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Review

Flavors of the future: Health benefits of flavor precursors and volatile compounds in plant foods

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ABSTRACT

Background: Consumers' food production requirements have changed considerably during the last decade. This includes growing interest in the use of aroma compounds to develop functional foods for providing health benefits and reducing chemically synthesized additives. More recently, beyond their flavoring properties, various reports have shown the potential role of volatile compounds in human health, including their antioxidant, anti-inflammatory, anti-cancer and anti-obesity activities. Thus, investigation into the pharmacological activities of flavor and volatile compounds has been increased.
Scope and approach: To our knowledge, no single review article is available that provides an overview of the health benefits and antimicrobial properties of volatile compounds. To address this, here it was aimed to review the current knowledge of the health benefit and antimicrobial properties of volatile compounds.
Key findings and conclusions: There are many plant or food products with health benefits and antimicrobial activities. However, existing literature indicates that terpenoids, phenolics and alkaloids are among natural taste compounds, which are the most attractive sources in terms of developing new antimicrobial agents and health-promoting ingredients. Future investigation is required to demonstrate key properties of volatiles/non-volatile taste compounds such as synergic actions, organoleptic impacts, process stability and efficacy dosage, particularly in cooperation with different research disciplines.

1. Introduction

The eating preference of consumers toward functional foods has, recently, necessitated the search for new innovations in the flavor industry (Martínez-Mayorga & Franco, 2014; Younesi & Ayseli, 2015). Therefore, successful functional food must offer both nutrients specific to health-promoting functionality and desirable sensory attribute to meet the needs of consumers (Sun-Waterhouse & Wadhwa, 2013). Furthermore, among consumers there is a common belief that foods containing chemical preservatives are not healthy even though they are considered as functional foods (Bigliardi & Galati, 2013). There is considerable interest in the potential use of volatile compounds to extend of shelf-life of food products based on their natural preservative properties. It is believed that volatile compounds will create an excellent opportunity to decrease the application of chemical preservatives in functional foods or minimally processed products such as fresh sliced apples (Lanciotti et al., 2003; 2004).

More recently, a growing body of evidence has suggested that flavor precursors such as phenolic compounds may prevent or delay the onset of diseases such as cancer (Antonio et al., 2010; Holzapfel et al., 2013; Linnewiel-Hermoni et al., 2015), type 2 diabetes (Flanagan, Bily, Rolland, & Roller, 2014; Van Dam, 2006), neurodegenerative disorders (Tohda, Kuboyama, & Komatsu, 2005; Younesi, 2014), cardiovascular diseases (CVD) (Kalaska et al., 2014) and obesity (Park, 2015).

However, most of phenolic compounds cause aversive avoidance reaction of the consumer in terms of astringent or bitter taste (Drewnowski & Gomez-Carneros, 2000). It is well-known that these compounds are the main precursor of some volatile ones in plant foods Interestingly, several of them also show antimicrobial properties and health benefits (Li et al., 2015; Rekha, Selvakumar, Sethupathy, Santha, & Sivakamasundari, 2013; Xavier, Babusha, George, & Ramana, 2015).

On the other hand, more than 11,000 volatile compounds have

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been identified in foods since 1950s. It is apparent, however, that the flavor industry has not yet undertaken position to develop volatile compounds in order to prevent or delay diseases (Martínez-Mayorga & Franco, 2014). A survey of the literature indicated that numerous reviews of flavor have been published during the last decade, but few of them suggest that flavor compounds (volatile or non-volatile) can show health benefits (Schwab, Davidovich-Rikanati & Lewinsohn, 2008). If mechanistic models can establish a link between flavor compounds and disease condition, then the identified compounds can be used development of new functional ingredients or drugs (Martínez-Mayorga & Franco, 2014).

Therefore, the aims of this work were, firstly, to provide an overview of flavor precursors and their volatile compounds that are linked to prevention of complex diseases secondly and mainly, to discuss application of volatile compounds as natural food preservatives to improve safety of processed food products (Fitzgerald et al., 2004; Lanciotti et al., 2003; 2004).

To the best of our knowledge, this appears to be the first review on the health benefits of flavor precursors and their volatiles. The paper concludes with comments on the use of volatile compounds for human health and shelf-life extension of food products. Because there are many compounds that can affect flavor, this review will only focus on flavor and volatiles that primarily influence both odor and taste receptors.

2. Health benefits of non-volatile taste compounds in plant foods

Naturally occurring polyphenolic compounds are well-known with their numerous medicinal properties. They are promising nutraceutical or drug candidates (Schwab et al., 2008). More recently, it has been reported, however, that increasing dosage of the phenolic compounds in functional foods often lead to astringent and bitter flavors (Soto-Vaca, Losso, Xu, & Finley, 2012). Consequently, manufacturers cannot simply add these compounds into a food product when developing functional foods that have acceptable sensory properties, as well as the desired health benefits. It is worthy of note that taste is a more important considered point of the healthy products, as opposed to perceived nutrition or health value for customers (Augustin & Sanguansri, 2015; Drewnowski & Gomez-Carneros, 2000).

It has been long known that phenolic compounds play an important role in the flavor of beer, hops, cocoa, coffee, tea and fruit-based products (Soto-Vaca et al., 2012; Sun-Waterhouse & Wadhwa, 2013). According to numerous reports, the majority of volatile compounds are derived from an array of nutrients such as fatty acids and non-volatile taste constituents like phenolic compounds, carotenoids (Selli, Kelebek, Ayseli, & Tokbas, 2014) or alkaloids (Ludwing, Clifford, Lean, Ashihara, & Crozier, 2014). With this in mind, we have searched for health benefits of flavor precursors and their volatiles based on flavor/odor descriptions by using data derived from the scientific literature (Li et al., 2015; Rekha et al., 2013). Research studies on health benefits of flavor precursors and volatile compounds in plant foods are summarised in Table 1.

In beer, the phenolic compounds originating from barley and hops affect bitter, astringent and tangy flavor. These compounds are critical to the foam and microbial stability of the beer. Isoxanthohumol (IXN) and 8-prenylnaringenin (8 PN) are the most important prenylflavonoids found in hops. There have been several studies that demonstrate the health benefits of hops, particularly with their potential role in reducing hot flushes in menopausal women. Most recently, the estrogenicity of the 8-PN has been established (Keiler, Zierau, & Kretzschmar, 2013).

The predominant phenolic compounds in tea, cocoa and coffee are phenolic acids and flavonoids (Soto-Vaca et al., 2012).For the sake of example, volatile compounds of roasted foods such as coffee or cocoa may be formed from non-volatile taste compounds through several different chemical reactions such as Maillard or Strecker degradation. In addition, the roasting procedure is reported to generate key volatile compounds of coffee from non-volatile bitter taste compounds (Kreppenhofer, Frank, & Hofmann, 2011). Normally, green coffee beans are largely non-aromatic and lack the characteristic aroma of roasted coffee but contain a large number of chemical precursors such as chlorogenic acids (CGAs) and trigonelline that contribute to the flavor of coffee (Fisk, Kettle, Hofmeister, Virdie, & Silanes Kenny, 2012; Ludwing, Sánchez, De Peña, & Cid, 2014; Poisson, Schmalzried, Davidek, Blank, & Kerler, 2009).

There is strong substantial evidence that CGAs contribute to the astringency; trigonelline generates pyridines and pyrroles that may be consequently responsible for some burnt/smokey flavors in coffee (Petisca, Pérez-Palacios, Farah, Pinho, & Ferreira, 2013). The flavor formation and health benefit of the non-volatile taste components of coffee are illustrated in Fig. 1. This example has firstly allowed us to build up a great picture of the taste compounds (volatile and non volatile), their benefits as functional ingredient or natural preservative during the flavor cycle (Poisson et al., 2009; Xavier et al., 2015). One can interpret the figure in several ways. It shows, firstly, that flavor precursors and their volatile compounds in many plant foods are able to improve food quality and human health beyond their flavoring properties (Flanagan et al., 2014; Meghwal & Goswami, 2012). Secondly, further flavor studies need to provide better health benefits of natural taste compounds of plant foods although it is well-studied food product like coffee (Flanagan et al., 2014; Rodríguez-Mateos et al., 2014).

3. Health benefits of trigonelline in coffee and fenugreek

Fenugreek (*Trigonella foenum-graecum* L.) has strong spicy and seasoning type sweet flavor (Meghwal & Goswami, 2012). It is wellknown that alkaloids and volatile compounds are two major constituents of fenugreek, causing bitter taste and undesirable odor (Farah, De Paulis, Moreira, Trugo, & Martin, 2006; Meghwal & Goswami, 2012). However, trigonelline also contributes to the bitterness of the coffee and is well-known as a precursor of pyridines and pyrroles in roasted foods (Buffo & Cardelli-Freire, 2004; Petisca et al., 2013). For example, 1-H-pyrrole-2-carboxylaldehyde was previously reported to be an aroma-active compound in coffee by Mestdagh, Davidek, Chaumonteuil, Folmer, and Blank (2014). Furthermore, Ludwing et al. (2014) demonstrated that 1H-pyrrole and 1-methylpyrrole have antioxidant activities in coffee.

To date, studies have indicated that flavonoids, saponins and alkaloids of fenugreek have promising medicinal properties (Meghwal & Goswami, 2012). Due to its potential bioactivity, trigonelline inhibits the invasiveness of cancer cells *in vitro* (Antonio et al., 2010; Meghwal & Goswami, 2012) and improves memory (Chang & Ho, 2014; Farah et al., 2006; Tohda et al., 2005). In addition, this alkaloid has been considered as a novel phytoestrogen (Allred, Yackley & Vanamala, 2009) and antimicrobial agent (Ozçelik, Kartal, & Orhan, 2011). Researchers have recently investigated antimicrobial activities of several alkaloids, most of which especially trigonelline show remarkable antiviral activity against HSV-1 (Herpes simplex virus type-1). This result indicates that trigonelline can be an important antimicrobial drug candidate (Boulogne, Petit, Ozier-Lafontaine, Desfontaines, & Loranger-Merciris, 2012; Ozçelik et al., 2011).