



Matcha (Japanese ground green tea) and cognitive function

Klaus W. Lange^{a,b,c*} and Yukiko Nakamura^{a,b,c}

^aUniversity of Regensburg, Regensburg, Bavaria, Germany

^bNara Institute of Science and Technology, Ikoma, Nara, Japan

^cJapan Society for Culture, Science and Technology, Germany

*Corresponding author: Klaus W. Lange, University of Regensburg, 93040 Regensburg, Germany. E-mail: Klaus.Lange@ur.de

DOI: 10.26599/JFB.2026.95035451

Received: June 06, 2026; Revised received & accepted: August 29, 2026

Citation: Lange, K.W., and Nakamura, Y. (2026). Matcha (Japanese ground green tea) and cognitive function. J. Food Bioact. 35: 1–11.

Abstract

Matcha is a finely ground powder made from shade-grown green tea leaves. It is primarily produced in Japan. Drinking matcha tea results in higher intake of green tea bioactives than drinking other types of green tea. Studies have found that matcha consumption may enhance cognitive function in situations with and without psychological stress, in the short and long term, and in different age groups. The effects of matcha on cognitive function may be due to stress reduction, improved sleep quality, an increased supply of vitamin K, altered intestinal microbiota composition, decreased oxidative stress, enhanced cholinergic brain function, and increased cortical capillary network angiogenesis. Matcha's stress-reducing efficiency appears to be influenced by differences in the quantities and ratios of its components, which may affect cognitive function. Matcha must contain high levels of theanine to have beneficial effects on stress and anxiety. Furthermore, the ratio of epigallocatechin gallate and caffeine to theanine and arginine must be low. Since not all marketed matcha products worldwide meet these conditions, quality control is important. Harnessing matcha's beneficial properties may effectively support cognitive function and prevent cognitive decline and dementia.

Keywords: Matcha; Green tea; L-theanine; Cognition; Dementia.

1. Introduction

Matcha is a finely ground powder made from shade-grown green tea leaves. According to the [International Organization for Standardization \(2022\)](#), matcha must be derived from the tender leaves, buds, and shoots of the *Camellia sinensis* (L.) O. Kuntze var. *sinensis*, which are grown in the shade. The leaves are steamed, dried, and ground into a fine powder without being rolled.

Powdered tea originated in China during the Tang Dynasty (618–907 CE), when tea leaves were ground into a fine powder and formed into cakes. The practice of steeping the powder in hot water is documented in “The Classic of Tea” by the Chinese tea master Lu Yu ([Lu, 1995](#)). During the Song dynasty (960–1279 CE), various tools were used to prepare a beverage called *mòchá* (powdered tea) by whisking tea powder with hot water in a bowl. Matcha was traditionally produced and consumed in Zen Buddhist monasteries ([Surak, 2012](#)). These powdered tea practices were

transmitted through cultural exchanges between China and Japan around the 12th century, primarily through Zen Buddhist monks who traveled to China to obtain books and sutras from Chinese scholars and encountered *mòchá* in temples. While the practice of *mòchá* faded in China over the next few centuries, it continued in Japan and became an integral part of Japanese Zen Buddhist culture. Matcha was also highly valued by the upper classes during the Muromachi period (1336–1573 CE), when it became fashionable to drink tea from expensive Chinese ceramics. However, tea masters such as Sen no Rikyū emphasized modesty and simplicity. This gave rise to the Japanese tea ceremony, a meditative and spiritual ritual emphasizing respect, harmony, and mindfulness (*chado* or *chanoyu*).

The practice of growing tea plants in the shade by covering them with straw, reeds, or bamboo fabrics originated in Japan in the 15th century ([Inoue et al., 2019](#)). It was originally intended to protect tea sprouts from frost damage. This practice resulted in

the development of the bright green Japanese matcha tea with its distinctive aroma and flavor. Shade cultivation inhibits photosynthesis in tea leaves, enhancing the synthesis and accumulation of biologically active compounds, including theanine, caffeine, chlorophyll, and various catechins, such as epigallocatechin gallate (EGCG). Consequently, the tea leaves retain a higher umami content (Ishigaki, 1981). Limiting exposure to sunlight also increases the amount of caffeine and total free amino acids (Ashihara, 2015; Horie et al., 2017) as well as the concentration of chlorophyll in the leaves. This results in a vibrant green color (Yoshida et al., 1959). Most matcha is produced in Japan, where it is an essential part of the traditional tea ceremony. It is also used to flavor and dye foods such as mochi, matcha lattes, green tea ice cream, desserts, and various confections.

Matcha tea contains 60–70% non-water-soluble ingredients, including fat-soluble vitamins (D, E, and K), dietary fiber, chlorophyll, and protein. Water-soluble ingredients include polyphenols, vitamins B1, B2, B3, and B12, fiber, amino acids (especially L-theanine), saponin, and minerals (Maeda-Yamamoto et al., 2013). Matcha tea leaves are protected from sunlight before harvesting, resulting in lower catechin content than green tea types prepared from leaves grown in sunlight (Goto et al., 1996; Ikegaya et al., 1984). However, catechin concentrations are three times higher when matcha is dissolved in water compared to loose-leaf green tea (Fujioka et al., 2016). Matcha has a higher caffeine content because the buds and young leaves of tea plants contain more caffeine than mature leaves (Ashihara and Suzuki, 2004). Matcha's high umami flavor comes from its high amino acid content, including L-theanine, glutamic acid, succinic acid, gallic acid, and theogallin (Kaneko et al., 2006; Ruan et al., 2010). Reducing light intensity through shading increases the total nitrogen, free amino acid (including theanine), and caffeine content of developing tea shoots in the early stages of the shading cycle. Meanwhile, unshaded leaves experience a decline in these quality-enhancing constituents. Sunlight breaks down theanine into glutamate and ethylamine (Anan and Nakagawa, 1974; Ashihara, 2015). Theanine levels also depend on the nitrogen absorbed by *C. sinensis* plant roots (Ruan et al., 2010). Thus, insufficient shielding from sunlight and a low nitrogen supply lead to the production of matcha that is low in theanine and high in EGCG.

Numerous research studies have examined the effects of green tea and its constituents, including catechins, L-theanine, and caffeine. Consuming green tea has been suggested to be associated with various health benefits regarding cardiovascular disease, cancer, and liver disease (Clement, 2009; Filippini et al., 2020; Lange, 2022). Additionally, research has explored the effects of green tea on mood, stress, and cognitive performance (Einöther and Martens, 2013; Lange et al., 2022a; Lange et al., 2022b; Sokary et al., 2023; Wang et al., 2022).

Consuming green tea is thought to promote clarity of mind and cognitive function. Matcha has long been consumed in Zen Buddhist monasteries due to its positive effects on the mind, consciousness, and mental well-being. The effects of green tea on cognitive performance and mood are mainly attributed to the amino acid L-theanine and the psychostimulant caffeine (Camfield et al., 2014). Caffeine can improve energy, motivation, concentration, and performance (Paulus et al., 2015). Combining caffeine and L-theanine enhances concentration, vigilance, and performance in complex cognitive tasks more than either compound alone (Einöther and Martens, 2013; Dietz and Dekker, 2017). EGCG has been found to increase calmness and reduce stress (Scholey et al., 2012).

Consuming matcha tea leads to a much higher intake of green tea phytochemicals than drinking other types of green tea (Dietz

and Dekker, 2017). Although matcha and green tea are both produced from the same plant, *Camellia sinensis*, they have different compositions due to their different cultivation, processing, and preparation methods. The quantities of compounds contained in green tea and matcha differ significantly. The ingestion of EGCG after consuming matcha tea has been found to be three times higher than after consuming other high-quality green teas (Weiss and Anderton, 2003). Matcha tea infusions provide significantly more antioxidant compounds than green tea. The oxygen radical absorbance capacity per gram of matcha tea powder is about ten times higher than that of average green tea (Dietz and Dekker, 2017).

Previous studies have found that three compounds found in matcha tea—L-theanine, EGCG, and caffeine—can affect cognitive performance. In recent years, several randomized controlled studies have examined the effects of matcha tea on cognitive function.

2. Randomized controlled trials investigating the effects of matcha on human cognitive function

2.1. Study by Dietz et al. (2017)

The first human intervention study examined the impact of consuming a realistic amount of matcha tea powder (4 g), equivalent to two servings of matcha tea, on the cognitive performance of individuals who consume moderate to habitual amounts of caffeine (Dietz et al., 2017). The study employed a randomized, placebo-controlled, repeated-measures, single-blind design to administer matcha tea and a solid food product (snack bar) containing matcha. Matcha tea contains approximately twice as much caffeine as L-theanine (Aucamp et al., 2000). Unlike other intervention studies that investigated the effects of tea on cognition and administered L-theanine and caffeine at a ratio of 2:1 in favor of L-theanine, Dietz et al. (2017) used a more realistic ratio of 2:1 in favor of caffeine.

A total of 23 healthy young participants (19 females and four males, with an average age of 24.7 years and an age range of 20 to 35 years) participated in four testing sessions. During each session, the participants consumed one of the following products: matcha tea, a matcha bar (each containing 4 g of matcha powder), a placebo tea, or a placebo bar. Participants completed a set of cognitive tests assessing attention, information processing, working memory, and episodic memory at baseline and 60 minutes after consuming each product. Cognitive performance was evaluated using a computerized battery of cognitive tests based on the Cognitive Drug Research methodology. This battery's sensitivity to acute cognitive improvements after the administration of various substances has been established (Wesnes, 2002; Wesnes, 2003). The battery's cognitive tasks assessed immediate word recall, simple reaction time, digit vigilance, choice reaction time, spatial working memory, numeric working memory, delayed word recall, delayed word recognition, and delayed picture recognition (Dietz et al., 2017).

Overall, this study investigated the effects of consuming two average portions of matcha, either as a beverage or incorporated into a snack bar, on the cognitive performance of healthy young individuals. The results showed that matcha had little effect on most cognitive tasks compared to the placebo conditions. However, consuming matcha products showed statistically significant improvements in tasks primarily assessing basic attention abilities and psychomotor speed. The beverage performed better than the snack bar, particularly in tasks assessing spatial working memory speed and delayed picture recognition. Interactions with glucose or other compounds present in the bar may have negatively affected

the bioavailability of matcha. Thus, the role of the food matrix (liquid versus solid) requires further investigation. Additionally, no change in participants' mood, as assessed by the Profile of Mood States (POMS), was observed.

2.2. Study by Sakurai et al. (2020)

Another trial aimed to evaluate the effects of daily matcha tea powder supplementation on cognitive function in community-dwelling elderly individuals without a diagnosis of dementia or mild cognitive impairment (Sakurai et al., 2020). The study was a randomized, placebo-controlled, double-blind 12-week trial. Participants received 1.5 g of matcha powder or a placebo black tea-flavored powder twice daily for 12 weeks. Their cognitive function was evaluated using the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) and the Mini-Mental State Examination (MMSE) (Folstein et al., 1975). Memory function was evaluated using the Wechsler Memory Scale–Delayed Recall (WMS-DR) (Wechsler, 2010). Of the participants, 54 completed all cognitive tests at the beginning and end of the trial (15 men and 39 women with a mean age of 73.6 years and an age range of 60 to 84 years; $n = 28$ in the active condition and $n = 26$ in the placebo condition).

There were no statistically significant changes in cognitive test scores (MoCA and MMSE) between the beginning of the trial and the 12-week follow-up, nor between the active and placebo groups. There was also no significant change in memory test scores between the active and placebo groups (Sakurai et al., 2020). However, a sex-specific analysis revealed a statistically significant improvement in the MoCA score in the active group of females compared to the placebo group. Further analysis of the MoCA's cognitive domains found significant improvement in the language domain for female participants in the active group compared to the placebo group. No significant changes were observed in MMSE scores or memory testing. In the male subgroup, no significant changes in the MoCA, MMSE, or memory function scores were found between the active and placebo groups (Sakurai et al., 2020).

The beneficial effects of matcha on cognition in female participants aligns with previous findings showing that healthy elderly women had improved working memory after taking a large dose of decaffeinated green tea extract (Liu et al., 2018). Additionally, the lack of positive effects of matcha on men's cognitive abilities may be due to the significantly smaller number of male participants compared to females. This study used three cognitive tests: two screening tests for dementia and a logical memory delayed recall test. Using tests that assess more complex cognitive functions may have revealed additional effects of matcha tea on cognitive functioning. In summary, the findings of this study suggest that daily matcha powder supplementation may protect against cognitive decline in community-dwelling elderly women.

2.3. Study by Baba et al. (2021c)

Psychological stress may affect cognitive function. A randomized, placebo-controlled, parallel-group, double-blind study investigated the effects of matcha intake on the attentional function of young adults after mild acute stress (Baba et al., 2021c). The study included 42 healthy men and women aged 25 to 34 years whose stress levels were assumed to be work-related. Participants were randomly assigned to the matcha or placebo group. Those in the matcha group consumed 2 g of matcha daily for two weeks. Mild psychological stress was induced using the Uchida-Kraepelin test, which involves adding single-digit numbers for 30 minutes and

is thought to increase sympathetic nervous system activity (Li et al., 2004). Then, memory, attention, facial expression recognition, working memory, visual information processing, and motor function were assessed using the Cognitrix cognitive function test battery developed by CNS Vital Signs (Gualtieri and Johnson, 2006). Subjective levels of fatigue were evaluated using a visual analog scale before the Uchida-Kraepelin test and after the Cognitrix tests (Baba et al., 2021c).

Compared to baseline, the visual analog scale responses obtained after the Uchida-Kraepelin and Cognitrix tests indicated increased fatigue and decreased concentration, thinking ability, and energy levels, suggesting that taking these tests induced mild stress. Matcha intake did not affect the participants' fatigue, concentration, thinking ability, or energy levels. However, the matcha group had significantly faster reaction times on the Stroop test for attentional function than the placebo group. Additionally, the matcha group demonstrated a statistically significant increase in correct responses for positive emotions in the emotion perception test. This test evaluates social cognitive function by measuring the ability to recognize facial expressions, which deteriorates with fatigue (van der Helm et al., 2010). No significant differences between groups were observed in the other tests. Taken together, these results suggest that matcha mitigates the decline in attentional function and has a beneficial effect on social cognition after exposure to mild stress in young adults.

2.4. Study by Baba et al. (2021b)

Another study examined the effects of matcha on cognitive function in middle-aged and older adults exposed to mild, acute psychological stress. Furthermore, the role of the caffeine in matcha in improving cognitive function was investigated by comparing the effects of matcha and caffeine (Baba et al., 2021b). Since previous studies showed that the effects of catechins (Baba et al., 2020) and L-theanine (Baba et al., 2021a) on cognitive function differ depending on intake duration, the effects of single and continuous matcha administration for 12 weeks were examined. In a randomized, placebo-controlled, parallel-group, double-blind study, 51 healthy Japanese men and women aged 50 to 69 years who had self-reported a decline in cognitive function were randomly assigned to one of three groups: matcha, caffeine, or placebo. Participants ingested nine capsules daily, containing either matcha (2 g total), caffeine, or a placebo. The daily caffeine intake (66 mg) was the same in the matcha and caffeine groups. The effects of matcha, caffeine, and placebo were examined after the first capsule (single dose) and after 12 weeks of continuous intake under mild stress conditions. Mild acute stress was induced using the Uchida-Kraepelin test (UKT) (Li et al., 2004), and tests from the Cognitrix battery were used to examine cognitive function (Gualtieri and Johnson, 2006).

The main results of this study are as follows. Caffeine improved attentional function after a single dose, which may explain the reduced reaction time after consuming matcha. The effect of caffeine on accelerating reaction time and focus appears to be only acute. However, matcha was found to improve work performance more than caffeine. Additionally, continuous intake was more beneficial for the matcha group under stress than for the caffeine group (Baba et al., 2021b). In summary, ingesting matcha (which contains caffeine) improves attention and work performance under psychological stress compared to caffeine alone. Future studies should analyze the effects of different caffeine and theanine dosages, the ratio of theanine to caffeine, and the interaction between caffeine, theanine, and catechins.

2.5. Study by Uchida et al. (2024)

A cross-sectional observational study showed that the risk of cognitive decline, as indicated by a score below 26 on the Japanese version of the Mini Mental State Examination (MMSE-J), was significantly lower among individuals who consumed at least 200 milliliters of green tea daily. These results suggested a positive correlation between regular green tea consumption and maintained cognitive function (Kuriyama et al., 2006). Thus, a recent 12-month, randomized, placebo-controlled, parallel-group, double-blind clinical study examined the potential of matcha to delay cognitive decline in community-dwelling older adults aged 60 to 85 years (Uchida et al., 2024). To examine the effects of matcha consumption in the early stages of cognitive impairment, the study included individuals with mild cognitive impairment and subjective cognitive decline (Molinuevo et al., 2017). Although mild subjective cognitive decline is not classified as a disease, several studies have suggested an association between subjective cognitive decline and an increased risk of developing cognitive impairment (Mitchell et al., 2014; Pike et al., 2022). Ninety-nine participants (64 with subjective cognitive decline and 35 with mild cognitive impairment) were randomized into two groups: one receiving 2 g of matcha daily and the other receiving a placebo.

Cognitive testing and other assessments were performed at the beginning and end of the 12-month intervention period. The primary outcome measures were the Japanese version of the Montreal Cognitive Assessment (MoCA-J) and the Alzheimer's Disease Cooperative Study-Activities of Daily Living (ADCS-ADL) scores. Additional outcome measures included the Mini-Mental State Examination-Japanese version (MMSE-J), the Repeatable Battery for the Assessment of Neuropsychological Status-Japanese version (RBANS), the Alzheimer's Disease Assessment Scale-Cognitive Subscale-Japanese version (ADAS-Jcog), and the CNS Vital Signs computerized neurocognitive battery (Gualtieri and Johnson, 2006; Iverson et al., 2007). The CNS Vital Signs battery tests used to assess cognitive functioning in this study included the Stroop test, as well as tests of shift attention, continuous performance, and perception of emotion. These tests used scores of social acuity, reaction time, complex attention, cognitive flexibility, executive function, and simple attention. Additionally, sleep quality was assessed using the Japanese version of the Pittsburgh Sleep Quality Index (PSQI) (Doi et al., 2000).

Compared to the placebo group, the matcha group showed no statistically significant changes in MoCA-J and ADCS-MCI-ADL scores. However, matcha consumption led to significant improvements in certain cognitive functions, such as social acuity, as assessed by the perception of facial emotions test. Additionally, PSQI scores indicated an improvement in sleep quality from baseline to 12 months with matcha consumption (Uchida et al., 2024).

The absence of effects of matcha on the primary outcomes, the Montreal Cognitive Assessment-Japanese version (MoCA-J) and the Alzheimer's Disease Cooperative Study-Activities of Daily Living (ADCS-ADL), may be due to their insensitivity to slight changes in cognitive function. These tools are commonly used for clinical diagnoses of cognitive impairment and dementia rather than for assessing early stages of cognitive decline. Studies have shown that facial emotion recognition is affected in individuals with subjective cognitive decline and mild cognitive impairment (Pietschnig et al., 2016; Weiss et al., 2008). Furthermore, a cross-sectional analysis of over 4,000 individuals revealed impaired recognition of facial emotions in the early stages of cognitive impairment (Virtanen et al., 2017). The study by Uchida et al. (2024) suggests that matcha consumption may enhance social cognition.

The decreasing trend in the PSQI score in the matcha group may be due to theanine. Theanine intake (200 mg/day) for four weeks has been shown to significantly decrease the PSQI score in healthy adults (Hidese et al., 2019).

In conclusion, this study's findings suggest that regular matcha consumption may improve emotional perception and sleep quality in elderly individuals with mild cognitive impairment, offering an effective cognitive enhancement strategy. However, this needs to be confirmed by future studies with larger sample sizes that employ more objective measures to examine sleep architecture.

Table 1 presents a summary of randomized controlled trials investigating the effects of matcha on human cognitive function.

3. Potential mechanisms involved in matcha's effects on cognitive functioning

3.1. Stress reduction

Both physical and psychological stress can affect the neuronal functioning related to cognition in the hippocampus and other brain regions (Kim and Kim, 2023). Perceived stress can have long-term physiological and psychological consequences, and it has recently been suggested to be independently associated with prevalent and incident cognitive impairment (Kulshreshtha et al., 2023). Furthermore, exposure to chronic stress appears to considerably contribute to the development of cognitive dysfunction in various mental disorders (Girotti et al., 2024).

The stress-reducing and anti-anxiolytic effects of green tea are commonly attributed to L-theanine (Wang et al., 2022). The potential of matcha to reduce stress, as well as the effects of its quantity and ratio on stress reduction, were examined in a mouse model of psychosocial stress. The outcome variable was suppression of hypertrophy of the adrenal glands, which play a critical role in stress response (Unno et al., 2018). Adrenal hypertrophy has been shown to be suppressed by antidepressant and anxiolytic medications (Unno et al., 2013).

To induce psychosocial stress, the mice were exposed to confrontational stress related to their territory for 24 hours after being reared individually for six days. Their adrenal glands became significantly enlarged, reaching peak size after 24 hours. The experimental dose of matcha was chosen based on human consumption, with 2–3 g of matcha for humans corresponding to 33–50 mg/kg for mice. The stress-reducing effects of matcha were assessed by weighing the adrenal glands. The effects of matcha and its components were examined in 15 groups of mice, for a total of 86 animals. The mice consumed a powdered diet containing matcha or its components for seven days (single rearing for six days and confrontational stress for one day). The administered matcha samples varied in their molar amounts of caffeine and EGCG (Unno et al., 2018).

Theanine and arginine are the most and second most abundant amino acids in Japanese matcha, respectively. They were confirmed to have a significant stress-reducing effect. Meanwhile, glutamate and glutamine, the third and fourth most abundant amino acids, showed no effect (Unno et al., 2016). Suppressing adrenal hypertrophy required a theanine dosage of 0.32 mg/kg or more (Unno et al., 2016). Theanine intake was found to suppress adrenal hypertrophy in a dose-dependent manner, and a similar correlation was observed for arginine. No relationship was seen between caffeine intake and adrenal hypertrophy.

The effect of theanine on adrenal gland weight was reversed when the molar concentration of caffeine was twice as high and the molar ratio of EGCG was equal. However, a 0.7 molar ratio of ar-

Table 1. Randomized controlled trials of the effects of matcha on cognitive functions in humans

Authors	Participants	Independent variables	Dependent variables	Results	Conclusions	Limitations
Dietz et al. (2017)	23 young adults (4 men, 19 women; mean age 24.7 years).	Matcha tea, matcha bar (single dose of 4 g of matcha powder), placebo tea, placebo bar.	Cognitive performance (attention, information processing, working memory, episodic memory) assessed 60 min after matcha or placebo administration.	Significant improvements in basic attention abilities and psychomotor speed after intake of matcha tea and matcha bar (better performance after matcha tea than matcha bar). Little effect on other cognitive tasks.	Improved basic attentional functions after matcha intake. Food matrix plays a role.	Small sample size. Limited generalization.
Sakurai et al. (2020)	54 elderly adults without mild cognitive impairment or dementia (15 men, 39 women; mean age 73.6 years).	Daily matcha tea powder (1.5 g) or placebo for 12 weeks.	MoCA, MMSE, Wechsler Memory Scale–Delayed Recall.	No significant changes in MoCA and MMSE after 12 weeks. No significant differences in MoCA, MMSE, and memory test scores between active and placebo groups. Significant improvement in MoCA score and MoCA language domain in females of active group versus placebo. No changes in men.	Possible protective effect of matcha powder against cognitive decline in elderly women.	Short intervention period of 12 weeks. Small number of male participants.
Baba et al. (2021b)	42 young adults (16 men, 26 women; mean age 29.8 years).	Daily matcha (2 g) or placebo for 2 weeks.	Subjective fatigue. Cognitive functions (Cognitrix battery) under mild psychological stress.	No effect of matcha on fatigue, concentration, or thinking. Significantly faster reaction times in attentional function. Significant increase in correct responses for positive emotions in emotion perception test.	Mitigating effect of matcha on decline in attentional function. Beneficial effect of matcha on social cognition.	Short intervention period of 2 weeks. Limited generalization.
Baba et al. (2021a)	51 middle-aged and elderly adults (23 men, 28 women; mean age 58 years) with self-reported decline in cognitive function.	Single dose and continuous administration for 12 weeks of matcha (2 g), caffeine (66 mg, same as in matcha), or placebo.	Cognitive functions (Cognitrix battery) under mild stress.	Only acute beneficial effect of caffeine on reaction time and focus. Better improvement of work performance by matcha than caffeine. Better effects of continuous intake of matcha under stress compared to caffeine.	Improved attention and work performance after matcha under mild psychological stress compared to caffeine alone.	Short intervention period of 12 weeks. Limited generalization.
Uchida et al. (2024)	99 older adults (64 with subjective cognitive decline, 35 with mild cognitive impairment).	Daily matcha (2 g) or placebo for 12 months.	MoCA-J, ADCS-ADL, MMSE-J, RBANS, ADAS-Jcog, Cognitrix cognitive battery, PSQI	Significantly improved perception of facial emotions after matcha intake. Improved sleep quality (PSQI) with matcha intake. No significant changes in MoCA-J and ADCS-MCI-ADL scores after matcha intake.	Improved emotional perception and sleep quality in mild cognitive impairment. Possible cognitive enhancement.	Small sample size. No objective measures of sleep quality.

ginine to theanine counteracted the antagonizing effects of caffeine and EGCG, suggesting an essential role of arginine in suppressing adrenal hypertrophy. The molar ratio of caffeine and EGCG to theanine and arginine was 1.8 in samples that effectively reduced stress and ≥ 3.6 in samples that were ineffective (Unno et al., 2018). These findings suggest that the molar ratios of arginine, caffeine, and EGCG influence the stress-reducing effects of theanine.

In conclusion, the dose-dependent suppression of adrenal hypertrophy in mice after consuming matcha suggests a stress-reducing effect. However, the molar ratio of arginine, caffeine, and EGCG appears to influence the stress-reducing effects of theanine. For an effective stress-reducing outcome, the molar ratio of caffeine and EGCG to theanine and arginine should be less than two.

Based on the results of the animal study, test-matcha, which was expected to have a stress-reducing effect, and placebo-matcha, which was not, were selected for a randomized, parallel-group, single-blind trial (Unno et al., 2018). Thirty-nine healthy students (23 men and 16 women with a mean age of 23 years) were randomly assigned to the test-matcha group ($n = 19$) or the placebo-matcha group ($n = 20$). The participants consumed test- or placebo-matcha tea daily for 15 days, ingesting 3 g of matcha per day. The caffeine content of the test and placebo matcha was not different. The 7-day period of routine university life and the first eight days of the students' practice program outside the university were analyzed. Salivary α -amylase activity was measured as an indicator of stress and sympathetic nervous system activation in response to physiological and psychosocial stress (van Stegeren et al., 2006). Anxiety in response to stress was assessed using the Japanese State-Trait Anxiety Inventory (STAI).

Before the practice phase outside the university, the STAI values of the participants who consumed test-matcha were significantly lower than those of the placebo-matcha group. By the eighth day of practice, however, there was no significant difference between the two groups. Although the baseline level of α -amylase activity before consuming matcha did not differ between participants in the test- and placebo-matcha groups, the level at the university was significantly lower in the test-matcha group. Throughout the practice program, α -amylase activity was lower in the test-matcha group. Subjective stress levels after practice were slightly lower in the test group than in the placebo group. In summary, matcha tea ingestion resulted in a statistically significant decrease in anxiety levels and reduction in physiological stress compared to the placebo group (Unno et al., 2018).

The stress-reducing effect of matcha was also tested in cookies containing either test-matcha (caffeine and EGCG to theanine and arginine molar ratio of 1.79) or placebo-matcha (caffeine and EGCG to theanine and arginine molar ratio of 10.64). Healthy university students consumed three pieces of cookie containing 4.5 g of matcha daily for 15 days (Unno et al., 2019). Salivary α -amylase activity decreased significantly in the test-matcha group compared to the placebo group. Thus, the caffeine and EGCG to theanine and arginine ratio appears to be an essential indicator for stress suppression. In summary, matcha in confectionery products has a stress-reducing effect. However, to have this effect, matcha must contain less caffeine and EGCG than twice the molar amount of theanine and arginine. The daily intake of matcha in confectionery products with a low caffeine and EGCG-to-theanine and arginine molar ratio may provide stress-reducing benefits to individuals who do not drink green tea.

In conclusion, healthy individuals who consumed 3 g of matcha tea daily showed significant reductions in anxiety and physiological stress. Stress reduction was also observed with cookies formulated with a specific ratio of matcha components (theanine, arginine, caffeine, and EGCG).

3.2. Sleep quality

There appears to be a close relationship between sleep quality and cognitive function (Xu et al., 2011; Sun et al., 2013; Yaffe et al., 2014). In a longitudinal study of individuals aged 50 to 80, the risk of developing mild cognitive impairment over an average observation period of 5.2 years was significantly higher for participants with a PSQI score greater than 5 (indicating poor sleep quality) than for those with a score of 5 or less (Brachem et al., 2020). These findings suggest that improving sleep quality may positively impact cognitive function. Aging is commonly associated with deteriorating sleep quality, and sleep disturbances and short sleep duration are risk factors for dementia (Sabia et al., 2021). Sleep deprivation can lead to inflammation and an increased amyloid- β burden in the brain (Shokri-Kojori et al., 2018; Irwin and Vitiello, 2019). Uchida et al. (2024) found that older adults with subjective cognitive decline or mild cognitive impairment experienced statistically significant improvements in social cognition and reduced PSQI scores after consuming 2 g of matcha daily for 12 months. Thus, matcha may benefit cognitive functioning in the elderly by improving sleep quality.

Theanine in matcha has been shown to improve sleep quality and cognitive function. However, caffeine is believed to negatively impact sleep quality. A recent randomized, placebo-controlled, parallel-group, double-blind study investigated the effects of matcha on various sleep parameters (Baba et al., 2024). Healthy men and women aged 27 to 64 consumed 2.7 grams of matcha daily for four weeks. No statistically significant differences were found between the matcha and control groups regarding sleep latency, total sleep time, wake time after sleep onset, or sleep efficiency, as assessed by electroencephalography (EEG). However, a sleep questionnaire completed immediately after waking revealed an increased satisfaction with sleep time. Additionally, EEG measures indicated a significant reduction in wake-up time following matcha consumption. Furthermore, Beck Depression Inventory-II scores tended to decrease (Baba et al., 2024). In summary, continuous matcha consumption may improve subjective sleep quality and emotional stability without significantly altering objectively measured sleep parameters. This may contribute to stress reduction and improved cognition (see section 3.1).

3.3. Vitamin K

Matcha powder contains several compounds, including EGCG, caffeine, and theanine, that have been linked to cognitive function. These compounds can significantly improve cognitive performance by modulating dopaminergic, cholinergic, and glutamatergic activities in the brain, either separately or synergistically (Dietz and Dekker, 2017). Matcha tea contains higher concentrations of fat-soluble nutrients, such as vitamins K and E, and lutein, than regular green tea. These nutrients have been reported to positively impact cognitive function (Nouchi et al., 2020; Presse et al., 2013). Low lifetime intake of vitamin K has been found to lead to mild cognitive impairment in aged rats (Carrié et al., 2011).

Several research findings suggest a relationship between vitamin K levels and cognitive functioning, indicating that vitamin K plays a role in brain function (Alisi et al., 2019). A deficiency in vitamin K may be associated with the onset of cognitive impairment (Ferland, 2012). Furthermore, vitamin K has procoagulant efficacy. Vitamin K antagonists are therefore widely used as oral anticoagulants, but they may negatively affect the volume of certain brain regions (Brangier et al., 2018) and cognitive functions,

such as verbal fluency and memory (Ferland et al., 2016).

Sakurai et al. (2020) attempted to explore the link between dietary habits and cognitive function in their study (see section 2.2). The researchers performed a multiple regression analysis to determine the relationship between daily nutrient intake (excluding the trial's test drinks), as assessed using the Brief Self-administered Diet History Questionnaire (Kobayashi et al., 2012), and the MoCA score difference for female participants. Higher vitamin K intake in the daily diet showed a statistically significant inverse correlation with increased MoCA scores after matcha administration. This suggests that matcha's positive effect on cognition may be more pronounced in individuals with lower daily vitamin K intake, as matcha consumption can supplement prevalent vitamin K deficiencies. Therefore, an adequate daily intake of vitamin K may be important for cognitive functioning, and the vitamin K in matcha tea may help maintain adequate levels and improve cognitive performance. Supplementing deficient vitamin K levels could possibly ameliorate cognitive deficits. However, further randomized trials with large samples and standardized methods for cognitive evaluation, dietary intake of vitamin K, and serum levels are needed to confirm the hypothesis that low vitamin K levels are related to cognitive decline.

3.4. Gut microbiota

The human gastrointestinal tract is home to diverse microbial species that can greatly impact brain function. Bidirectional communication along the gut–brain axis involves neural, metabolic, endocrine, and immune pathways and occurs between the intestines and the central nervous system (Bagheri et al., 2026). Research has reported a relationship between gut microbiota and cognitive function or impairment in various mental disorders (Lange, Lange, Nakamura, and Kanaya, 2020; Meyer et al., 2022). Emerging research suggests that enhancing cognition may be possible through human gut microbiota (Zhang et al., 2025). Matcha tea contains more nutrients, such as catechins and insoluble dietary fiber, than regular green tea and is believed to have positive effects on gut microbiota (Kochman et al., 2020).

A recent study examined the impact of matcha tea on gut microbiota. Young adults were randomly assigned to one of two groups: the matcha tea group ($n = 16$), which received 1.5 g of matcha tea, and the placebo group ($n = 17$). Both groups were required to drink the provided beverages for two weeks (Morishima et al., 2023). Feces were collected from the participants before and after the treatment period and analyzed using 16S rRNA metagenomic sequencing to determine the composition of the fecal microbiota. Beta diversity (or difference or dissimilarity) in microbial community composition was shown to be significantly altered two weeks after continuous matcha tea consumption, but not in the placebo group. The matcha tea group had 30 genera of bacteria that changed significantly, while the placebo group only had three. Bacterial genera whose abundance changed significantly before and after matcha tea consumption included *Fusobacterium* and *Coprococcus* (Morishima et al., 2023). Decreased abundance of *Fusobacterium* and increased abundance of *Coprococcus* in the gut microbiota of the matcha tea group are thought to confer potential health benefits to the host. A high proportion of *Fusobacterium* has been found in the gut microbiota of patients with inflammatory bowel disease and colorectal cancer (Lee et al., 2016; Repass, 2018), while a lower abundance of *Coprococcus* has been reported in people with inflammatory bowel disease (Nishino et al., 2018). EGCG appears to inhibit the growth of *Fusobacterium* (Liu et al., 2020), while insoluble dietary fiber may increase *Coprococcus*

abundance in the intestinal microbiota (Chen et al., 2019).

In conclusion, consuming matcha tea for two weeks altered the fecal microbiota. Further research is needed to determine whether matcha affects bacterial genera related to cognitive functions.

3.5. Other mechanisms

Various other mechanisms have been suggested to explain the effects of matcha on cognitive functioning. Matcha's antioxidant function, conferred by EGCG, may play a role in cognitive functioning since neurons are vulnerable to oxidative stress due to their high content of unsaturated fatty acids. Therefore, matcha may prevent cognitive impairment by suppressing oxidative stress and protecting the integrity of the brain's antioxidant systems (Kim et al., 2020).

Studies have shown that matcha improves cognitive dysfunction induced by metabolic imbalance in mice fed a high-fat diet (Kim et al., 2020). This study found that matcha protects against insulin resistance and cognitive impairment caused by cerebral inflammatory responses. Matcha improved short-term and long-term memory and spatial cognitive function by regulating glucose tolerance.

Matcha can also prevent cognitive impairment by improving the function of the central cholinergic transmission system, which is closely linked to cognitive function (Kim et al., 2020). In mice, a high-fat diet was shown to increase the expression of acetylcholinesterase, which catalyzes the breakdown of the neurotransmitter acetylcholine. A high-fat diet also triggers the aggregation of amyloid- β , inducing neuronal death in the brain (Kim et al., 2020). However, matcha intake improved cholinergic function by downregulating acetylcholinesterase and reducing amyloid- β expression, while also upregulating choline acetyltransferase in the hippocampus and cerebral cortex (Kim et al., 2020).

The central nervous system requires an adequate capillary network to maintain undisturbed brain function. Due to the age-related reduction in cortical capillaries, the discovery of the angiogenic potential and protective effects of matcha and its components, vitamin K₁ and lutein, on capillary aging in the cerebral cortex of mice could have clinical significance (Iwai et al., 2021).

4. Future directions

Epidemiological studies have shown that the high consumption of certain foods in Japan may have health and longevity benefits (Lange and Nakamura, 2024, 2025a, 2025b, 2026a, 2026b). In this respect, green tea and matcha have attracted attention due to their bioactive components, which may benefit human health, including cognitive function.

4.1. Effects of matcha on cognitive decline and dementia

Aging is often associated with the deterioration of cognitive function, which appears to depend on lifestyle factors, including nutrition (Lange et al., 2026). For example, several food bioactives, including polyunsaturated fatty acids (Lange, 2020a, 2020b) and natural antioxidants (Lange, 2018; Lange and Li, 2018; Lange, Lange, Nakamura, and Li, 2020), have been suggested to reduce the risk of cognitive decline and dementia. Considering the positive impact of matcha on cholinergic function in the brain (see section 3.5), one might wonder if matcha consumption can prevent

cognitive decline and dementia. A systematic review of observational studies found that green tea consumption may reduce the risk of mild cognitive impairment, cognitive impairment, dementia, and Alzheimer's disease (Kakutani et al., 2019). Other findings also suggest a beneficial role of matcha in preventing neurodegeneration and dementing disorders.

EGCG may serve as a neuroprotective agent due to its ability to influence the inflammatory processes associated with neurodegeneration (Valverde-Salazar et al., 2023). EGCG can also inhibit the co-aggregation of amyloid proteins, such as amyloid- β and human islet amyloid polypeptide. These proteins are associated with the development of Alzheimer's disease (Li et al., 2024). EGCG and other catechins found in green tea may prevent age-related cognitive decline by increasing the expression of genes involved in synaptic plasticity in the hippocampus (Unno et al., 2020). Additionally, systemic inflammation induced by lipopolysaccharides plays a significant role in neurodegeneration. EGCG inhibits the production of reactive oxygen species induced by lipopolysaccharides, suggesting its neuroprotective efficacy in inflammation-mediated neurodegenerative diseases (Liu et al., 2016).

Caffeine may also have neuroprotective effects against dementia (Merighi et al., 2023). It may decrease the risk of cognitive decline (Ritchie et al., 2007) and slow the aging process in the brain by reversing oxidative processes and reducing neuroinflammation (Ullah et al., 2015). The beneficial effects of caffeine in preventing neurodegeneration are also related to a reduction in amyloid- β deposition (Arendash et al., 2009). In a prospective cohort study of over 130,000 people with up to 43 years of follow-up, higher consumption of caffeinated coffee was associated with more favorable cognitive outcomes and a statistically significant association with a lower risk of dementia, while intake of decaffeinated coffee was not found to be significantly associated with dementia risk (Zhang et al., 2026).

Among 8,766 community-dwelling Japanese individuals, no statistically significant correlations were observed between green tea intake and hippocampal or total brain volume (Shibata et al., 2025). However, green tea consumption was inversely correlated with cerebral white matter lesions, suggesting a potential role of matcha in preventing dementia (Shibata et al., 2025). Further research is needed to confirm and expand upon the current findings regarding the role of matcha in preventing cognitive decline and dementia.

4.2. Quality of matcha marketed in Japan and other countries

The number of people consuming green tea and matcha for health benefits is increasing worldwide. The theanine content of matcha varies depending on the quality of the green tea used to make it. Matcha is rich in theanine and low in catechin. However, not all marketed matcha products satisfy these conditions. Low-grade green teas with low amino acid content have also been reported to be sold as "matcha" (Horie et al., 2018). A recent study examined the components of matcha sold in Japan and other countries. When humans ingest 3 g of matcha daily, matcha containing levels of theanine exceeding 17 mg/g may reduce stress. Fifty out of 76 Japanese samples met this condition. However, of the 67 samples sold in other countries, only six met this criterion (Unno et al., 2018). Additionally, for matcha to have stress-reducing efficacy, the molar ratio of caffeine and EGCG to theanine and arginine must be less than two. Thirty-two of the 76 Japanese samples and one of the 67 non-Japanese samples met this condition (Unno et al., 2018). This study assessed the stress-reducing effect of matcha (at a dose of 3 g daily) sold in Japan and other countries. It was

expected that about 42% of the matcha marketed in Japan would suppress stress, as opposed to only one of the matcha products sold abroad because the amounts of theanine and arginine were low while the amounts of caffeine and EGCG were high. Thus, not all marketed matcha satisfied the condition of high theanine and low catechin levels. Therefore, greater attention is needed when evaluating the cognitive and mental effects of matcha. The low amino acid content and the counteracting effect of caffeine and EGCG on theanine are rarely considered. This may lead to confusing findings. For example, a Profile of Mood States (POMS) assessment revealed no significant change in mood after consuming 4 g of matcha tea (Dietz et al., 2017). However, the molar ratio of caffeine and EGCG to theanine was greater than two. The POMS results may have differed if a matcha sample with lower caffeine and EGCG content had been used. In conclusion, quality checks are critical when using matcha samples to study cognitive function.

4.3. Side effects of matcha

Consuming matcha can have unwanted side effects since it involves ingesting relatively large amounts of oxalate due to its cultivation in the shade (Morita and Tuji, 2002). Oxalate binds to calcium ions to form calcium oxalate, which may cause kidney stones. Therefore, it may be necessary to evaluate the maximum daily intake of matcha tea for individuals who are sensitive to urinary stone formation. Additionally, oxalate can remove calcium from the body, which could lead to osteoporosis and heart disorders. Further research in this respect is required.

5. Conclusion

Because of how matcha is farmed and harvested, drinking matcha tea results in a much higher intake of green tea bioactive compounds than drinking other types of green tea. Studies in humans have shown that matcha consumption may enhance cognitive function in situations with and without psychological stress, in the short and long term, and in different age groups.

The mechanisms involved in matcha's effects on cognitive functioning may include stress reduction, improved sleep quality, an increased supply of vitamin K, altered intestinal microbiota composition, decreased oxidative stress, enhanced cholinergic brain function, and increased cortical capillary network angiogenesis.

The quantities and ratios of matcha components appear to influence the efficiency of its stress-reducing activity, which may affect cognitive function. Caffeine and EGCG counteract the stress-reducing effect of theanine, while arginine enhances it. To have beneficial effects on stress, anxiety, and mood, matcha must contain high levels of theanine and arginine while having a low ratio of EGCG and caffeine to theanine and arginine. Quality control in this respect is essential, as not all marketed matcha products worldwide meet these conditions.

In summary, harnessing matcha's stress-reducing properties and other benefits may effectively support overall daily well-being and cognitive functioning and possibly prevent cognitive decline and dementia.

References

- Alisi, L., Cao, R., Angelis, C.d.e., Cafolla, A., Caramia, F., Cartocci, G., Librandino, A., and Fiorelli, M. (2019). The relationships between vitamin K

- and cognition: A review of current evidence. *Front. Neurol.* 10: 239.
- Anan, T., and Nakagawa, M. (1974). Effect of light on chemical constituents in the tea leaves. *Nippon Nogeikagaku Kaishi (J. Jpn. Agric. Chem. Soc.)* 48: 91–96.
- Arendash, G.W., Mori, T., Cao, C., Mamcarz, M., Runfeldt, M., Dickson, A., Rezai-Zadeh, K., Tane, J., Citron, B.A., Lin, X., Echeverria, V., and Potter, H. (2009). Caffeine reverses cognitive impairment and decreases brain amyloid-beta levels in aged Alzheimer's disease mice. *J. Alzheimers Dis.* 17: 661–680.
- Ashihara, H. (2015). Occurrence, biosynthesis and metabolism of theanine (γ -glutamyl-L-ethylamide) in plants: A comprehensive review. *Nat. Prod. Commun.* 10: 803–810.
- Ashihara, H., and Suzuki, T. (2004). Distribution and biosynthesis of caffeine in plants. *Front. Biosci.* 9: 1864–1876.
- Aucamp, J.P., Hara, Y., and Apostolides, Z. (2000). Simultaneous analysis of tea catechins, caffeine, gallic acid, theanine and ascorbic acid by micellar electrokinetic capillary chromatography. *J. Chromatogr. A* 876: 235–242.
- Baba, Y., Inagaki, S., Nakagawa, S., Kaneko, T., Kobayashi, M., and Takihara, T. (2020). Effect of daily intake of green tea catechins on cognitive function in middle-aged and older subjects: A randomized, placebo-controlled study. *Molecules* 25: 4265.
- Baba, Y., Inagaki, S., Nakagawa, S., Kaneko, T., Kobayashi, M., and Takihara, T. (2021a). Effects of L-theanine on cognitive function in middle-aged and older subjects: A randomized placebo-controlled study. *J. Med. Food* 24: 333–341.
- Baba, Y., Inagaki, S., Nakagawa, S., Kobayashi, M., Kaneko, T., and Takihara, T. (2021b). Effects of daily matcha and caffeine intake on mild acute psychological stress-related cognitive function in middle-aged and older adults: A randomized placebo-controlled study. *Nutrients* 13: 1700.
- Baba, Y., Kaneko, T., and Takihara, T. (2021c). Matcha consumption maintains attentional function following a mild acute psychological stress without affecting a feeling of fatigue: A randomized placebo-controlled study in young adults. *Nutr. Res.* 88: 44–52.
- Baba, Y., Takihara, T., and Okamura, N. (2024). Matcha does not affect electroencephalography during sleep but may enhance mental well-being: A randomized placebo-controlled clinical trial. *Nutrients* 16: 2907.
- Bagheri, S., Ryszkiet, I., and Stanek, A. (2026). Gut microbiota impact on cognitive function in humans. *Nutrients* 18: 369.
- Brachem, C., Winkler, A., Tebrügge, S., Weimar, C., Erbel, R., Jöckel, K.-H., Stang, A., Dragano, N., Moebus, S., Kowall, B., and Jokisch, M. (2020). Associations between self-reported sleep characteristics and incident mild cognitive impairment: The Heinz Nixdorf Recall Cohort Study. *Sci. Rep.* 10: 6542.
- Brangier, A., Celle, S., Roche, F., Beauchet, O., Ferland, G., and Annweiler, C. (2018). Use of vitamin K antagonists and brain morphological changes in older adults: An exposed/unexposed voxel-based morphometric study. *Dement. Geriatr. Cogn. Disord.* 45: 18–26.
- Camfield, D.A., Stough, C., Farrimond, J., and Scholey, A.B. (2014). Acute effects of tea constituents L-theanine, caffeine, and epigallocatechin gallate on cognitive function and mood: A systematic review and meta-analysis. *Nutr. Rev.* 72: 507–522.
- Carrié, I., Bélanger, E., Portoukalian, J., Rochford, J., and Ferland, G. (2011). Lifelong low-phyloquinone intake is associated with cognitive impairments in old rats. *J. Nutr.* 141: 1495–1501.
- Chen, T., Chen, D., Tian, G., Zheng, P., Mao, X., Yu, J., He, J., Huang, Z., Luo, Y., Luo, J., and Yu, B. (2019). Soluble fiber and insoluble fiber regulate colonic microbiota and barrier function in a piglet model. *Biomed. Res. Int.* 2019: 7809171.
- Clement, Y. (2009). Can green tea do that? A literature review of the clinical evidence. *Prev. Med.* 49: 83–87.
- Dietz, C., and Dekker, M. (2017). Effect of green tea phytochemicals on mood and cognition. *Curr. Pharm. Des.* 23: 2876–2905.
- Dietz, C., Dekker, M., and Piqueras-Fiszman, B. (2017). An intervention study on the effect of matcha tea, in drink and snack bar formats, on mood and cognitive performance. *Food Res. Int.* 99: 72–83.
- Doi, Y., Minowa, M., Uchiyama, M., Okawa, M., Kim, K., Shibui, K., and Kamei, Y. (2000). Psychometric assessment of subjective sleep quality using the Japanese version of the Pittsburgh Sleep Quality Index (PSQI-J) in psychiatric disordered and control subjects. *Psychiatry Res.* 97: 165–172.
- Einöther, S.J., and Martens, V.E. (2013). Acute effects of tea consumption on attention and mood. *Am. J. Clin. Nutr.* 98: 1700S–1708S.
- Ferland, G. (2012). Vitamin K, an emerging nutrient in brain function. *Biofactors* 38: 151–157.
- Ferland, G., Feart, C., Presse, N., Lorrain, S., Bazin, F., Helmer, C., Berr, C., Annweiler, C., Rouaud, O., Dartigues, J.-F., Fourrier-Reglat, A., and Barberger-Gateau, P. (2016). Vitamin K antagonists and cognitive function in older adults: The Three-City Cohort Study. *J. Gerontol. A Biol. Sci. Med. Sci.* 71: 1356–1362.
- Filippini, T., Malavolti, M., Borrelli, F., Izzo, A.A., Fairweather-Tait, S.J., Horneber, M., and Vinceti, M. (2020). Green tea (*Camellia sinensis*) for the prevention of cancer. *Cochrane Database Syst. Rev.* 3: CD005004.
- Folstein, M.F., Folstein, S.E., and McHugh, P.R. (1975). “Mini-mental state” A practical method for grading the cognitive state of patients for the clinician. *J. Psychiatr. Res.* 12: 189–198.
- Fujioka, K., Iwamoto, T., Shima, H., Tomaru, K., Saito, H., Ohtsuka, M., Yoshidome, A., Kawamura, Y., and Manome, Y. (2016). The powdering process with a set of ceramic mills for green tea promoted catechin extraction and the ROS inhibition effect. *Molecules* 21: 474.
- Girotti, M., Bulin, S.E., and Carreno, F.R. (2024). Effects of chronic stress on cognitive function - From neurobiology to intervention. *Neurobiol. Stress* 33: 100670.
- Goto, T., Yoshida, Y., Kiso, M., and Nagashima, H. (1996). Simultaneous analysis of individual catechins and caffeine in green tea. *J. Chromatogr. A* 749: 295–299.
- Gualtieri, C.T., and Johnson, L.G. (2006). Reliability and validity of a computerized neurocognitive test battery, CNS Vital Signs. *Arch. Clin. Neuropsychol.* 21: 623–643.
- Hidese, S., Ogawa, S., Ota, M., Ishida, I., Yasukawa, Z., Ozeki, M., and Kunugi, H. (2019). Effects of L-theanine administration on stress-related symptoms and cognitive functions in healthy adults: A randomized controlled trial. *Nutrients* 11: 2362.
- Horie, H., Ema, K., Niskikawa, H., and Nakamura, Y. (2018). Comparison of the chemical components of powdered green tea sold in the US. *JARQ-Jpn. Agr. Res. Q.* 52: 143–147.
- Horie, H., Kaori, E., and Sumikawa, O. (2017). Chemical components of matcha and powdered green tea. *J. Cookery Sci. Japan* 50: 182–188.
- Ikegaya, K., Takayanagi, H., and Anan, T. (1984). Chemical composition of matcha (tencha). *Chagyo Kenkyu Hokoku (Tea Res. J.)* 60: 79–81.
- Inoue, Y., Nakao, A., Yauchi, J., Sase, T., and Konishi, S. (2019). Estimating the origin of shade-grown cultivation using soil from tea plantations in Uji City, Kyoto Prefecture (in Japanese). *Jpn. J. Soil Sci. Plant Nutr.* 90: 424–432.
- International Organization for Standardization. (2022). Matcha tea — Definition and characteristics. Available: <https://www.iso.org/obp/ui/en/#iso:std:iso:tr:21380:ed-1:v1:en>. Accessed February 26, 2026.
- Irwin, M.R., and Vitiello, M.V. (2019). Implications of sleep disturbance and inflammation for Alzheimer's disease dementia. *Lancet Neurol.* 18: 296–306.
- Ishigaki, K. (1981). Chemical components, taste, and flavor of tea, and cultivation of tea plants (in Japanese). *Kagaku to Seibutsu (Chemistry and Biology)* 19: 278–285.
- Iverson, G.L., Brooks, B.L., Weiss, M.D., Gualtieri, C.T., and Johnson, L.G. (2007). Clinical usefulness of CNS vital signs for assessing neurocognition in ADHD. *Clin. Neuropsychol.* 21: 686.
- Iwai, R., Ishii, T., Fukushima, Y., Okamoto, T., Ichihashi, M., Sasaki, Y., and Mizutani, K.-I. (2021). Matcha and its components control angiogenic potential. *J. Nutr. Sci. Vitaminol. (Tokyo)* 67: 118–125.
- Kakutani, S., Watanabe, H., and Murayama, N. (2019). Green tea intake and risks for dementia, Alzheimer's disease, mild cognitive impairment, and cognitive impairment: A systematic review. *Nutrients* 11: 1165.
- Kaneko, S., Kumazawa, K., Masuda, H., Henze, A., and Hofmann, T. (2006). Molecular and sensory studies on the umami taste of Japanese green tea. *J. Agric. Food Chem.* 54: 2688–2694.
- Kim, E.J., and Kim, J.J. (2023). Neurocognitive effects of stress: a metaparadigm perspective. *Mol. Psychiatry* 28: 2750–2763.
- Kim, J.M., Lee, U., Kang, J.Y., Park, S.K., Kim, J.C., and Heo, H.J. (2020).

- Matcha improves metabolic imbalance-induced cognitive dysfunction. *Oxid. Med. Cell Longev.* 2020: 8882763.
- Kobayashi, S., Honda, S., Murakami, K., Sasaki, S., Okubo, H., Hirota, N., Notsu, A., Fukui, M., and Date, C. (2012). Both comprehensive and brief self-administered diet history questionnaires satisfactorily rank nutrient intakes in Japanese adults. *J. Epidemiol.* 22: 151–159.
- Kochman, J., Jakubczyk, K., Antoniewicz, J., Mruk, H., and Janda, K. (2020). Health benefits and chemical composition of matcha green tea: A review. *Molecules* 26: 85.
- Kulshreshtha, A., Alonso, A., McClure, L.A., Hajjar, I., Manly, J.J., and Judd, S. (2023). Association of stress with cognitive function among older black and white US adults. *JAMA Netw. Open* 6: e231860.
- Kuriyama, S., Hozawa, A., Ohmori, K., Shimazu, T., Matsui, T., Ebihara, S., Awata, S., Nagatomi, R., Arai, H., and Tsuji, I. (2006). Green tea consumption and cognitive function: A cross-sectional study from the Tsurugaya Project 1. *Am. J. Clin. Nutr.* 83: 355–361.
- Lange, K.W. (2018). Red wine, resveratrol, and Alzheimer's disease. *Mov. Nutr. Health Dis.* 2: 31–38.
- Lange, K.W. (2020a). Lipids in the treatment of neurodegenerative diseases. In: Shahidi, F. (Ed.). *Bailey's industrial oil and fat products* (7th ed.), Vol. 7. Wiley, pp. 370–391.
- Lange, K.W. (2020b). Omega-3 fatty acids and mental health. *Glob. Health J.* 4: 18–30.
- Lange, K.W. (2022). Tea in cardiovascular health and disease: a critical appraisal of the evidence. *Food Sci. Hum. Wellness* 11: 445–454.
- Lange, K.W., and Li, S. (2018). Resveratrol, pterostilbene, and dementia. *Biofactors* 44: 83–90.
- Lange, K.W., Lange, K.M., and Nakamura, Y. (2022a). Green tea, epigallocatechin gallate and the prevention of Alzheimer's disease: clinical evidence. *Food Sci. Hum. Wellness* 11: 765–770.
- Lange, K.W., Lange, K.M., Nakamura, Y., and Kanaya, S. (2020). Is there a role of gut microbiota in mental health? *J. Food Bioact.* 9: 4–9.
- Lange, K.W., Lange, K.M., Nakamura, Y., and Li, S. (2020). Do natural antioxidants play a role in Alzheimer's disease? *J. Food Bioact.* 11: 2–10.
- Lange, K.W., and Nakamura, Y. (2024). Japanese food culture and human health - what we can learn from Japan. *J. Dis. Prev. Health Promot.* 8: 9–12.
- Lange, K.W., and Nakamura, Y. (2025a). Amazake (Japanese fermented rice beverage) and its potential health benefits. *Food Sci. Hum. Wellness* 14: 9250076.
- Lange, K.W., and Nakamura, Y. (2025b). Japanese cuisine and its health benefits: food bioactives, dietary features, and public health. *J. Food Bioact.* 31: 1–7.
- Lange, K.W., and Nakamura, Y. (2026a). Japanese-style diet and life expectancy. *J. Food Bioact.* 34: 22–30.
- Lange, K.W., and Nakamura, Y. (2026b). The Japanese diet of 1975 and health promotion: What can we learn from Japan? *J. Dis. Prev. Health Promot.* 10: 10–14.
- Lange, K.W., Nakamura, Y., and Lange, K.M. (2026). Food and nutrition in the prevention of dementia-A mini-review. *J. Food Bioact.* 33: 10–15.
- Lange, K.W., Nakamura, Y., Lange, K.M., and Zhao, H. (2022b). Tea and depression. *Food Sci. Hum. Wellness* 11: 476–482.
- Lee, Y., Eun, C.S., Lee, A.R., Park, C.H., and Han, D.S. (2016). *Fusobacterium* isolates recovered from colonic biopsies of inflammatory bowel disease patients in Korea. *Ann. Lab. Med.* 36: 387–389.
- Li, G.Y., Ueki, H., Kawashima, T., Sugatake, K., Muraoka, T., and Yamada, S. (2004). Involvement of the noradrenergic system in performance on a continuous task requiring effortful attention. *Neuropsychobiology* 50: 336–340.
- Li, X., Zhang, Y., Yang, Z., Zhang, S., and Zhang, L. (2024). The inhibition effect of epigallocatechin-3-gallate on the co-aggregation of amyloid- β and human islet amyloid polypeptide revealed by replica exchange molecular dynamics simulations. *Int. J. Mol. Sci.* 25: 1636.
- Liu, J.-B., Zhou, L., Wang, Y.-Z., Wang, X., Zhou, Y., Ho, W.-Z., and Li, J.-L. (2016). Neuroprotective activity of (-)-epigallocatechin gallate against lipopolysaccharide-mediated cytotoxicity. *J. Immunol. Res.* 2016: 4962351.
- Liu, Y., Fly, A.D., Wang, Z., and Klaunig, J.E. (2018). The effects of green tea extract on working memory in healthy women. *J. Nutr. Health Aging* 22: 446–450.
- Liu, Z., Bruijn, W.J.C.d.e., Bruins, M.E., and Vincken, J.-P. (2020). Reciprocal interactions between epigallocatechin-3-gallate (EGCG) and human gut microbiota in vitro. *J. Agric. Food Chem.* 68: 9804–9815.
- Lu, Y. (1995). *The classic of tea. Origins and rituals.* Ecco Press, Hopewell, NJ.
- Maeda-Yamamoto, M., Tachibana, H., Sameshima, Y., and Kuriyama, S. (2013). Green tea (cv. Benifuuki) powder and catechins availability. In: Preedy, V.R. (Ed.). *Tea in Health and Disease Prevention.* Elsevier, pp. 115–125.
- Merighi, S., Travagli, A., Nigro, M., Pasquini, S., Cappello, M., Contri, C., Varani, K., Vincenzi, F., Borea, P.A., and Gessi, S. (2023). Caffeine for prevention of Alzheimer's disease: Is the A2A adenosine receptor its target? *Biomolecules* 13: 967.
- Meyer, K., Lulla, A., Debroy, K., Shikany, J.M., Yaffe, K., Meirelles, O., and Launer, L.J. (2022). Association of the gut microbiota with cognitive function in midlife. *JAMA Netw. Open* 5: e2143941.
- Mitchell, A.J., Beaumont, H., Ferguson, D., Yadegarfar, M., and Stubbs, B. (2014). Risk of dementia and mild cognitive impairment in older people with subjective memory complaints: meta-analysis. *Acta Psychiatr. Scand.* 130: 439–451.
- Molinieuo, J.L., Rabin, L.A., Amariglio, R., Buckley, R., Dubois, B., Ellis, K.A., Ewers, M., Hampel, H., Klöppel, S., Rami, L., Reisberg, B., Saykin, A.J., Sikkes, S., Smart, C.M., Snitz, B.E., Sperling, R., van der Flier, W.M., Wagner, M., and Jessen, F. (2017). Implementation of subjective cognitive decline criteria in research studies. *Alzheimers Dement.* 13: 296–311.
- Morishima, S., Kawada, Y., Fukushima, Y., Takagi, T., Naito, Y., and Inoue, R. (2023). A randomized, double-blinded study evaluating effect of matcha green tea on human fecal microbiota. *J. Clin. Biochem. Nutr.* 72: 165–170.
- Morita, A., and Tuji, M. (2002). Nitrate and oxalate contents of tea plants (*Camellia sinensis* L.) with special reference to types of green tea and effect of shading. *Soil Sci. Plant Nutr.* 48: 547–553.
- Nasreddine, Z.S., Phillips, N.A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L., and Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *J. Am. Geriatr. Soc.* 53: 695–699.
- Nishino, K., Nishida, A., Inoue, R., Kawada, Y., Ohno, M., Sakai, S., Inatomi, O., Bamba, S., Sugimoto, M., Kawahara, M., Naito, Y., and Andoh, A. (2018). Analysis of endoscopic brush samples identified mucosa-associated dysbiosis in inflammatory bowel disease. *J. Gastroenterol.* 53: 95–106.
- Nouchi, R., Suiko, T., Kimura, E., Takenaka, H., Murakoshi, M., Uchiyama, A., Aono, M., and Kawashima, R. (2020). Effects of lutein and astaxanthin intake on the improvement of cognitive functions among healthy adults: A systematic review of randomized controlled trials. *Nutrients* 12: 617.
- Paulus, R., Roth, A., Titus, L., Chen, R., Bridges, M.C., and Woodyard, S. (2015). Impact of various caffeine vehicles on mood and cognitive, neurological and physiological functions over five hours. *Ohio J. Sci.* 115: 12–23.
- Pietschnig, J., Aigner-Wöber, R., Reischenböck, N., Kryspin-Exner, I., Moser, D., Klug, S., Auff, E., Dal-Bianco, P., Puszwald, G., and Lehrner, J. (2016). Facial emotion recognition in patients with subjective cognitive decline and mild cognitive impairment. *Int. Psychogeriatr.* 28: 477–485.
- Pike, K.E., Cavuoto, M.G., Li, L., Wright, B.J., and Kinsella, G.J. (2022). Subjective cognitive decline: Level of risk for future dementia and mild cognitive impairment, a meta-analysis of longitudinal studies. *Neuropsychol. Rev.* 32: 703–735.
- Presse, N., Belleville, S., Gaudreau, P., Greenwood, C.E., Kergoat, M.-J., Morais, J.A., Payette, H., Shatenstein, B., and Ferland, G. (2013). Vitamin K status and cognitive function in healthy older adults. *Neurobiol. Aging* 34: 2777–2783.
- Repass, J. (2018). Replication study: *Fusobacterium nucleatum* infection is prevalent in human colorectal carcinoma. *Elife* 7: e25801.
- Ritchie, K., Carrière, I., Mendonca, A.d.e., Portet, F., Dartigues, J.F., Rouaud, O., Barberger-Gateau, P., and Ancelin, M.L. (2007). The neuroprotective effects of caffeine: A prospective population study (the Three City Study). *Neurology* 69: 536–545.
- Ruan, J., Haerdter, R., and Gerendás, J. (2010). Impact of nitrogen supply on carbon/nitrogen allocation: A case study on amino acids and cat-

- echins in green tea *Camellia sinensis* (L.) O. Kuntze plants. *Plant. Biol. (Stuttg.)* 12: 724–734.
- Sabia, S., Fayosse, A., Dumurgier, J., van Hees, V.T., Paquet, C., Sommerlad, A., Kivimäki, M., Dugravot, A., and Singh-Manoux, A. (2021). Association of sleep duration in middle and old age with incidence of dementia. *Nat. Commun.* 12: 2289.
- Sakurai, K., Shen, C., Ezaki, Y., Inamura, N., Fukushima, Y., Masuoka, N., and Hisatsune, T. (2020). Effects of matcha green tea powder on cognitive functions of community-dwelling elderly individuals. *Nutrients* 12: 3639.
- Scholey, A., Downey, L.A., Ciorciari, J., Pipingas, A., Nolidin, K., Finn, M., Wines, M., Catchlove, S., Terrens, A., Barlow, E., Gordon, L., and Stough, C. (2012). Acute neurocognitive effects of epigallocatechin gallate (EGCG). *Appetite* 58: 767–770.
- Shibata, S., Noguchi-Shinohara, M., Shima, A., Ozaki, T., Usui, Y., Taki, Y., Uchida, K., Honda, T., Hata, J., Ohara, T., Mikami, T., Maeda, T., Mimura, M., Nakashima, K., Iga, J., Takebayashi, M., Ninomiya, T., and Ono, K. (2025). Green tea consumption and cerebral white matter lesions in community-dwelling older adults without dementia. *NPJ Sci. Food* 9: 2.
- Shokri-Kojori, E., Wang, G.-J., Wiers, C.E., Demiral, S.B., Guo, M., Kim, S.W., Lindgren, E., Ramirez, V., Zehra, A., Freeman, C., Miller, G., Manza, P., Srivastava, T., De Santi, S., Tomasi, D., Benveniste, H., and Volkow, N.D. (2018). β -Amyloid accumulation in the human brain after one night of sleep deprivation. *Proc. Natl. Acad. Sci. U S A* 115: 4483–4488.
- Sokary, S., Al-Asmakh, M., Zakaria, Z., and Bawadi, H. (2023). The therapeutic potential of matcha tea: A critical review on human and animal studies. *Curr. Res. Food Sci.* 6: 100396.
- Sun, J., Kang, J., Wang, P., and Zeng, H. (2013). Self-relaxation training can improve sleep quality and cognitive functions in the older: A one-year randomised controlled trial. *J. Clin. Nurs.* 22: 1270–1280.
- Surak, K. (2012). Making tea, making Japan: Cultural nationalism in practice. Stanford University Press, Stanford, CA.
- Uchida, K., Meno, K., Korenaga, T., Liu, S., Suzuki, H., Baba, Y., Tagata, C., Araki, Y., Tsunemi, S., Aso, K., Inagaki, S., Nakagawa, S., Kobayashi, M., Kakuma, T., Asada, T., Ota, M., Takiyama, T., and Arai, T. (2024). Effect of matcha green tea on cognitive functions and sleep quality in older adults with cognitive decline: A randomized controlled study over 12 months. *PLoS One* 19: e0309287.
- Ullah, F., Ali, T., Ullah, N., and Kim, M.O. (2015). Caffeine prevents d-galactose-induced cognitive deficits, oxidative stress, neuroinflammation and neurodegeneration in the adult rat brain. *Neurochem. Int.* 90: 114–124.
- Unno, K., Furushima, D., Hamamoto, S., Iguchi, K., Yamada, H., Morita, A., Horie, H., and Nakamura, Y. (2018). Stress-reducing function of matcha green tea in animal experiments and clinical trials. *Nutrients* 10: 1468.
- Unno, K., Furushima, D., Hamamoto, S., Iguchi, K., Yamada, H., Morita, A., Pervin, M., and Nakamura, Y. (2019). Stress-reducing effect of cookies containing matcha green tea: Essential ratio among theanine, arginine, caffeine and epigallocatechin gallate. *Heliyon* 5: e01653.
- Unno, K., Hara, A., Nakagawa, A., Iguchi, K., Ohshio, M., Morita, A., and Nakamura, Y. (2016). Anti-stress effects of drinking green tea with lowered caffeine and enriched theanine, epigallocatechin and arginine on psychosocial stress induced adrenal hypertrophy in mice. *Phytomedicine* 23: 1365–1374.
- Unno, K., Iguchi, K., Tanida, N., Fujitani, K., Takamori, N., Yamamoto, H., Ishii, N., Nagano, H., Nagashima, T., Hara, A., Shimoi, K., and Hoshino, M. (2013). Ingestion of theanine, an amino acid in tea, suppresses psychosocial stress in mice. *Exp. Physiol.* 98: 290–303.
- Unno, K., Pervin, M., Taguchi, K., Konishi, T., and Nakamura, Y. (2020). Green tea catechins trigger immediate-early genes in the hippocampus and prevent cognitive decline and lifespan shortening. *Molecules* 25: 1484.
- Valverde-Salazar, V., Ruiz-Gabarré, D., and García-Escudero, V. (2023). Alzheimer's disease and green tea: Epigallocatechin-3-gallate as a modulator of inflammation and oxidative stress. *Antioxidants (Basel)* 12: 1460.
- van der Helm, E., Gujar, N., and Walker, M.P. (2010). Sleep deprivation impairs the accurate recognition of human emotions. *Sleep* 33: 335–342.
- van Stegeren, A., Rohleder, N., Everaerd, W., and Wolf, O.T. (2006). Salivary alpha amylase as marker for adrenergic activity during stress: Effect of betablockade. *Psychoneuroendocrinology* 31: 137–141.
- Virtanen, M., Singh-Manoux, A., Batty, G.D., Ebmeier, K.P., Jokela, M., Harmer, C.J., and Kivimäki, M. (2017). The level of cognitive function and recognition of emotions in older adults. *PLoS One* 12: e0185513.
- Wang, L., Brennan, M., Li, S., Zhao, H., Lange, K.W., and Brennan, C. (2022). How does the tea L-theanine buffer stress and anxiety. *Food Sci. Hum. Wellness* 11: 467–475.
- Wechsler, D. (2010). The Wechsler Memory Scale. 4th ed. Pearson Assessments, London, UK.
- Weiss, D.J., and Anderton, C.R. (2003). Determination of catechins in matcha green tea by micellar electrokinetic chromatography. *J. Chromatogr. A* 1011: 173–180.
- Weiss, E.M., Kohler, C.G., Vonbank, J., Stadelmann, E., Kemmler, G., Hinterhuber, H., and Marksteiner, J. (2008). Impairment in emotion recognition abilities in patients with mild cognitive impairment, early and moderate Alzheimer disease compared with healthy comparison subjects. *Am. J. Geriatr. Psychiatry* 16: 974–980.
- Wesnes, K. (2002). Assessing cognitive function in clinical trials: latest developments and future directions. *Drug Discov. Today* 7: 29–35.
- Wesnes, K. (2003). The Cognitive Drug Research computerised assessment system: Application to clinical trials. In: de Deyn, P.P., Thiery, E., and D'Hooze, R. (Ed.). *Memory: Basic concepts, disorders and treatment*. Uitgeverij Acco, pp. 453–472.
- Xu, L., Jiang, C.Q., Lam, T.H., Liu, B., Jin, Y.L., Zhu, T., Zhang, W.S., Cheng, K.K., and Thomas, G.N. (2011). Short or long sleep duration is associated with memory impairment in older Chinese: The Guangzhou Biobank Cohort Study. *Sleep* 34: 575–580.
- Yaffe, K., Falvey, C.M., and Hoang, T. (2014). Connections between sleep and cognition in older adults. *Lancet Neurol.* 13: 1017–1028.
- Yoshida, H., Inuzuka, M., Fuchinoue, H., Shimoda, M., Nomura, S., and Watanabe, H. (1959). Fundamental studies on the production of tea leaves for kabusecha (part 1). The influences of shade on the biological conditions of tea leaves (in Japanese). *Tea Ind. Res. Rep.* 13: 30–38.
- Zhang, R., Ding, N., Feng, X., and Liao, W. (2025). The gut microbiome, immune modulation, and cognitive decline: Insights on the gut-brain axis. *Front. Immunol.* 16: 1529958.
- Zhang, Y., Liu, Y., Li, Y., Li, Y., Gu, X., Kang, J.H., Eliassen, A.H., Wang, M., Rimm, E.B., Willett, W.C., Hu, F.B., Stampfer, M.J., and Wang, D.D. (2026). Coffee and tea intake, dementia risk, and cognitive function. *JAMA* 335: 961–974.