Available online at www.sciencedirect.com
ScienceDirect
Food Science and Human Wellness 4 (2015) 9–27
Food Science and Human Wellness
www.elsevier.com/locate/fshw

# Tea aroma formation

Chi-Tang Ho [a,*], Xin Zheng [a], Shiming Li [b,**]

[a] Department of Food Science, Rutgers University, New Brunswick, NJ 08901, USA
[b] College of Life Sciences, Huanggang Normal University, Hubei 438000, China

Received 15 February 2015; accepted 23 March 2015

**Abstract**

Besides water, tea is one of the most popular beverages around the world. The chemical ingredients and biological activities of tea have been summarized recently. The current review summarizes tea aroma compounds and their formation in green, black, and oolong tea. The flavor of tea can be divided into two categories: taste (non-volatile compounds) and aroma (volatile compounds). All of these aroma molecules are generated from carotenoids, lipids, glycosides, etc. precursors, and also from Maillard reaction. In the current review, we focus on the formation mechanism of main aromas during the tea manufacturing process.


*Keywords:* Tea; Aroma; Formation; Volatile; Taste

## 1. Background

Tea is the second most widely consumed beverage around the world after water [1]. The popularity of tea as a global beverage rests on its pleasant flavor, mildly stimulating effects, and nutritional properties, which people find appealing and attractive. According to the manufacturing process, tea can be divided into at least three basic types: non-fermented green tea, fully fermented black tea, and semi-fermented oolong tea [2,3]. The flavor of tea can be divided into two categories: aroma, which consists mainly of volatile compounds; and taste, which consists mainly of non-volatile compounds. The volatile aromas are important criterion in the evaluation of tea quality.

Nowadays, more than 600 volatile compounds have been reported during the tea manufacturing process, and these compounds can be divided into 11 classes [4–6]. All of these aromas are generated from four main pathways: carotenoids as precursors, lipids as precursors, glycosides as precursors, and Maillard reaction pathway. To the best of our knowledge, no previous study has provided the details of formation mechanisms for tea aromas. Therefore, in the present study, we review main aromas starting from the manufacturing process, with biological and chemical mechanisms.

## 2. Carotenoids as precursors

Carotenoids include β-carotene, lutein, zeaxanthin, neoxanthin, xanthophyll, and lycopene, and more have been identified as precursors for many tea flavors. Many of them play key roles in deciding the quality of tea. Fig. 1 lists the most common aroma compounds derived from carotenoids. There are mainly thirteen carbon cyclic compounds, such as β-ionone (1, woody), β-damascenone (2, floral, flowery, cooked apple), $C_{13}$-spiroether theaspirone (3, sweet floral, tea-like), and theaspirone (4) as well as oxygenated theaspirone derivatives (5 and 6, fruity) [7].

There are two main mechanisms of carotenoid degradation. One is enzymatic oxidative degradation (Table 1) and the other is non-enzymatic oxidation. The enzymatic pathway is catalyzed by dioxygenases during fermentation (Fig. 2a) [7]. First, carotenoids are cleaved by dioxygenases, forming primary oxidation products. Subsequently, the enzymatic transformation of oxidation products gives rise to aroma precursors, followed by acid hydrolysis to liberate volatile aroma compounds. The order of carotenoid enzymatic oxidation is

* Corresponding author at: Department of Food Science, Rutgers University, New Brunswick, NJ 08901, USA. Tel.: +1 848 932 5553.
** Corresponding author at: College of Life Sciences, Huanggang Normal University, Hubei 438000, China. Tel.: +86 713 883 3611.
*E-mail addresses:* ho@aesop.rutgers.edu (C.-T. Ho), shiming@rutgers.edu (S. Li).
Peer review under responsibility of Beijing Academy of Food Sciences.

http://dx.doi.org/10.1016/j.fshw.2015.04.001
2213-4530/

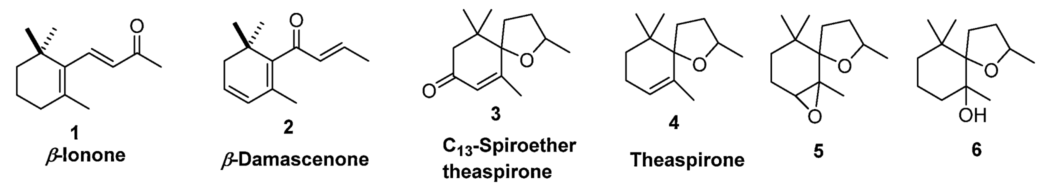


Fig. 1. Carotenoid-derived aroma compounds.

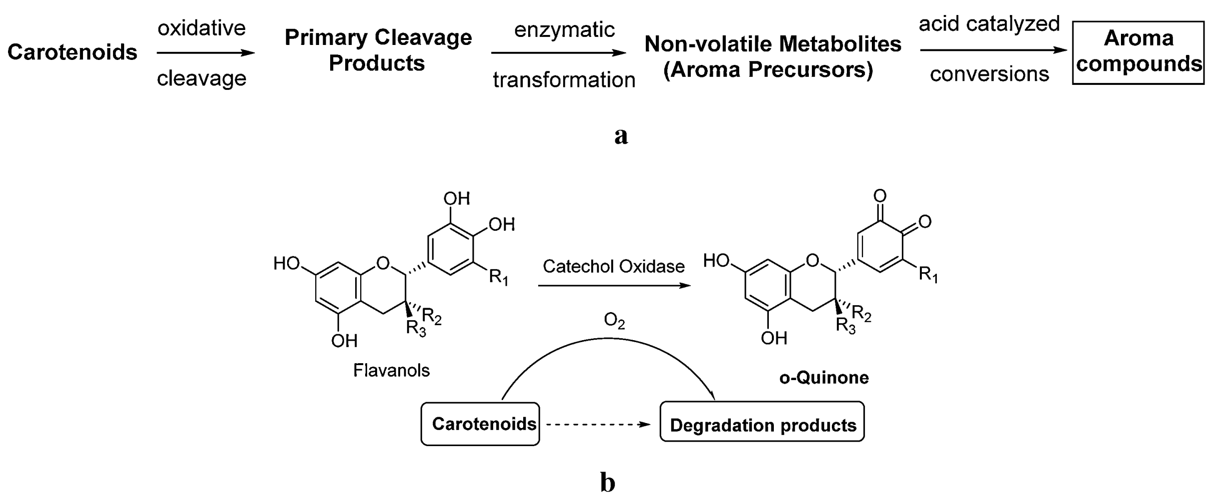


Fig. 2. (a) Enzymatic degradation of carotenoids [7]. (b) Flavonol oxidation participates in carotenoid degradation (red arced arrow indicates the driving force of flavonol oxidation in carotenoid degradation) [8].

β-carotene > zeaxanthin > lutein. It should be pointed out that aromas originating from carotenoid degradation must be assisted with the oxidative tea flavanols during fermentation. The oxidized tea flavanols–quinones are oxidizing reagents for the degradation of carotenoids. This suggests that the oxidation of tea flavanols by catechol oxidase remarkably affects the formation of tea aromas during the manufacturing process (Fig. 2b) [8]. Without the oxidation of non-volatile compounds, no aroma could be detected during the manufacturing process. Therefore, it is evident that there is a relationship between non-volatile and volatile compounds.

Table 1
Carotenoid-derived aromas produced by primary and secondary enzymatic oxidation [8].

| Carotenoids in tea leaves | Primary oxidation products | Secondary oxidation products |
|---|---|---|
| β-Carotene | β-Ionone | Dihydroactinidiolide; 5,6-Epoxyionone 2,2,6-Trimethylcyclohexanone; Theaspirone 2,2,6-Trimethyl-6-hydroxycyclohexanone |
| α-Carotene | β-Ionone; α-Ionone | Theaspirone |
| Phytoene | Linalool | – |
| Phytofluene | Linalool | – |
| Lycopene | Linalool | 6,10-Dimethyl-3,5,9-undecatriene-2-one |
| γ-Carotene | β-Ionone | Theaspirone |
| Cryptoxanthin | β-Ionone | Theaspirone |
| Lutein | Terpenoid-like aldehydes/ketones | Theaspirone |
| Neoxanthin | β-Damascenone | – |

β-Damascenone (Fig. 3) and β-ionone (Fig. 4a) are two representative aromas formed from carotenoid degradation. β-damascenone has an apple-like flavor and has an extremely low threshold in water (0.002 ppb). It was first identified in Bulgarian rose oil in 1970 [9] and is an essential odor in black tea infusion [10–12]. It comes from the enzymatic oxidation of neoxanthin (Fig. 3). The first step is the cleavage of neoxanthin by dioxygenases between the C-9 and C-10 double bond, yielding grasshopper ketone. Next, this ketone is enzymatically reduced to allenic triol, which is known as a progenitor of β-damascenone. The last step is acid-catalyzed dehydration to odoriferous β-damascenone [13]. In addition, it can directly originate from neoxanthin in non-enzymatic reactions, such as thermal degradation or oxidation, under acidic conditions during the tea manufacturing process [14].

β-Ionone (Fig. 4a) is a significant contributor to the flavor of green and black tea and has a low odor threshold (0.007 ppb). It can be produced either by enzymatic reactions during fermentation or thermal degradation during the green tea manufacturing process (Fig. 4a) [15]. It comes from the primary oxidation of β-carotene. Fermentation and heat-drying steps are both needed to generate the final product β-ionone. β-ionone can be further oxidized to 5,6-epoxy-β-ionone. After two reduction steps, it is converted to a saturated triol that undergoes an intramolecular cyclization followed by an oxidation reaction generating dihydroactinidiolide and theaspirone, which are viewed as critical aromas in determining the characters of black tea (Fig. 4b)