Food Research International 53 (2013) 608–618

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Processing and chemical constituents of Pu-erh tea: A review

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ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form 6 February 2013
Accepted 21 February 2013

Keywords:
Pu-erh tea
Chemical constituents
Processing

ABSTRACT

Pu-erh tea is a unique microbial fermented tea produced from the sun-dried leaves of large-leaf tea species (*Camellia sinensis* (Linn.) var. *assamica* (Masters) Kitamura) in the Yunnan province of China. Pu-erh tea has become increasingly popular in Southeast Asia may be due to its multiple health benefits. The special sensory characteristics of Pu-erh tea arise from the multitudinous chemical changes and transformations of the chemical constituents of the sun-dried green tea leaves that occur during the post-fermentation process. Many functional components have been isolated from Pu-erh tea and identified. In this paper, modern processing techniques and their effects on the transformation of the chemical constituents and the major chemical components of Pu-erh tea are reviewed and discussed.

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1. Introduction

Tea is one of the most popular beverages consumed in the world and its biological activities and health benefits have been widely explored (Lin & Lin-Shiau, 2006). It is normally produced from the leaves of two varieties of the plant *Camellia sinensis*: var. *sinensis* and var. *assamica* (Chen, Yu, & Tong, 2000; Wang, Provan, & Helliwell, 2000). Based on the processing procedures utilised, tea can be divided into green tea (non-fermented), oolong tea (semi-fermented), black tea (fully fermented by oxidizing enzyme) and dark tea (post-fermented by microbe). Unlike green tea, oolong tea or black tea, dark tea is a unique microbial fermented tea, and its production is only limited to the areas of China and Japan (Jiang et al., 2011). In China, dark tea is traditionally further divided into Yunnan Pu-erh tea, Hunan Fu-zhuan tea, Hubei Qing-zhuan tea, Sichuan Bian-xiao tea and Guangxi Liu-bao tea according to the different producing areas and the processing technologies employed. Among these teas, Pu-erh tea is of special concern, and is also the most representative dark tea. This tea has attracted more and more attention worldwide as a "hot topic" in the recent field of tea science.

Currently, Pu-erh tea is becoming increasingly popular especially in Southeast Asia mainly due to its multiple health-promoting effects (Mok, Chang, Wang, & So, 2008) as well as its special flavour and taste (Ahmed et al., 2010; Liang, Zhang, & Lu, 2005; Lv, Lin, Tan, & Guo, 2012; Lv, Zhong, et al., 2012). Pu-erh tea is favoured by an increasing number of consumers and therefore its market demand has expanded greatly. Because the consumption of Pu-erh tea has rapidly increased, the last decade has witnessed the rapid development of the Pu-erh tea industry and its escalated production. The Pu-erh tea output peaked in 2007 at approximately 99 thousand tonnes, which was almost a 9-fold increase compared to that of 2001, and accounted for 58.2% of the total Chinese dark tea produced (Tang, 2008). Microbial fermentation plays a crucial role in the formation of the special characteristics of Pu-erh tea, which result from dramatic changes in the chemical components of the tea leaves. However, its modern processing technology and the types of Pu-erh tea are little known outside China. In addition, reports of the chemical components of Pu-erh tea as well as other types of dark tea are limited (Ling et al., 2010).

Studies of the processing technology as well as the chemical constituents of Pu-erh tea have progressed in the last several years. With the rapidly growing popularity of this unique tea, it is important to review the recent advances comprehensively. Therefore, the present paper attempts to assess the developments in Pu-erh tea production and describe the chemical constituents of Pu-erh tea.

2. The definition of Pu-erh tea and its types

2.1. The definition of Pu-erh tea

Pu-erh tea is a unique microbial fermented tea. This tea is produced using the sun-dried leaves of large-leaf tea species (*C. sinensis* (Linn.) var. *assamica* (Masters) Kitamura) in the Yunnan province of China. The solid-state fermentation by microorganisms provides the special

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0963-9969/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.foodres.2013.02.043

characteristics of a mellow taste, a stable flavour and the brownish red colour of the Pu-erh tea infusion.

As a well-known tea from ancient times with an interesting history, Pu-erh tea initially formed during long-distance transport of sun-dried green tea on horseback (Zhou, Zhang, Xu, & Yang, 2005), and the very path came to be known later as the famous Chinese Tea-horse Road (Shao, Powell, & Clifford, 1995a). Presently, Pu-erh tea is a national product of geographical indication and the producing areas are confined to certain regions in Yunnan province, including 11 cities, 75 counties, and 639 townships (specifically, between parallels 21°10′ and 26°22′ north latitude, 97°31′ and 105°38′ east longitude). The processing technology of solid state fermentation by microorganisms is widely used in the modern manufacture of Pu-erh tea, which has improved its manufacturing efficiency effectively.

2.2. Types of Pu-erh tea products and their relationships

Broadly speaking, the Pu-erh tea products on the market can be categorised into several types according to different standards (Yang, Chen, & Zhang, 2006), as shown in Fig. 1. First, Pu-erh tea can be divided into Pu-erh raw tea and Pu-erh ripen tea according to the processing technology and the quality characteristics (Fig. 1A). The former, a kind of green tea, is made directly from the sun-dried green tea by further autoclaving and compressing process, and its chemical constituents and quality are therefore very similar to those of the sun-dried green tea. Pu-erh ripen tea is normally made from the sun-dried green tea by microbial post-fermentation at higher temperature (about 50 °C) and higher humidity conditions. In addition, the compressed Pu-erh raw tea can be turned into Pu-erh ripen tea after natural ageing during long-term storage period, which is generally known as Pu-erh ageing tea. Secondly, Pu-erh tea can be divided into loose tea and compressed tea according to shape. After the autoclaving and drying processes, the compressed tea can be made by compressing the loose tea into different moulds to make different shapes (Fig. 1). Among the types of Pu-erh compressed tea, cake tea is the most common. Other desired shapes of compressed tea can be made as required, e.g., melon-shaped, tuocha-shaped, mushroom-shaped, brick-shaped and column-shaped (Fig. 1B).

Due to the domination of the production and consumption of the Pu-erh tea industry, Pu-erh tea in this paper generally refers to the microbial fermented Pu-erh ripen tea.

3. The manufacture process of Pu-erh tea

The modern manufacture process of Pu-erh tea is illustrated in Fig. 2. The material of sun-dried green tea is produced from the leaves of large-leaf tea species, *C. sinensis* (Linn.) var. *assamica* (Masters) Kitamura. Fresh tea leaves with one bud and two or three leaves are commonly used. After plucking, the fresh tea leaves are spread on bamboo mats for about 8 h in order to partially dry them. The tea leaves are then subjected to inactivation process of enzymes, by which they are fixed by heating in a drum to inactivate the endogenous polyphenol oxidase (PPO) (Liang et al., 2005). The temperature during the fixation process of the fresh green tea is much lower than that for making steamed, roasted and baked green teas. The lower temperature is considered to be in favour of the subsequent post-fermentation process. Because the deactivation of enzymes is incomplete (Ahmed et al., 2010) and partial enzyme activity is therefore retained. As a result, traces of theaflavins (TFs) could be detected in the obtained sun-dried green tea (Shao et al., 1995a) for the oxidative polymerization of catechins catalysed by PPO. The rolling time in the rolling process for Pu-erh tea is shorter than that for green tea, resulting in a relatively lower rate of the cell breakage rate and producing the loose rolled leaves, which facilitates their ventilation and the post-fermentation. Before the post-fermentation step, the rolled tea leaves are partially dried to give moisture contents of about 8% under the sun for 3 to 5 h at temperature above 30 °C. In the process of post-fermentation, the sun-dried tea leaves are piled up for a few weeks (Shao et al., 1995a), leading to a series of oxidation, condensation and degradation of tea chemical constituents, which are catalysed by the extracellular enzymes produced by microorganisms and thus to the production of the special sensory characteristics of Pu-erh tea. During the post-fermentation process, the leaves are turned over every two other days to prevent the excessive increase in temperature. Excessive post-fermentation induces the reduction of the antioxidant activity of Pu-erh tea (Zhang, Wang, Chen, Tan, & Wang, 2012) and thus should be avoided. After drying at below 60 °C following the post-fermentation (Hou et al., 2009; Wang, Gong, & Qiu, 2010; Wang, Xiao, et al., 2010), the loose Pu-erh ripen tea has been made and can then be compressed into different shapes after autoclaving and drying.

Many microorganisms are involved in the post fermentation of Pu-erh tea (Zhu, Yang, Li, & Zhang, 2008), including *Aspergillus niger*, *Penicllium*, *Rhizopus*, *Aspergillus glaucus*, *Saccharomyces*, *Aspergillus terreus*, *Aspergillus candidus* and *Bacterium*. Among these microorganisms, several *Aspergillus* spp. are regarded as the dominant species (Abe et al., 2008; Chen, Zhu, Wang, Zhang, & Yang, 2006; Zhao, Tong, Zhou, Wang, & Liu, 2010; Zhou et al., 2004). These microorganisms play a crucial role in the quality formation of the Pu-erh tea (Abe et al., 2008; Xu, Yan, & Zhu, 2005). The natural fermentation process normally takes a few weeks. In order to shorten the fermentation time, the dominant species of microorganisms are now extraneously inoculated in the modern processing technology (Chen, Chan, Chang, Liu, & Chen, 2009; Chen, Liu, & Chang, 2010; Hou, Jeng, & Chen, 2010; Liang et al., 2009). Research has revealed that artificial fungus-inoculated solid-state formation could give the main, specific and excellent sensory characteristics of Pu-erh tea, including the infusion colour, taste and aroma, which are comparable with spontaneous fermentation that produces the Pu-erh tea aged naturally for a long time (Chen, Zhang, Zhu, Yang, & Zhang, 2008; Liang et al., 2009). However, different microorganisms have different effects on the chemical compositions of Pu-erh tea (Fu, Song, Xu, & Li, 2012), such as the concentrations of lovastatin (Hao, Tong, Zhou, & Liu, 2012). Therefore, the selection of the microorganism stains used for the post-fermentation of Pu-erh tea is an important issue for the production of certain bioactive compounds and standardising the modern Pu-erh tea production. In addition, the discoveries of bioactive compounds and productions that account for the special characteristics of Pu-erh tea, which are responsible for health improvement and the aroma, colour and taste of the tea, respectively, will guild the production of high-quality Pu-erh tea.

4. Chemical components of Pu-erh raw tea

Pu-erh raw tea is produced from the leaves of *C. sinensis* var. *assamica* as sun-dried green tea form and its autoclaving compressed one. The chemical constituents of these two forms are very similar to one another and to those of fresh tea leaves, which have been identified by high performance liquid chromatography (HPLC) (Wang, Cheng, Zhou, Ye, & He, 2009), near infrared spectroscopy (NIRS) (Zhou et al., 2009), Fourier transform infrared spectroscopy (FTIR) (Ning, Zhang, Wang, Wan, & Zeng, 2011) and metabolomic analysis (Lee et al., 2011). However, the levels of these constituents are quite different because heat during autoclaving may induce the degradation of some tea chemical compounds.

To date, many compounds have been isolated and identified from the fresh leaves of *C. sinensis* var. *assamica* and Pu-erh raw tea (Hashimoto, Nonaka, & Nishioka, 1989; Zhang, Liu, Li, & Yang, 1995; Zhao, Ma, et al., 2011; Zhou & Yang, 2000). Among them, the flavonoids and the hydrolysable tannis are considered to be the major constituents possessing strong antioxidative properties (Gao, Zhang, Yang, Chen, & Jiang, 2008). As shown in Fig. 3, these

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