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Review

Antioxidant activity of *Citrus* fruits

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ABSTRACT

Citrus is well-known for its nutrition and health-promotion values. This reputation is derived from the studies on the biological functions of phytochemicals in *Citrus* fruits and their derived products in the past decades. In recent years, the antioxidant activity of *Citrus* fruits and their roles in the prevention and treatment of various human chronic and degenerative diseases have attracted more and more attention. *Citrus* fruits are suggested to be a good source of dietary antioxidants. To have a better understanding of the mechanism underlying the antioxidant activity of *Citrus* fruits, we reviewed a study on the antioxidant activity of the phytochemicals in *Citrus* fruits, introduced methods for antioxidant activity evaluation, discussed the factors which influence the antioxidant activity of *Citrus* fruits, and summarized the underlying mechanism of action. Some suggestions for future study were also presented.

Contents

Abbreviations: ABTS, 2,2′-azino-bis(3-ethylbenzthiazoline-6-sulfpnic acid); APX, ascorbate peroxidase; As, arsenic; AuNPs, gold nanoparticles; B, boron; Ca, calcium; CAA, cellular antioxidant activity; CAT, catalase; CL, chemiluminescence; Co, cobalt; CO_3^{2-}, carbonate; COX, cyclooxygenase; CP, *Citrus* peels; CPT, carnitine palmitoyl transferase; Cr, chromium; Cu, copper; Cu^{2+}, copper ions; CUPRAC, cupric ion-reducing antioxidant capacity; db, dried base; DNAG, deacetylation millington acid 17-β-D-glucoside; DPPH, 1,1-diphenyl-2-pierylhydrazy; DW, dry weight; Fe, iron; Fe^{2+}, ferrous ions; FRAP, ferric reducing-antioxidant power; Ge, germanium; GGT, γ-glutamyltranspeptidase activity; GPx, glutathione peroxidase; G6PD, glucose-6-phosphate dehydrogenase; GR, glutathione reductase; GSH, reduced glutathione; GSHPx, glutathione peroxidase; GSt, glutathione-S-transferase; HO-1, heme oxigenase-1; H_2O_2, hydrogen peroxide; HPLC, high performance liquid chromatography; HPLC-FRSD, high performance liquid chromatography-free radical scavenging detection; HOCl, hypochlorus acid; K, potassium; LDL, oxidation of low density lipoprotein; LG, limonin 17-β-D-glucoside; LOX, lipoxygenase; LPO, lipid peroxidation; MDA, malondialdehyde; Mg, magnesium; Mn, manganese; Mo, molybdenum; MPO, myeloperoxidase; MPR, myoglobin protective ratio; Na, sodium; NAG, millington acid 17-β-D-glucoside; NF-κB, nuclear factor kappa B; Ni, nickel; NO, nitric oxide; NOS, nitric oxide synthase; NOX, NADPH oxidase; NPs, nanoparticles; NQO, NADPH-quinone oxidase; Nrf-2, nuclear factor E2-related protein 2; O^{2-}, superoxide anion; $^1O_2$, singlet oxygen; OH, hydroxyl radical; OG, obacunone 17-β-D-glucoside body; $ONOO^-$, eroxynitrite; ORAC, oxygen radical absorbance capacity; PAL, phenylalanine ammonia lyase; P, phosphorus; PCL, photochemiluminescence; POD, peroxidase; PON, paraoxonase; PPO, polyphenoloxidase; RNS, reactive nitrogen species; ROO, peroxyl radical; ROS, reactive oxygen species; S, sulfur; Se, selenium; Si, silicon; SNPAC, silver nanoparticle antioxidant capacity; SOD, superoxide dismutase; SOD_2, mitochondrial superoxide dismutase; TAC, total antioxidant capacity; TEAC, Trolox equivalent antioxidant capacity; TRAP, total radical-trapping antioxidant parameter; XO, xanthine oxidase; Zn, zinc.

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1. Introduction

Citrus, the genus *Citrus* L. of the family Rutaceae, is one of the most important fruit crops in the world. It is widely grown in the tropical and subtropical areas of the world, and many other areas, with an annual production of approximately 102 million tons (Mehl et al., 2014). *Citrus* fruits are well-accepted by consumers of all over the world because of their attractive colours, pleasant flavors and aroma. Along with an increase of production, advances in storage and processing techniques, and the realization of a year-round supply, *Citrus* fruits have now become an important dietary source of nutrients for Chinese people.

Antioxidant activity denotes the ability of a bioactive compound to maintain cell structure and function by effectively clearing free radicals, inhibiting lipid peroxidation reactions, and preventing other oxidative damage (Bravo, 1998). It is also a foundation of many other biological functions, such as anti-cancers, anti-inflammation and anti-aging (Cai, Luo, Sun, & Corke, 2004; Ke, Pan, Xu, Nie, & Zhou, 2015). More importantly, the prevention of many chronic diseases, such as cancer, diabetes and cardiovascular disease, has been suggested to be associated with the antioxidant activity (Rajendran et al., 2014; Yu et al., 2005). Therefore, a deep study of natural antioxidants, such as those from fruits and vegetables, is of great importance to human health.

Citrus fruits are rich sources of useful phytochemicals, such as vitamins A, C and E, mineral elements, flavonoids, coumarins, limonoids, carotenoids, pectins, and other compounds (Zhou, 2012). These phytochemicals, consumed through fresh fruits or their derived products, have been suggested to have a wide variety of biological functions including antioxidant, antiinflammation, antimutagenicity, anticarcinogenicity and anti-aging to human health (Ke et al., 2015; Rajendran et al., 2014; Zhang et al., 2015).

To provide a comprehensive view of current studies on the antioxidant activity of *Citrus* fruits, the antioxidant components and their antioxidant activities, evaluation methods, and the internal and external factors that influence the antioxidant capacity of *Citrus* fruits were systematically reviewed. Most importantly, the mechanisms of antioxidant action of *Citrus* fruits were summarized for the first time.

2. The antioxidant components of *Citrus* fruits and their antioxidant activities

2.1. Vitamins in Citrus fruits and their antioxidant activities

There are more than 170 antioxidants from *Citrus* fruits that have been reported in the current literature, including vitamins, mineral elements, phenolic compounds, terpenoids and pectin (Zhou, 2012). Table 1 summarizes their representative types, chemical structures and antioxidant properties.

Vitamins are organic substances vital for body function and indispensable to our life. Among the 13 vitamins reported in literature, six of them are found in *Citrus* fruits, including vitamin A, vitamin B1, vitamin B2, vitamin C, vitamin E and vitamin B3 (Zhou, 2012). Of these vitamins, vitamin A, vitamin C and vitamin E were evaluated for their antioxidant activities (Amitava & Kimberly, 2014).

Vitamin A is a class of fat-soluble organic compounds, which includes retinol, retinal, retinoic acid, and several provitamin A (β-carotene) (Amitava & Kimberly, 2014). *Citrus* fruits are rich in carotenes and cryptoxanthin. The content of vitamin A in candied orange (*Citrus sinensis* Osbeck) is 0.27 mg/kg, and 2.77 mg/kg in tangerine (*Citrus reticulata* Blanco.) (Zhou, 2012). According to the reports, vitamin A can react with free radicals (especially singlet oxygen ($^1O_2$)) and peroxyl radicals to show its antioxidant property (Table 1).

Vitamin C, L-ascorbic acid or simply ascorbate, is a water-solubility substance. It is a major vitamin found in *Citrus* and rich in the flesh and peel of fruits. The content of vitamin C in the extraction of satsuma mandarin (*Citrus unshiu* Marc.), pomelo (*Citrus maxima* (Burm Merr.), navel orange (*C. sinensis* Osbeck), and tangerine (*C. reticulata* Blanco.) reached 30–40 mg/100 g, 60 mg/100 g, and 30 mg/100 g, respectively (Ye, 2005). Vitamin C is a natural free radical scavenger, which can effectively scavenge a variety species of reactive oxygen species (ROS) and give off semi dehydroascorbic acid, clearing $^1O_2$ and reducing sulfur radicals (Table 1, Amitava & Kimberly, 2014).

Vitamin E, another fat-soluble vitamin, is a group of compounds that include both tocopherols and tocotrienols. Vitamin E is mainly