenylated coumarin [13].

2.4 Limonoids

Limonoids are heavily oxygenated, modified triterpenes dominant in citrus fruits. The term 'limonoid' is derived from limonin, which was first identified as the bitter constituent of *Citrus* seeds in 1841. This group of secondary metabolites exhibits a wide range of biological properties, including anticancer, antibacterial, antifungal, antimalarial, and antiviral activities [25]. Limonoids have the potential to inhibit colon cancer, ovarian cancer, and neuroblastoma and inhibit the growth of estrogen receptor-negative and positive human breast cancer cells [26].

2.5 Carotenoids

Carotenoids – also known as carotenes – belong to the group of lipid-soluble hydrocarbons; and their oxygenated derivatives are called xanthophylls. The name 'carotenes' is derived from the red colour of carrots; but they are commonly distributed in various other plants also as they are found in green leaves, in most yellow and red fruits, and many roots. The colour of egg-yolk and some fish is also due to carotenoids [3]. Citrus contains many carotenoids. The most abundant carotenoids in the human diet, lutein, zeaxanthin, lycopene, and the pro-vitamin A carotenoids, α - and β -carotene and β -cryptoxanthin, are found in fruits and vegetables. They are antioxidants, have positive

effects on the immune system, promote bone formation and health, stimulate gap junction communication between cells, promote eye health, and lower the risk of cancer. Much data support beneficial health effects of ingesting carotenoids; however, the only well-established health benefit of carotenoids in humans is the ability of several to form vitamin A [4]. The relationship between β -carotene and lung cancer has been most studied and the data have been more consistent. Animals are unable to synthesise carotenoids de novo, and rely upon the diet as a source of these compounds [28].

2.6 Phenol Acids

Phenolic acids are secondary metabolites, which are abundantly present in citrus fruits after ascorbic acids [29]. The term "phenolic acids", in general, designate phenols that possess one carboxylic acid functional group. These compounds have been studied mainly for their properties against oxidative damage leading to various degenerative diseases, such as cardiovascular diseases, inflammation and cancer. Indeed, tumour cells, including leukaemia cells, typically have higher levels of reactive oxygen species (ROS) than normal cells so that they are particularly sensitive to oxidative stress [30]. Phenolic acids can be classified into two groups based on their structure: benzoic acid derivatives and cinnamic acid derivatives. They comprise of a benzene ring attached to a carboxylic group (benzoic acids) or a propenoic acid (cinnamic acids) [31]. Phenolic acids have a crucial role in diabetes. They influence the function of glucose and insulin receptors. Among all the properties shown by phenolic acids, the best is the inhibition of α -glucosidase and α -amylase (two key enzymes) accountable for the conversion of dietary carbohydrates into glucose. They exhibit antimicrobial activity and also work as food preservatives [32].

Plant and its preparations are the major source of phenolic acids in human diet. The intake of plant/plant material containing high amount of phenolic acids as well as flavonoids enhance resistance due to activation of immune-stimulation and scavenging the SO_x radicals the body [29].

2.7 Essential Oils

Essential oils were composed of many valuable natural products that may be described as

mixtures of hydrocarbons, oxygenated compounds and non-volatile residues. They include terpenes, sesquiterpenes, aldehydes, alcohols, esters and sterols [33]. Species of the genus *Citrus* have been highlighted because they are rich in essential oils which are very versatile and often used as flavorings in several goods, such as beverages, soaps, cosmetics and household products. The essential oils have also been frequently used in medical treatments due to their antimicrobial, antifungal, antibacterial and antiparasitic properties [34]. Essential-oil-based products or natural aroma chemicals are in higher demand in the cosmetic, food, perfume, and pharmaceutical industries [35].

2.8 Vitamins C and Other Nutrients in Citrus

The positive health benefits of Citrus fruits have been ascribed in part to the presence of vitamin C (ascorbic acid) in abundance [36]. Citrus is an excellent source of vitamin C. Most persons can achieve 100% of the Recommended Daily Allowance (RDA) for vitamin C by consuming moderate amounts of citrus fruits. Vitamin C is a water-soluble essential nutrient which acts as an antioxidant, is involved in iron metabolism, the biosynthesis of carnitine, neurotransmitters and in the cross-linking of these fibers in bone, and is a cofactor in various enzymatic and hormonal processes. Vitamin C is also involved in the immune system by stimulating white blood cell function. Vitamin C can help reduce the risk of pre-eclampsia during pregnancy, and in some studies vitamin C has been shown to lessen the severity and duration of cold symptoms [4]. Vitamin C plays a key role in the absorption of inorganic iron; which can aid in the treatment of anaemia provided that adequate medicines are also administered. This vitamin is also important in the formation of collagen. A deficiency of this vitamin is responsible for the weakness of those tissues in which collagen is an essential element (ligaments, tendons, dentin, skin, blood vessels and bones).

Besides Vitamin C, Citrus fruits are abundant in other macronutrients, including sugars, dietary fiber, potassium, folate, calcium, thiamin, niacin, vitamin B6, phosphorus, magnesium, copper, riboflavin and pantothenic acid [37]. Citrus contains no fat, sodium or cholesterol. The average energy value of citrus is very low which can be important for consumers concerned about obesity [4].

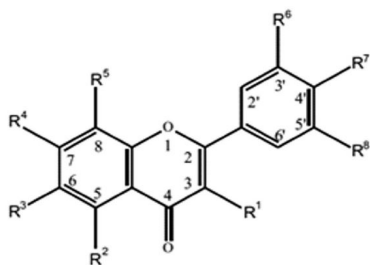


Fig. 1. General Structure of flavonoids [19]

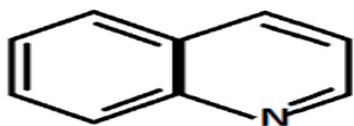


Fig. 2. General structure of Alkaloids
<https://www.eptesnatura.com/product-category/phyto-alkaloids/>

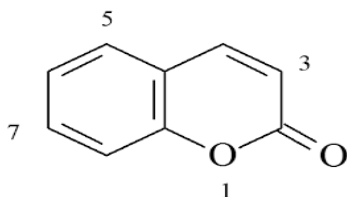


Fig. 3. Molecular structure of coumarin (2H-chromen-2-one) [24]

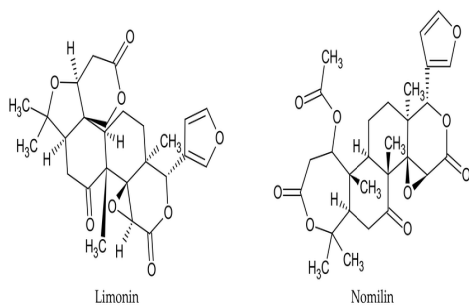


Fig. 4. Chemical structure of limonoids, characteristic of *Citrus limon* [27]

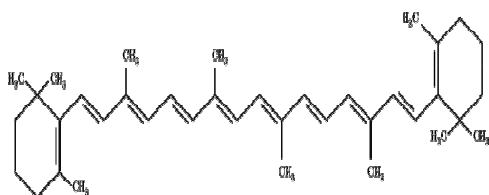


Fig. 5. β -Carotene [28]

3. CITRUS FRUITS UNDER REVIEW

3.1 Sweet Oranges

Oranges has antioxidant capacity both in the juice and its byproducts, such as the albedo (mesocarp), which can be consumed fresh associated with the pulp (endocarp) or used in the preparation of products with functional properties for human consumption. The antioxidant substances present in the albedo can inhibit reactive free radicals and, consequently, protect other molecules against oxidation, generating health-promoting effects in the prevention of degenerative diseases, including cancer. The orange (*Citrus sinensis*) belongs is one of the most cultivated fruit trees. Its fruits are among the most commercialized and consumed worldwide [38].

3.2 Lime

The traditional uses of *Citrus aurantifolia* from several literature reviewed are described as antibacterial, antidiabetic, antifungi, antihypertensive, antiinflammation, antilipidemia, antioxidant, antiparasitic and antiplatelet activities. It is used for the treatment of cardiovascular, hepatic, osteoporosis and urolithiasis diseases and acts as a fertility promoter [39]. Lime (*C. aurantifolia*) juice has been shown to effectively serve as hypolipidemic, it possess the ability to interact with orthodox medicines [40].

3.3 Lemon

Lemon is among the most important crops in the world. Lemon is very rich in important natural compounds, including citric acid, ascorbic acid, minerals, flavonoids, and essential oils [41]. Pharmacological profile of lemon includes the prevention of kidney stones, soothing of sore throat, aiding weight loss, suppression of itches (anti-inflammatory and anesthetic effects), anticancer properties, pH balance and management of fever. Lemon has been used against rheumatism, arthritis and bone related diseases, asthma, nausea and the treatment of bone infections among others [42]. *Citrus limon* also contains other important natural nutritional components, such as phenolic compounds, dietary fiber, and carotenoids. There is now increasing evidence to show that lemon fruit have strong antioxidant, antimicrobial and anti-inflammatory properties, and intake of lemon is

associated with a decrease risk of cardiovascular diseases and certain forms of cancer. Therefore, lemon fruits are becoming popular health-promoting fruits [43].

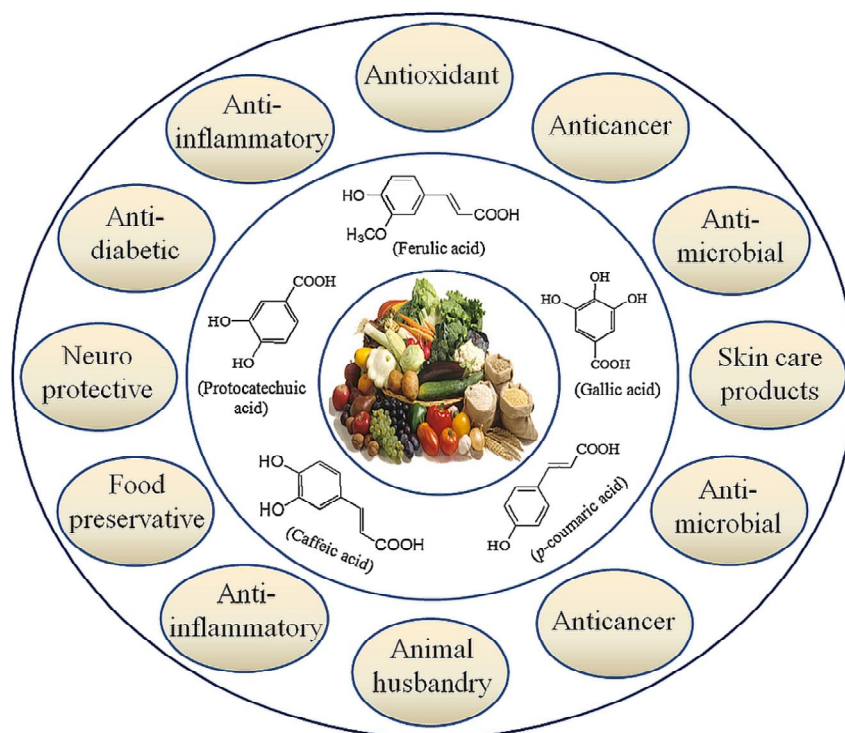


Fig. 6. Schematic representation of different applications of phenolic acids [32]

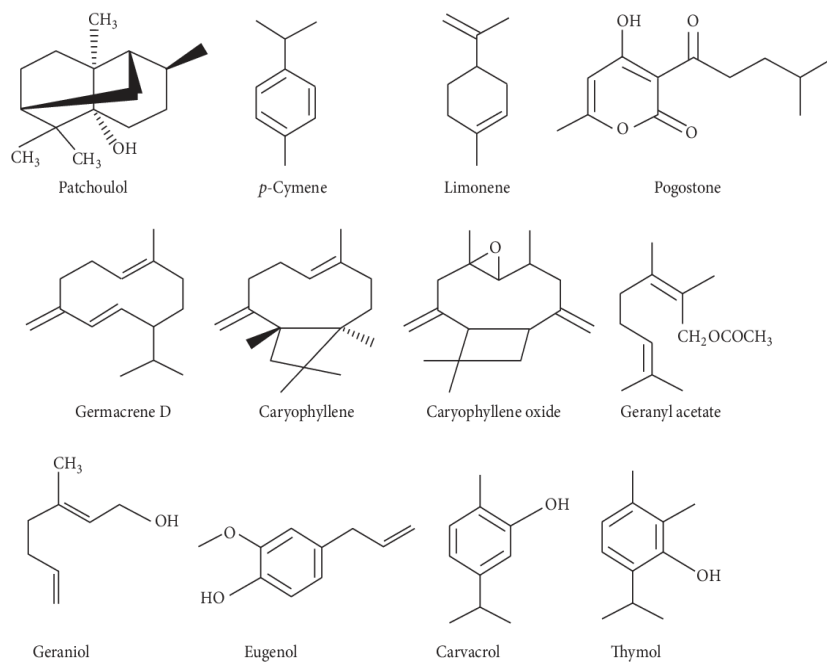


Fig. 7. Structures of some important chemical compounds of essential oils [35]

A great deal of attention has been paid to the antibacterial activities of *C. limon* juice as a potential and promising source of pharmaceutical agents [36].

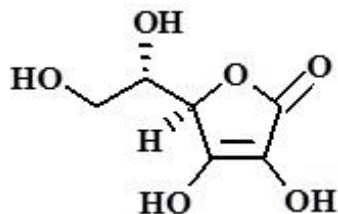


Fig. 8. Chemical structure of vitamin C [31]

3.4 Grapefruits

Grapefruit (*Citrus paradisi* Macfadyen) is a group of large citrus of recent origin, likely resulting from a cross between pummelo and sweet orange. Grapefruit is an excellent source of many nutrients and phytochemicals that contribute to a healthy diet, mainly including polyphenols, vitamin C, lycopene, pectin and fibre. Currently, there is much evidence that grapefruit have strong antioxidant, anti-microbial and anti-inflammatory properties. Therefore, grapefruit is becoming an increasingly popular health-promoting fruit [44].



Plate1.

<https://steemit.com/farms/@iboiosi/land-preparation-and-cultural-practices-of-orange-citrus-sinensis>



Plate 2. <https://depositphotos.com/stock-photos/lime-green.html>



Plate 3.

<https://dutable.com/2019/03/14/nutritional-and-health-benefits-of-lemon>



Plate 4. <https://guardian.ng/news/health-benefits-of-grapefruit>

4. CONCLUSION AND RECOMMENDATIONS

In conclusion, it is important to incorporate citrus fruits into our daily diets as it is rich in antioxidants, supplies energy and nutrients to our body for combating diseases [45]. Citrus fruits are rich sources of vital phytochemicals with biological activities to prevent diseases.

We recommend more research on citrus varieties that predominant in the tropics and encourage promotion of the nutritional and health benefits of citrus consumption.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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