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The science of matcha: Bioactive compounds, analytical techniques and biological properties

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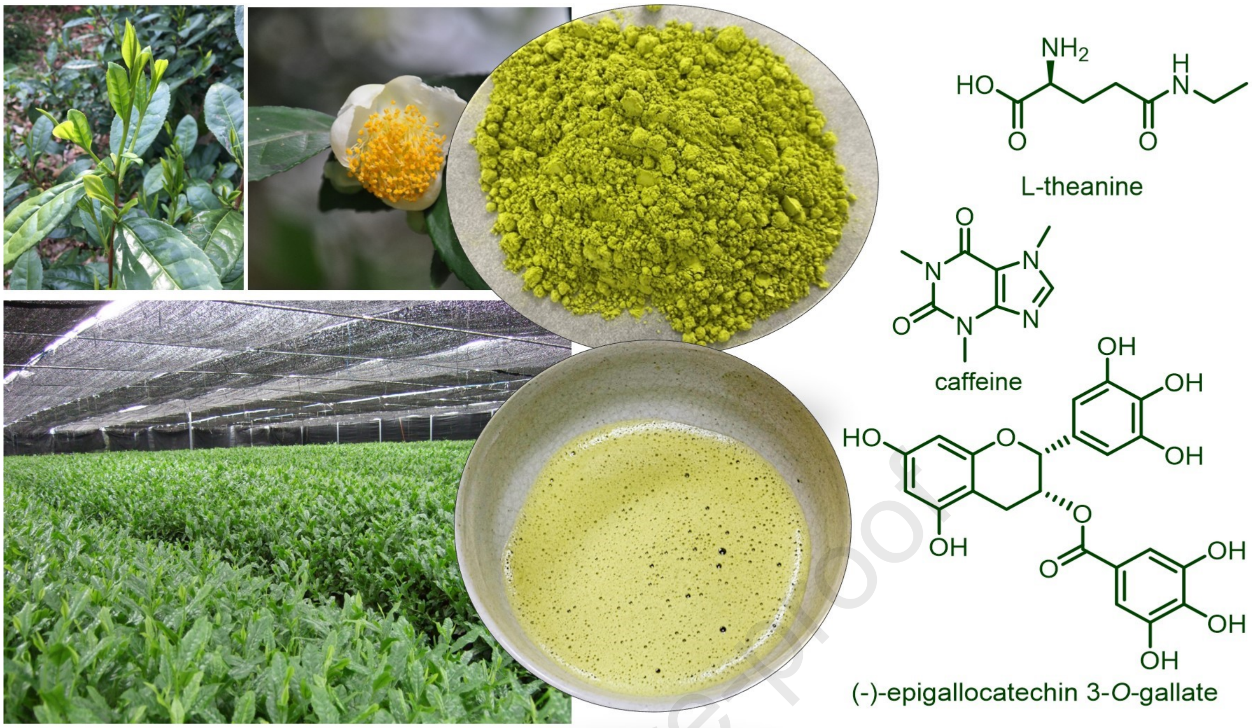
Abstract

Background: The interest in the plant-derived healthy foods, nutraceuticals, functional foods and food supplements is increasing in recent times as potential agents in maintenance of health and the prevention and treatment of diseases. Matcha tea powder is obtained from the leaves of tea plant (*Camellia sinensis* (L.) Kuntze) grown under specific condition using about 90% shade. As compared to green tea, a hot water extract of tea leaves, matcha is consumed as a whole powder of leaves. Matcha powderis reported to have higher content of some bioactive components such as catechins, theanine and caffeine. In recent years, there is an increased market demand and consumption of matcha as a drink and as a component in various beverages, snacks and other food products.

Scope and approach: In this review, the available scientific information of the chemical constituents and their analysis and biological activities are critically analyzed. These results may help to understand current status of research on matcha and the gaps which help to guide future research related to evidence based product formulations.

Key findings and conclusions: Various studies have reported the difference in bioactive compounds in matcha as compared to green tea and other tea formulations. The content and composition were mostly affected by the cultivation and processing techniques. Analysis of marketed samples in various countries have shown the variable content of the bioactive compounds. Thus, there is a need for proper standardization for maintaining the quality. Matcha as a whole, its extract and compounds have shown promising biological activities in in vitro and animal studies. However, comparatively only a few clinical studies are performed, which need future attention. There should also be detailed study regarding matcha-containing foods' formulation.


L-theanine
caffeine
(-)-epigallocatechin 3-O-gallate

Trends in Food Science and Technology

The Science of Matcha: Bioactive Compounds, Analytical Techniques and Biological Properties

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Abstract

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Scope and approach: In this review, the available scientific information of the chemical constituents and their analysis and biological activities are critically analyzed. These results may help to understand current status of research on matcha and the gaps which help to guide future research related to evidence based product formulations.

Key findings and conclusions: Various studies have reported the difference in bioactive compounds in matcha as compared to green tea and other tea formulations. The content and composition were mostly affected by the cultivation and processing techniques. Analysis of marketed samples in various countries have shown the variable content of the bioactive compounds. Thus, there is a need for proper standardization for maintaining the quality. Matcha as a whole, its extract and compounds have shown promising biological activities in in vitro and animal studies. However, comparatively only a few clinical studies are performed, which need future attention. There should also be detailed study regarding matcha-containing foods' formulation.

Keywords: Matcha; green tea; *Camellia sinensis*; functional foods; market

1. Introduction

The interest in the plant-derived healthy foods, nutraceuticals, functional foods and food supplements is increasing in recent times as potential agents in maintenance of health and the prevention and treatment of diseases. Various phytochemicals including polyphenols present in tea, coffee, vegetables, legumes are gaining the importance (Ganesan & Xu, 2017; Petti & Scully, 2009; Pietta, 2000).

From ancient times, the young leaves of tea plant (*Camellia sinensis* (L.) Kuntze, Syn.: *Thea sinensis* L., Theaceae) are used to prepare various tea formulations (Carloni et al., 2013; Y. Kim, Goodner, Park, Choi, & Talcott, 2011). Different reports suggest that the tea is second most consumed drink in the world after water (Hodgson & Croft, 2010; Huang et al., 2018; Y. Kim et al., 2011; Weiss & Anderton, 2003) and its worldwide market is growing day by day. Tea formulations are not only an important part of daily cuisine but are also consumed for their health beneficial/functional effects of their high content of polyphenols (e.g. catechins and phenolic acids), amino acids (eg. theanine, gamma amino butyric acid) and caffeine (Devkota et al., 2021; Hodgson & Croft, 2010).

Commonly available tea formulations are divided based on their processing such as non-fermented teas (e.g. white tea, green tea), partially fermented oolong tea and fully fermented black tea (Zhao et al., 2011). For obtaining above mentioned teas, tea plants are cultivated in open field without using any artificial shade and for the preparation of normal green tea, dried tea leaves are extracted with hot water. However, one more variety of tea which is gaining worldwide interest is the matcha tea powder. For preparing matcha tea, the tea plants are grown under shade (about 90% shade) by covering the cultivation areas/fields with different materials (Yuki Kurauchi et al., 2019) (Figure 1). Thus cultivated tea leaves are picked, washed, dried and then ground using stone mills to make powder known as matcha tea powder (Fujioka et al., 2016)

(Figure 1). The use of stone mills to make tea leaves powder is reported to have started in the 11th century in China and later started in Japan in the 14th century, which supports the long history of use of tea powders (Fujioka et al., 2016). For consuming matcha powder, the whole powder is mixed with hot water so that the whole content of leaves are consumed not only the extract (Yuki Kurauchi et al., 2019; Weiss & Anderton, 2003). The chemical composition of the matcha powder is reported to be different of that of green tea due to various factors such as cultivation conditions, processing and also the consumption of whole powder not the extract and most of these studies report that the content of catechins, caffeine and theanine is higher in tea leaves cultivated for preparing matcha as compared to those for normal tea (Dietz, Dekker, & Piqueras-Fiszman, 2017; Komes, Horžić, Belščak, Ganić, & Vulić, 2010; Yuki Kurauchi et al., 2019; Weiss & Anderton, 2003). In recent years, there is constant growth in the market and consumption of matcha not only as a drink but as a functional component in other beverages, snacks, chocolates, ice creams and many others both in Japan and overseas (Kochman, Jakubczyk, Antoniewicz, Mruk, & Janda, 2020; Kurauchi et al., 2019). Although used only in tradition ceremony in past years, it has received great attention in recent years as an ingredient in drinks, beverages, snacks, and many other products. In 2016, the global matcha market size was valued at USD 2.62 billion and it is expected to grow at a CAGR of 7.6% from 2017 to 2025. The modern use of matcha in different products such as snacks started from Japan in now spreading to many countries in Asia to Australia, Europe and America. (https://www.grandviewresearch.com/industry-analysis/matcha-market).

With increasing market demand, it is important to understand the current scientific information related to chemical constituents, biological activities and advancement in formulation techniques of matcha powder. Thus, the main aims of this review are to compile and analyze the bioactive chemical constituents, their analytic techniques and biological activities.

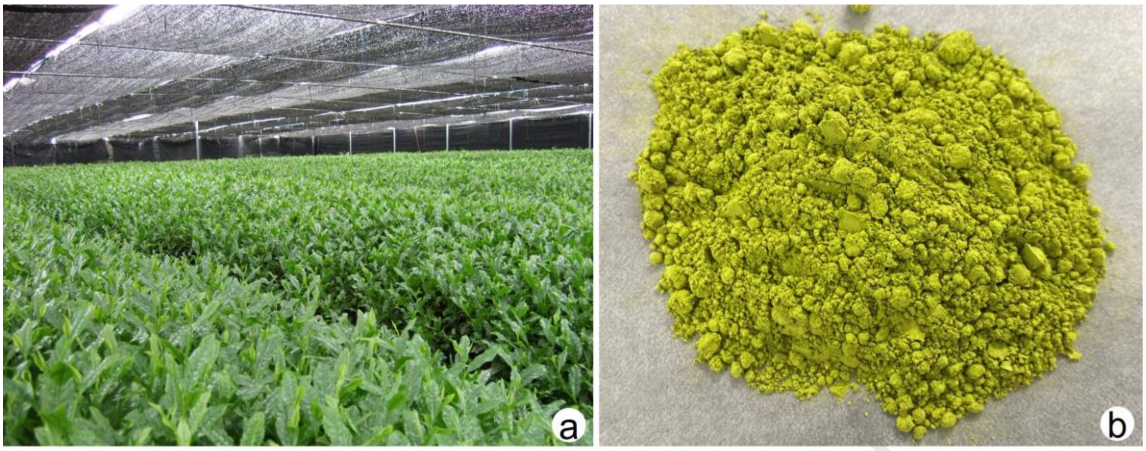

Figure 1. Photographs of Cultivation of tea plants for matcha using sun shades (a) and matcha powder (Photograph (a) is a courtesy of Aoiseicha Co., Ltd., Aichi, Japan and the matcha powder in photograph (b) was provided by AIYA Co. Ltd., Aichi, Japan)

2. Bioactive chemical constituents and analytical techniques

Since the first report of isolation and characterization of catechin from tea leaves by Tsujimura in 1930 ((Tsujimura, 1930), there have been hundreds of studies related to the chemical constituents an health beneficial activities of tea catechins (Devkota et al., 2021; Khan et al., 2019; Yeung et al., 2018). Flavonoids specially flavans, also known as tea catechins, such as catechin, epicatechin (EC), epigallocatechin (ECG), epicatechin 3-*O*-gallate (ECG) and epigallocatechin 3-*O*-gallate (EGCG) (Figure 2) along with phenolic acids such as gallic acids are well known as bioactive compounds of tea leaves (Carloni et al., 2013; Devkota et al., 2021). Apart from them, there are many other biologically important molecules such as flavonols (e.g. kaempferol, quercetin, rutin), phenolic acids (protocatechuic acid, gallic acid, caffeic acid, sinapic acid, ellagic acid, etc., amino acids (e.g. L-theanine, gamma amino butyric acid (GABA)), methyl xanthines (caffeine, theophylline, theobromine), chlorophyll and volatile compounds (e.g. pentanal, heptanal, 2-butanone) (Ananingsih, Sharma, & Zhou, 2013; Carloni et al., 2013; Jakubczyk, Kochman, Kwiatkowska, Kałduńska, et al., 2020; Y. Kim et al., 2011; Kochman, Jakubczyk, Antoniewicz, Mruk, & Janda, 2020;

Kurauchi et al., 2019; Zhao et al., 2011) (Figure 2). The composition of the bioactive compounds in tea leaves such as polyphenols, amino acids, caffeine are reported to be depending upon the cultivation condition, time of collection, processing and final formulations (Carloni et al., 2013; Y. Zhao et al., 2011).

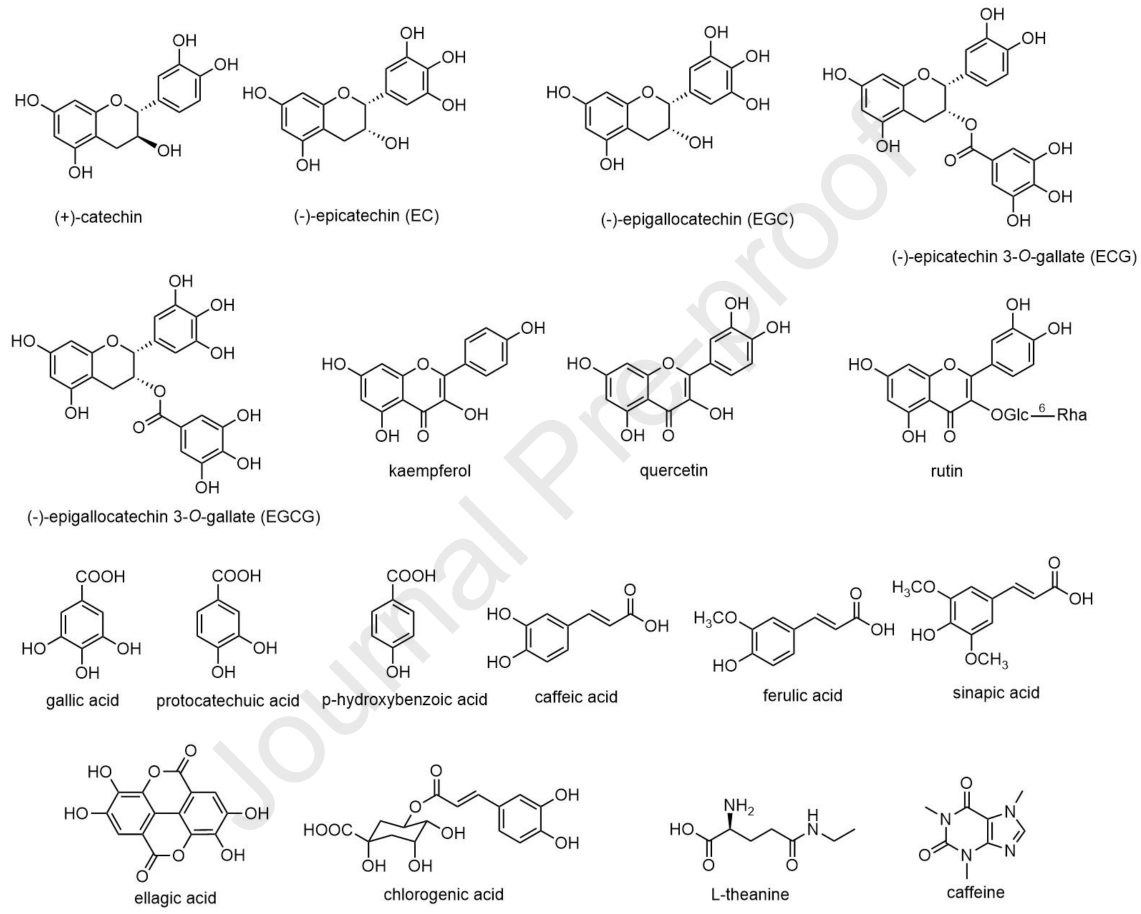

Figure 2. Structures of flavonoids, phenolic acids and other compounds present in matcha

Various studies have reported the chemical constituents of matcha collected from different places and their differences in chemical constituents and biological activities (Goto, Horie, Ozeki, Masuda, & Warashina, 1994; Kenjiro, Hirotsugu, & Toyomasa, 1984; Koláčková, Kolofiková, et al., 2020). The contents of these bioactive compounds in match tea powders vary greatly among the commercial samples available in market.

These contents also vary accordingly to the extraction procedures for these bioactive compounds. Use of hydroalcoholic solvents or water for extraction and the temperature of extraction condition and the duration of extraction time greatly affects the contents of these bioactive compounds (Koláčková et al., 2020; Komes et al., 2010). The detailed list of the bioactive compounds such as flavonoids (including catechins), methylxanthines and phenolic acids are provided in Table 1, 2 and 3, respectively.

The qualities of matcha available in Japanese market in relation to their prices have been studied. Ikegaya, Takayanagi, & Anan (1984) reported that the contents of total nitrogen, caffeine, free amino acids and L-theanine decreased along with decreasing prices. The contents of caffeine and catechins were reported to be 3.23-3.85% and 8.85-9.75%, respectively. Goto, Horie, Ozeki, Masuda, & Warashina (1994) compared the qualities of various tea products available in Japanese markets and regarding the matcha samples the contents of total amino acids, tannins and caffeine were reported to 3.50-5.50%, 7.83-10.57% and 2.93-3.29%, respectively. Ikeda (2002) also compared the qualities and the marketing prices of total 25 commercial matcha powers available in Japanese market and reported that the content of total tannins varied from 6.99% to 9.83%. Recently, Unno et al. (2018) analyzed the contents of theanine, amino acids, GABA, catechins, caffeine and catechins in 76 matcha samples sold in Japanese market and 67 matcha sample sold in market outside of Japan. The contents of each component largely varied from one sample to another in samples from both markets. For example, the content of L-theanine was reported to be in the range from 7.25 to 40.62 mg/g in samples from Japanese market and in the range from 0.32 to 27.09 mg/g in samples from the markets outside of Japan. The contents of amino acids and GABA also varied in similar pattern. The details of the contents of catechins and caffeine in these samples are given in Table 1 and 2, respectively.

Koláčková, Kolofiková, et al. (2020) analyzed the nutritional composition, phenolic compounds and antioxidant activities of the water extract and 80% MeOH extract of 12 different matcha products available in Czech republic market using high performance liquid chromatography (HPLC) and other methods. There was variation in the contents of flavonoids (Table 1), caffeine (Table 2) and phenolic acids (Table 3). Caffeine content was found to be 14.4-34.1 mg/g. Total phenolic content and flavonoid contents were 169-273 mg gallic acid equivalents/g and 99-139 mg rutin equivalents/g, respectively which were higher as compared to water extracts. Their antioxidative activities also varied accordingly. Another recent study reported that matcha contains 44.8 mg/L of vitamin C, 1968.8 mg/L of flavonoids, and 1765.1 mg/L of polyphenols in an infusion made with 1.75 g of plant material in 100 mL of water (Jakubczyk, Kochman, Kwiatkowska, Kałdunska, et al., 2020).

Table 1. Contents of catechins and other flavonoids in various matcha tea powder samples

Bioactive compound classes/individual compounds	**Analysis method**	**Samples**	**Contents**	**Reference**
Catechin	Micellar electrokinetic chromatography	Commercially available sample in US market	0.83 mg/g of dry leaf (MeOH extract) Not detected (water extract)	(Weiss & Anderton, 2003)
	HPLC	Commercially available sample in Croatia market	6.62 mg/L of water extract (80°C)	(Komes et al., 2010)
Epicatechin	Micellar electrokinetic chromatography	Commercially available sample in US market	4.0 mg/g of dry leaf (MeOH extract) 2.4 mg/g of dry	(Weiss & Anderton, 2003)

			leaf (water extract)	
	HPLC	Commercially available sample in Croatia market	120.7 mg/L of water extract (80°C)	(Komes et al., 2010)
	HPLC	Commercial samples from Japanese market	0.87-10.75 mg/g	(Unno et al., 2018)
	HPLC	Commercial samples from markets outside of Japan	0.18-15.40 mg/g	(Unno et al., 2018)
Epigallocatechin	Micellar electrokinetic chromatography	Commercially available sample in US market	12.6 mg/g of dry leaf (MeOH extract) 0.75 mg/g of dry leaf (water extract)	(Weiss & Anderton, 2003)
	HPLC	Commercially available sample in Croatia market	324.88 mg/L of water extract (80°C)	(Komes et al., 2010)
	HPLC	Commercial samples from Japanese market	4.09-44.43 mg/g	(Unno et al., 2018)
	HPLC	Commercial samples from market outside of Japan	1.86-55.22 mg/g	(Unno et al., 2018)
Epicatechin	Micellar	Commercially	12.8 mg/g of dry	(Weiss &

3-*O*-gallate	electrokinetic chromatography	available sample in US market	leaf (MeOH extract) 0.25 mg/g of dry leaf (water extract)	Anderton, 2003)
	HPLC	Commercially available sample in Croatia market	102.67 mg/L of water extract (80° C)	(Komes et al., 2010)
	HPLC	Commercial samples from Japanese market	8.58-16.37 mg/g	(Unno et al., 2018)
	HPLC	Commercial samples from market outside of Japan	0.63-27.96 mg/g	(Unno et al., 2018)
Epigallocatechin 3-*O*-gallate	Micellar electrokinetic chromatography	Commercially available sample in US market	57.4 mg/g of dry leaf (MeOH extract) 0.32 mg/g of dry leaf (water extract)	(Weiss & Anderton, 2003)
	HPLC	Commercially available sample in Croatia market	345.55 mg/L of water extract (80° C)	(Komes et al., 2010)
	HPLC	Commercial samples from Japanese market	13.15-86.76 mg/g	(Unno et al., 2018)
	HPLC	Commercial samples from	3.02-88.23 mg/g	(Unno et al., 2018)

		market outside of Japan		
Gallocatechin	HPLC	Commercially available sample in Croatia market	70.49 mg/L of water extract (80° C)	(Komes et al., 2010)
Gallocatechin 3-*O*-gallate	HPLC	Commercially available sample in Croatia market	6.62 mg/L of water extract (80°C)	(Komes et al., 2010)
Kaempferol	HPLC	Commercially available samples in Czech Republic market	4.2-20.4 μg/g mg/g of weight (80% MeOH extract) 1.7-16.2 μg/g of weight (water extract)	(Koláčková, Kolofiková, et al. 2020)
Quercetin	HPLC	Commercially available samples in Czech Republic market	8.4-17.2 μg/g mg/g of weight (80% MeOH extract) 10.5-84.9 μg/g of weight (water extract)	(Koláčková, Kolofiková, et al. 2020)
Rutin	HPLC	Commercially available samples in Czech Republic market	570-2870 μg/g of weight (80% MeOH extract) 361-1590 μg/g of weight (water extract)	(Koláčková, Kolofiková, et al. 2020)

Table 2. Contents of methylxanthines including caffeine in various matcha tea powder samples

Bioactive compound classes/individual compounds	**Analysis method**	**Samples**	**Contents**	**Reference**
Total methylxanthines	HPLC	Commercially available sample in Croatia market	322.30 mg/L of water extract (80°C)	(Komes et al., 2010)
Caffeine	Micellar electrokinetic chromatography	Commercially available sample in US market	6.4 mg/g of dry leaf (MeOH extract) 23.9 mg/g of dry leaf (water extract)	(Weiss & Anderton, 2003)
	HPLC	Commercially available sample in Croatia market	300.00 mg/L of water extract (80°C)	(Komes et al., 2010)
	HPLC	Commercial samples from Japanese market	5.95-50.16 mg/g	(Unno et al., 2018)
	HPLC	Commercial samples from market outside of Japan	0.85-40.96 mg/g	(Unno et al., 2018)
	HPLC	Commercially available samples in Czech Republic	14.4-34.1 mg/g	(Koláčková, Kolofiková, et al. 2020)

		market		
Theobromine	HPLC	Commercially available sample in Croatia market	12.18 mg/L of water extract (80°C)	(Komes et al., 2010)
Theophyline	HPLC	Commercially available sample in Croatia market	10.12 mg/L of water extract (80°C)	(Komes et al., 2010)

Table 3. Contents of phenolic acids (μg/g of dry powder) of various matcha tea powder samples commercially available samples in Czech Republic market as analyzed by HPLC (Koláčková, Kolofiková, et al. 2020)

Phenolic acid	**80% MeOH extract**	**Water extract**
Gallic acid	45.4-423.0	39.4-184.0
Protocatechuic acid	54.4-299.0	46.1-291.0
p-Hydroxybenzoic acid	9.7-243.0	13.5-167.0
Chlorogenic acid	3040-4800	2640-3920
Caffeic acid	13.3-223.0	9.3-78.3
Ferulic acid	45.5-289.0	5.6-171.0
Sinapic acid	104.0-1400	89.0-592.0
Ellagic acid	38.1-371.0	79.4-246.0

From above data, it is relevant that is very difficult to generalize the contents of bioactive compounds in marketed samples of matcha. There should be more proper guidelines and standardization methods to evaluate the chemical composition and their respective biological activities.

There have also been attempts to develop new analytic methods for the determination of bioactive components in green tea samples including matcha. Weiss and Anderton analyzed the contents of catechins and caffeine in methanol (MeOH) and water extracts of commercially available match in US market by using micellar electrokinetic chromatography (Weiss & Anderton, 2003). Content of caffeine was very high in water extract as compared to MeOH extract (Table 2) but the content of catechins was very low in water extract (Table 1). Similarly, the content of EGCG while drinking matcha would be around at least 3 times higher as compared to other green tea samples. Guo et al. (2021) et al. reported near infrared (NIR) based methods for the quantification of various constituents such as polyphenols, aminoacids, etc. in matcha powder. Similarly, Ouyang, Wang, Park, Kang, & Chen (2021) also reported visible-near infrared hyperspectral imaging technology for the analysis of components in matcha. Baba, Amano, Wada, & Kumazawa (2017) developed gas chromatography-olfactometric techniques for the determination of volatile components and odorants responsible for the characteristic aroma of matcha.

Traditionally, stone mills are used to prepare matcha powder from tea leaves. Recently, Fujioka et al. (2016) et al. reported that the use of ceramic mills to make powders can enhance the catechin extraction from the powder and also the extract obtained from such powder had stronger antioxidant activity.

3. Biological activities of matcha

Bioactive components present in tea leaves such as catechins, phenolic acids, amino acids, vitamins and caffeine are reported to be beneficial for human health having various biological activities such as chemopreventive, antioxidant and mood enhancing activities (de Souza, Gambeta, Stern, & Zanoveli, 2018; Higashiyama, Htay, Ozeki, Juneja, & Kapoor, 2011; Kurauchi et al., 2019; Pervin et al., 2018; Schröder et al., 2019; Smith, 2002; Unno et al., 2019). On the other hand, as matcha powder contains all components of the tea leaves, it is suggested to have improved biological activities as compared to green tea (water extract) (Bonuccelli, Sotgia, & Lisanti, 2018; Dietz et al., 2017; Koláčková et al., 2020; Yuki Kurauchi et al., 2019; Pervin et al., 2018; Weiss & Anderton, 2003). Matcha has been first identified and employed to treat diverse human ailments in Japan, in the form of matcha green tea. Biological activities of matcha are closely associated with its bioactive phytochemicals such as caffeine, tannins and other polyphenols. Due to the presence of bioactive polyphenols and vitamin C, matcha could have crucial biological effects. In the following sections, the reported biological activities of matcha based on recently reported scientific evidences are discussed in detail.

3.1. Antioxidant activities

Matcha infusion possess strong antioxidant properties because catechins and polyphenols compounds in the matcha are previously reported to have strong antioxidant effects (Koláčková et al., 2020; Zhao, Li, Liu, & Yang, 2014). Matcha tea infusion showed potent free radical scavenging activity as evidenced by increased 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical scavenging activity and ferric ion reducing antioxidant power. The antioxidant effects of matcha was influenced by the temperature as matcha infusion at higher temperature showed better antioxidant properties than lower temperature infusion (Jakubczyk, Kochman, Kwiatkowska, Kałdunska, et al., 2020). Therefore, consumption of matcha in the form of matcha tea (green tea) could results increased antioxidant efficacy. Another study also confirms the antioxidant potential of matcha employing DPPH and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) free radical scavenging assays (Kim et al., 2020). This study also reports that storing matcha in higher temperature for long period leads to the reduced free radical scavenging activity. catechins, crucial bioactive compound in matcha, could also leads to the profound antioxidant activity of matcha (Henning et al., 2003).

3.2. Anxiolytic and stress-reducing activities

Drinking tea is a mood freshener suggesting that matcha can counter anxiety. In fact, a recent experimental study revealed the anxiolytic properties of matcha (Kurauchi et al., 2019). Matcha tea powder significantly increased the time-duration and distance travelled in open arm maze indicating that matcha can improve open field behavior of mice. These open-field behaviors of anxious-mice were also improved by different organic solvent extract fractions of matcha. The possible mechanism of action for the anxiolytic activity of matcha was associated with the activation of dopaminergic and serotonergic neurotransmission system, because the anxiolytic activity of matcha was abolished when these signaling were blocked by using specific inhibitors. Matcha extract also increased overall locomotor actions in mice. Another study also reported that continued ingestion of high-quality matcha reduced the anxiety-like behavior in psychologically and physiologically stressed mice (Monobe et al., 2019). It was notable that sencha, a common Japanese green tea, did not demonstrate anxiolytic effect in this model mice. The anxiolytic effects was expected by the higher molar ratio of (caffeine + EGCG)/(theanine + arginine) in the Matcha.

Supporting the anxiolytic effect of matcha another independent study revealed the stress relieving ability of matcha green tea on animals as well as in clinical trials. Consumption of matcha tea lowered adrenal hypertrophy, which is an important stress marker. In addition, consumption of matcha enriched cookies significantly inhibited the stress marker salivary α-amylase activity in comparison to the placebo group. These findings clearly revealed that consumption of matcha either in the form of drink or beverages or cookies can reduce the impact of stress (Unno et al., 2019). Presence of threonine was reported to be responsible for the stress reducing effect of matcha. The anxiolytic or stress reducing effects of matcha was influenced by the presence of caffeine and epigallocatechin gallate (EGCG) in the matcha. Higher amount of threonine and the lesser ration of caffeine, EGCG, and arginine against theanine is noticed to have high beneficial effect of matcha (Unno et al., 2018).

3.3. Matcha as memory and cognitive function booster

Biological roles of matcha in central nervous system is also associated with cognition and memory. Besides its stress reducing ability, matcha was also evaluated for the improvement of cognitive function. Presence of active ingredient such as epigallocatechin gallate, theanine, and caffeine was responsible for the cognition improvement functions of matcha (Dietz et al., 2017). A recent study reported that consumption of matcha tea partially improved the cognitive performance of matcha tea in human participants, however, matcha tea consumption significantly improved the memory and task measuring dimension of attention. In addition, participants consuming matcha showed a better episodic secondary memory and speed of attention (Dietz et al., 2017) indicating that matcha can boost cognition and memory in humans. Therefore, matcha could be an appealing therapeutic strategy in dementia and Alzheimer’s disease, where improving memory can lead to the significant social benefits in patients.

3.4. Neuroprotective activities

Matcha could have possible neuroprotective effects because of its antioxidant, anxiolytic, stress reducing, and memory boosting properties. Indeed, a few previous studies reported the neuroprotective effects of matcha and its bioactive phytochemicals. Theanine and catechins showed neuroprotective effects against neuronal cell death. Theanine inhibited the glutamic acid-induced cortical neuronal death in rats. Theanine administration through ventricular route also protected the hippocampal CA1 pyramidal neurons and CA3 neurons against transient forebrain ischemia-induced neuronal death in gerbils. Alteration of the glutamate receptor functioning and glutamate transporter by theanine was mechanistically associated with the neuroprotective effect of theanine. In addition, theanine mediated prevention of oxidative alteration of LDL together with its antioxidant effects is responsible to lower the prevalence and complication of atherosclerosis which is a reason behind the protection against ischemic cerebrovascular diseases (Kakuda, 2002). Beneficial effect of green tea against Alzheimer's disease (AD) and Parkinson's disease (PD) pathogenesis has also been reported previously. Catechins from matcha was reported to have supportive neuroprotective effects through lowering inflammation, oxidative stress, apoptosis, and fibrous protein (Aβ and α-synuclein) accumulation. Catechins, more specifically EGCG, prevented fibrous protein accumulation suggesting its possible role in prevention as well as management of the AD and PD complications (Pervin et al., 2018). Neuroinflammation is a key mechanism responsible for the neuronal toxicity and neurodegeneration in most of the neurological complications (Adhikari-Devkota et al., 2019; Collins, Toulouse, Connor, & Nolan, 2012; Cui et al., 2010; Williams & Spencer, 2012). Treatment of EGCG was reported to inhibit the neuroinflammation by lowering the level of inflammatory mediators and their responsible pathways. EGCG inhibited the production of proinflammatory cytokines like TNF-α, IL-6, and IL-1β in palmitic acid- activated microglia together with inhibition of lipid accumulation. All these anti-inflammatory functions of EGCG was possible through the inhibition of the JAK2/STAT3 signaling pathway in microglia following EGCG treatment (Mao et al., 2019; Ohishi, Goto, Monira, Isemura, & Nakamura, 2016).

3.5. Anti-angiogenic and anti-inflammatory activities

Catechins from matcha such as EGCG were reported to inhibit or alter the neutrophil function by lowering the amount of neutrophil elastase. Neutrophil though is involved in hosting immune response; it also plays a critical inflammatory role in several acute and chronic inflammatory conditions. Inhibition of neutrophil elastase by Matcha green tea and EGCG might be responsible for the anti-inflammatory effect of matcha. A recent report suggested that even the 3 μM concentration of EGCG lowered the apoptosis and the subsequent cell death mediated by activated neutrophils (Donà et al., 2003). Green tea catechins EGCG also pronouncedly reduced neutrophil chemotaxis that has been induced by chemokines or inflammatory mediators. Additionally, EGCG as well as the green tea extract significantly inhibited angiogenesis in inflammatory angiogenesis model, especially neutrophil induced angiogenesis in in vivo conditions. Interestingly, inhibition of angiogenesis, fibrosis and inflammation in the pulmonary system is reported following EGCG treatment. This study revealed the strong anti-inflammatory, anti-fibrosis, or antiangiogenic potential of green tea itself as well as its active catechins.

3.6. Regulating blood glucose and microbiota by matcha

Phytochemicals presents in matcha green tea were reported to be involved in the digestion or metabolism of food products. EGG present in green tea inhibited the digestion of the starch suggesting their possible role in altering the functions of gut microbiota and to prevent the sudden increase of glucose level in patients (Forester, Gu, & Lambert, 2012). Another study supported this result by reporting that consumption of matcha in a supplement was useful for controlling the gut microbiota and blood glucose level. Altogether, consumption of green tea can be considered as a beneficial functional food for hyperglycemic/diabetic patients (Zhang et al., 2020)

3.7. Activities related to anti-obesity and other metabolic diseases

The effect of matcha on different physiological parameters of diabetic patients, including oxidative stress, metabolic conditions, and anthropometric conditions were reported in a recent study, which revealed that drinking matcha tea 4 times a day significantly lowered the systolic blood pressure, body weight, body mass index, and waist circumference. Altogether, consumption of green tea can help in maintaining blood pressure, body weight, and body mass index (Mousavi, Vafa, Neyestani, Khamseh, & Hoseini, 2013). Presence of antioxidant and biologically active catechins make matcha tea this an important functional food. Matcha green tea powder (MGTP) enriched bread biscuit was developed to study the consumer acceptability and health benefits. However, biscuits with low MGTP did not significantly affect the postprandial effect in comparison to the non-enriched one was well its well acceptability in the consumers. The reason could be because of very less amount of phytochemicals in low MGTP biscuits (Phongnarisorn, Orfila, Holmes, & Marshall, 2018).

Catechins from matcha green tea are reported to reduce total cholesterols as well as its absorption which were associated with less cardiac abnormalities in experimental rats consuming high cholesterol food. Rats were treated with EGCG in different concentration to evaluate their effects on attenuating cholesterol, lipids and glucose. Plasma level of low-density lipoproteins and total amount of cholesterol were dramatically attenuated upon EGCG administration. Additionally, animals administered oral dose of EGCG showed less cholesterol absorption (Raederstorff, Schlachter, Elste, & Weber, 2003). Another study also supported these findings as feeding of matcha in high-fat diet administered mice significantly lowered the serum level of triglycerides and cholesterol. Additionally, matcha also decreased the level of low-density lipoprotein and increased high density lipoproteins. In addition, matcha can downregulate the lipid and glucose level in mice (Xu, Ying, Hong, & Wang, 2016). Therefore, consumption of matcha can lead to the attenuation of bad cholesterol, which indicate that matcha could have potential health benefit to counter cardiovascular diseases associated with increased cholesterol and lipids.

Exercise-induced fat oxidation was reported to be increased by the consumption of caffeine, EGG and catechin which are the key ingredients of Matcha. Consumption of 1 g of Matcha in different drinks by female participants caused the increased fat oxidation, which was associated with balancing metabolic effects (Willems, Şahin, & Cook, 2018). Another study also reported that green tea consumption can boost the fat oxidation in resting as well as in post exercise (Gahreman, Wang, Boutcher, & Boutcher, 2015). In addition, similar results were observed by other research groups, in which the expression of fat metabolism genes and adipogenesis genes were altered upon matcha consumption. Matcha increased fat metabolism genes in skeletal muscle and decreased adipogenesis genes in the liver, which was possibly mediated through PPAR-γ coactivator 1-α and PPARs activation was responsible for the increase fat oxidation in rest as well as exercise induced state (Gahreman et al., 2015).

In another study, Zhou et al. (2020) reported the anti-obesity activity of matcha in experimental high-fat diet-induced obese mouse model. Authors reported that the supplementation of matcha in diet decreased the weight gain, fat accumulation and the levels of sugar and fats in blood. The ethanolic extract of matcha also showed the potent anti-inflammatory activity in palmitic acid-induced inflammation of microglial BV-2 cells through inhibition of the release of inflammatory cytokines and the expression and phosphorylation of JAK2 and STAT3. Matcha is also reported to prevent the accumulation of visceral and hepatic lipid, increase in blood glucose level, abnormal liver function and steatosis hepatitis in high fat diet fed male C57BL/6 mice (Zhou, Yu, Ding, Xu, & Wang, 2021). The anti-obesity activity of green tea powder along with three major components i.e. catechins, caffeine and L-theanine is also reported using female ICR mice model (Zheng, Sayama, Okubo, Juneja, & Oguni, 2004)

3.8. Hepatoprotective and renoprotective activities

Potential effects of matcha on protecting liver and kidney was also reported. EGCG which is an active ingredient of matcha was reported to protect kidney damage that has been induced in the diabetic nephropathy in rats. Oral administration of different concentrations of matcha in diabetic rats reduced the progression of liver and kidney damage in rats with type-2 diabetes. Matcha lowered the formation of different toxic AGEs including N(6)-(carboxylethyl)lysine (CEL) and N(6)-(carboxylmethyl)lysine (CML), inhibition of the expression of AGEs receptor further validated the protective effect of matcha from AGEs and their downstream pathways signaling that critically play a key role. Additionally, matcha treatment significantly lowered the level of total cholesterol, triglyceride, and glucose in the serum and liver which not only enhanced the liver protection but also helped to boost overall cardiovascular system. AGEs and their reactive products accumulation are the key players in the renal toxicity following Type 2 DM and inhibition of this important cascade undoubtedly can help renal system to be protected from DM mediated toxicities. Altogether, administration of matcha might play a critical role in the protection of hepatic, renal, and cardiovascular system against type 2 diabetes complications (Yamabe, Kang, Hur, & Yokozawa, 2009).

3.9. Anti-arthritic activity

Prevention of collagen-induced arthritis in mice by a polyphenolic fraction from green tea has been reported recently (Haqqi et al., 1999). Polyphenolic fractions of green tea (GTP) showed strong anti-arthritic effect against collagen-induced arthritis in animals. Polyphenols from green tea was supplied to animals orally, which inhibited the incident of arthritis almost 50 to 70% in comparison to the control group. GTP also lowered the arthritis index and significantly inhibited inflammatory markers including TNF-α, interferon gamma, and cyclooxygenase in comparison to the control group animals indicating that its anti-inflammatory effects were associated with the reduction of arthritis index. In addition, fewer inflammatory cells infiltration was observed upon GTP-administration. Treatment of animal with GTP showed dramatic reduction in endopeptidase activity indicating matcha as a potential natural remedy for arthritis (Haqqi et al., 1999).

3.10. Other biological activities

Catechins like EGCG showed a strong antibacterial effect. It also helps to reverse the tetracycline resistance by certain bacteria. EGCG stopped the bacterial growth and invasion indicating the potential antibacterial effect of matcha (Roccaro, Blanco, Giuliano, Rusciano, & Enea, 2004). In addition, catechins present in green tea were suggested to have strong antiviral potency because they inhibit the proteases which are involved in the pathogenesis viral infection like influenza and human adeno virus. EGCG significantly lowered the viral infection by blocking the viral replication. (Song, Lee, & Seong, 2005). Oral care product containing matcha lowered the accumulation of dental plaque. Prevalence of gingivitis and calculus was also reduced notably upon matcha consumption (Lindinger, 2016)

4. Conclusion and future prospects

Matcha, powder of specially cultivated tea leaves, is gaining popularity in functional food and other food markets all over the world. Various studies have reported the difference in bioactive compounds in matcha as compared to green tea and other tea formulations. The content and composition were reported to be affected by the cultivation and processing techniques. Analysis of marketed samples in various countries have shown the variable content of the bioactive compounds and it is very difficult to generalize the contents of bioactive compounds in marketed samples of matcha. There should be more proper guidelines and standardization methods to evaluate the chemical composition and their respective biological activities. Matcha as a whole, its extract and compounds have shown promising biological activities in in vitro and animal studies. However, comparatively only a few clinical studies are performed, which need future attention. The pharmacokinetic studies related to the components in matcha, their synergistic or antagonistic activities with therapeutic agents should be studied in detail. There should also be detailed research regarding formulation of matcha-containing foods.

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Conflict of interest

K.H. is an employee of Astellas Pharma Inc., Japan. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figure legends

Figure 1. Photographs of Cultivation of tea plants for matcha using sun shades (a) and matcha powder (Photograph (a) is a courtesy of Aoiseicha Co., Ltd., Aichi, Japan and the matcha powder in photograph (b) was provided by AIYA Co. Ltd., Aichi, Japan)

Figure 2. Structures of flavonoids, phenolic acids and other compounds present in matcha

Highlights

- Matcha tea powder is obtained from the leaves of tea plant grown under specific condition.
- The food market demand of matcha is increasing rapidly in recent years.
- Catechins, phenolic compounds, amino acids, and caffeine are major components
- Studies have shown its antioxidant, antianxiety and anti-stress activities among others