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Review

Application of microencapsulation for the safe delivery of green tea polyphenols in food systems: Review and recent advances

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ABSTRACT

Green tea has been associated with the prevention and reduction of a wide range of severe health conditions such as cancer, immune, and cardiovascular diseases. The health benefits associated with green tea consumption have been predominantly attributed to green tea polyphenols. The functional properties of green tea polyphenols are mainly anti-oxidative, antimutagenic, anticarcinogenic, anti-microbial, etc. These excellent properties have recently gained considerable attention in the food industry. However, their application is limited by their sensitivity to factors like temperature, light, pH, oxygen, etc. More, studies have reported the occurrence of unpleasant taste and color transfer during food processing. Lastly, the production of functional food requires to maintain the stability, bioactivity, and bioavailability of the active compounds. To tackle these obstacles, technological approaches like microencapsulation have been developed and applied for the formulation of green tea-enriched food products. The present review discusses the novelty in microencapsulation techniques for the safe delivery of green tea polyphenols in food matrices. After a literature on the green tea polyphenols composition, and their health attributes, the encapsulation methods and the coating materials are presented. The application of green tea encapsulates in food matrices as well as their effect on food functional and sensory properties are also discussed.

1. Introduction

Green tea obtained from the leaves of the tea plant (*Camelia sinensis*) is considered to possess the highest antioxidant capacity among other types of tea due to the fact that it is consumed fresh without prior withering and oxidative process. Green tea consumption takes its origin in Asia and India where it has been longtime used as a remedy to various deceases. More recently, it has gained a lot of interest due to researches revealing the positive effects of green tea polyphenols consumption on health (Chen & Chan, 1996). Earlier studies have announced that the main components responsible for the health properties attributed to green tea are polyphenols (Graham, 1992). Polyphenols are classified into flavanols, flavandiols, flavonoids, and phenolic acids which may account for up to 30% of the dry weight. Most of the green tea polyphenols are flavonols, namely catechins.

Polyphenols present in green tea have been subjected to numerous studies and it has been revealed that they possess many heath promoting properties (Table 1). The most known property of green tea polyphenols is their anti-oxidant activity, but they are also credited with anti-diabetic, anti-carcinogenic, anti-fungal, anti-viral, anti-obesity and anti-inflammatory properties (Basu & Lucas, 2007; Khan & Mukhtar, 2007). The positive effects of green tea polyphenols can highly benefit the food industry by improving the nutritional values of food formulations. The supplementation of food products with natural bioactive components is gaining a lot of interest and green tea polyphenols are among the most promising bioactive compounds. Unfortunately, it has been brought to light that the use of polyphenols in food products is limited by their sensitivity to diverse factors, in particular temperature, pH, oxygen, exposure to light, enzymes, etc. (Lu, Li, & Jiang, 2011). The bitterness and astringency exhibited by green tea polyphenols catechins also represents a major drawback for their incorporation into food product (Giroux et al., 2013). More, the

Abbreviations: GTE, green tea extract; EGCG, (-)-epigallocatechin gallate; ECG, (-)-epicatechin gallate; LDL-C, low density lipoprotein cholesterol; PTPase, protein tyrosine phosphatase; GTP, green tea polyphenols; MD, maltodextrin; GA, gum arabic; CTS, chitosan; DPD, *N,N,*-diethyl-*p*-phenylenediamine; SLNs, solid lipid nanoparticles; GTESLNs, green tea extract Solid lipid nanoparticles; GTPE, green tea polyphenols extract; TPC, total polyphenols content; FRAP, ferric reducing antioxidant power; ORAC, oxygen radical absorbance capacity; AA, acid ascorbic

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Table 1
Green tea polyphenols biological properties.

Compound tested	Biological properties	Actions/organ/species	References
Green tea catechins	Antioxidant activity	Stabilization of seal blubber and menhaden oils; PV, conjugated dienes	(Wanasundara & Shahidi, 1998)
ECG, EC, C	Antioxidant activity	Antiradical activity against alkyl peroxyl radical	Nakao, Takio, and Ono (1998)
Green tea extracts	Antioxidant activity	Degradation and oxidation products of stigmasterol in TAG of sunflower oil	Rudzińska, Korczak, Gramza, Wsowicz, and Dutta (2004)
Green tea polyphenols (500 mg/kg/day)	Anticarcinogenic	Pancreas;N-nitroso-bis-(2-oxopropyl)amine (BOP); Syrian golden hamsters	Harada, Takabayashi, Oguni, and Hara (1991)
EGCG (oral application)	Anticarcinogenic	Spontaneous skin tumor; mice	Paul, Hayes, Kim, Athar, and Gilmour (2005)
Green tea catechins	Antimicrobial	EGC, ECG, EGCG inhibited the growth of *Staphylococcus aureus* and Vibrio cholerae.	Toda, Okubo, Ikigai, and Shimamura (1990)
EGCG	Antimicrobial	EGCG enhanced the in vitro resistance of alveolar macrophages to Legionella pneumophila infection by selective immunomodulatory effects on cytokine formation.	Yamamoto, Matsunaga, and Friedman (2004)
Green tea catechins	Antimicrobial	Weak inhibition of Helicobacter pylori growth.	Shin, Kim, Bae, Hyun, and Kim (2005)

formulation of green tea-enriched products requires to maintain the stability of EGCG and other green tea catechins (Bazinet, Farias, Doyen, Trudel, & Têtu, 2010). In addition, the bioavailability of the active ingredients in the food product represents a challenge as only a small proportion of the molecules remain available after consumption, affected by the detrimental conditions of the gastro-intestinal tract (low gastric pH, low permeability, enzymes, etc.). Therefore, to assure the effectiveness of food products formulated with green tea polyphenols, it is mandatory to apply mechanisms which can protect and preserve the bioactive compounds during process and upon consumption (Chen, Remondetto, & Subirade, 2006).

Microencapsulation techniques, which have been successfully used in the food industry, represent a solution to the challenge of incorporating green tea polyphenols in food products. It enables to (i) overcome the solubility incompatibilities between ingredients, (ii) protect sensitive ingredients such as polyphenols from degradation e.g. by oxidation, (iii) increase their bioavailability including the controlled release of encapsulated compounds. The fortification of food products with microcapsules of green tea polyphenols is a novel approach (Table 2). Therefore, the aim of the present review is to provide a comprehensive overview of the recent encapsulation techniques applied on green tea polyphenols, their application in the food industry and their effects on food systems properties.

2. Green tea polyphenols

2.1. Composition

Green tea possesses the highest content in phenolic content compared to other types of tea (Khokhar & Magnusdottir, 2002). Green tea leaves consist of flavonoids and phenolic acids up to 30% of fresh leaves dry weight. The main catechins of green tea are: (+)-catechin (C), (-)-epicatechin (EC), (-)-gallocatechin (GC), (-)-epicatechin gallate (ECG), (-)-epigallocatechin (EGC), (-)-epigallocatechin gallate (EGCG) as shown in Fig. 1. Studies have reported that the content of catechins in tea leaves depends on the type of infusion and the quality of the green tea leaves (Thanaraj & Seshardi, 1990). Catechins are found in greater amounts in green tea than in black or Oolong tea (Vinson & Dabbagh, 1998). Although catechins are the major phenolic constituents in green tea, other flavonoids and phenolic acids have been identified and quantified.

The class of flavonoids which has also been attributed beneficial effects on human health (Lee, Kang, & Cho, 2007) is divided into flavanols and flavonols (Fig. 2). Flavanols represent 70% of total phenolic content in green tea according to several studies (Wang, Provan, & Helliwell, 2000). Flavonols consist of gallocatechin, catechin gallate, gallocatechin gallate, epicatechin, epigallocatechin, epicatechin gallate and epigallocatechin gallate. The differences within each group are marked by the variation in number and arrangement of the hydroxyl groups and their extent of alkylation and/or glycosylation. Flavonols are characterized by the presence of unsaturation in the heterocyclic ring, an oxygen atom in C4 and a hydroxyl group in position 3. The main components are kaempferol, quercetin, and miricetin.

Phenolic compounds are predominantly found as hydroxybenzoic and hydroxycinnamic acids. Phenolic acids are phenols with one carboxylic acid functionality. This class of phenolic compounds is the less expressive in green tea.

2.2. Health benefits

Green tea beneficial attributes to health have been intensively studied. Indeed, both in vitro and in vivo studies reported numerous positive effects on health. The antioxidant properties of green tea polyphenols are without contest the most reported. Several studies confirmed that flavanols isolated from green tea possess very strong antioxidant activities (Zhang, Zheng, Chow, & Zuo, 2004; Gramza, Pawlak-Lemańska, Korczak, & Wsowicz, 2005 etc.). It has been identified that the presence of the phenolic hydroxy groups on the B-ring in ungalloylated catechins (EC and EGC) and in the B- and D-rings of the galloylated catechins (ECG and EGCG) is responsible for the antioxidant properties of green tea (Salah et al., 1995). It was also demonstrated that the presence of the 3,4,5-trihydroxy B-ring as well as the metal-chelating properties of green tea catechins were also important contributors to its antioxidant properties (Valcic, Muders, Jacobsen, Liebler, & Timmermann, 1999). The antioxidant power of green tea is reported in the literature as the example of Erba et al. (2005) who reported that the consumption of green tea associated with a balanced diet can improve the overall antioxidative status and protect against oxidative damage in humans. More, the antioxidant activity of green tea catechins to inhibit oxidation in raw minced red meat, poultry and fish muscle was found to be two to fourfold greater than that of a-tocopherol at the same concentration (Tang, Sheehan, Buckley, Morrissey, & Kerry, 2001). In another experiment conducted on marine oils, it was reported that a green tea dechlorophylized extract at 200, 500, and 500 ppm exhibited higher efficacy than that of BHA, BHT, and a-tocopherol (Wanasundara & Shahidi, 1998).

Besides the antioxidants properties, green tea polyphenols also exert properties against cardiovascular diseases. Epidemiological studies have demonstrated that green tea antioxidant properties are responsible for its positive effect on cardiovascular diseases. Furthermore, Higdon and Frei (2003) reported that the consumption of 300 to 450 ml of green tea could increase the antioxidant activity of blood serum. In addition, a study involving 240 men and women aged 18 years or older, revealed that the a-flavin-enriched green tea extract coupled with a low