

Tea and Wellness throughout Life

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Abstract

Tea (*Camellia sinensis*) is the most commonly consumed beverage globally after water, with black tea being the most popular type of tea drunk in Britain by people of all ages. The potential for tea to contribute to health and wellness throughout life is worthy of consideration. Tea is a low calorie drink with several bioactive polyphenol ingredients which are well known to have antioxidant activity. Black tea in particular is a source of the amino acid L-theanine which has been linked with benefits for mental, immune and cardiovascular health. Prevalence of poor health, including poor cardiovascular, metabolic, mental, brain, bone and immune health, which may result in serious outcomes, including heart disease, type 2 diabetes, osteoporosis, cognitive decline and an inability to fight infection, is high in the UK and the European region. Interest in safe, natural ingredients for promoting health and wellness is growing. Whilst tea has been consumed for centuries, its health benefits have emerged more powerfully during recent decades giving scientific credence to the traditional perception that tea makes those who include it in their pattern of daily life feel good. This review collates evidence from human studies which evaluate the health and wellness impacts of tea consumption throughout life including into old age. It explores the evidence available on tea and mental and cognitive health, cardiovascular health, metabolic health, bone health, gut health and immune health. It identifies the bioactive ingredients which are likely contributors to these health impacts and includes evidence from laboratory studies that help to explain the mechanisms by which these benefits may occur. Overall, this review concludes that tea consumption contributes to health and wellness throughout life and that everyone should be encouraged to enjoy three cups daily as part of a healthy lifestyle pattern.

Keywords: *Camellia sinensis*; Black tea; Green tea; Cognition; Mood; Cardiovascular; Weight; Immunity; Gut microbiota

Introduction

Tea has been drunk for thousands of years as part of a regular daily habit by people of all ages and is the most frequently consumed beverage globally beside water [1,2]. In the UK and the rest of Europe, the two most popular types of tea are black (fully fermented/aerated) and green (unfermented/non aerated), and also oolong and white tea, which are increasing in popularity. All these types of tea are manufactured from the leaves of the plant *Camellia sinensis sinensis* Assamica.

Most research agrees that the tea bush originated in the area of Northern India (Assam), the Himalayas and Southwest China [3]. There are two main varieties of the tea bush in commercial use *Camellia sinensis* (so called 'China-type') and *Camellia sinensis assamica* (so-called Assam-type). Type sinensis has smaller leaves and is frost resistant; Assamica-type has comparatively larger leaves and it not frost resistant' toSo called 'China-type' has smaller leaves and is frost resistant; assam-type has comparatively larger leaves and it not frost resistant [4]. This dictates which type is planted in which global location-including elevation. Tea is now commercially grown in over 50 countries although the bulk of production is in China, India and

Kenya [5]. The tea bush can grow to the height of a tree but is usually kept as a bush for ease of harvesting.

Across Europe, Britain is second only to the Republic of Ireland in terms of per capita tea consumption, with 84% of the British population drinking tea or herbal infusions daily, consuming 100 million cups daily or 36 billion cups annually [5].

Tea is, and always has been, drunk mainly for enjoyment, comfort, warming, relaxation, when thirsty and to socialise-all of which have a positive impact on health and well-being. It also contributes to hydration. However, scientific evidence is now providing increasing credence for the traditional belief that tea is important for health and well-being with encouraging data implying roles in mental and cognitive health as well as metabolic and cardiovascular health [2]. Alongside this, the evidence-base around tea ingestion, its associated compounds and aspects of gut health and immune health has also been progressively evolving [6].

The potential for tea to provide health and wellness benefits across the European region, including the UK is worthy of consideration. Obesity, for example, is a serious public health problem, as it

significantly increases the risk of chronic diseases such as type 2 diabetes mellitus, cardiovascular disease and certain cancers. For specific individuals, obesity may further be linked to a wide range of mental problems and a poor sense of well-being. For society as a whole, obesity and overweight have substantial direct and indirect costs that put a considerable strain on healthcare and social resources.

In the UK, the 2019 Health Survey for England (HSE) shows that around two thirds of adults are overweight or obese [7]. Amongst children aged 2-15 years, 18% of boys and 13% of girls are obese. A total of 43% of adults drink amounts of alcohol that put them at health risk (more than 14 units each week). Latest data from the UK National Diet and Nutrition Survey (NDNS) of adults in England show that only 31% of adults aged 19-64 are eating the recommended five portions of fruit and vegetables per day and the average (mean) intake is 4.2 portions per day [8]. Fewer men than women meet the five-a-day guideline, and young people aged 11 to 18 are also less likely than other adults to achieve their five-a-day with only 8% achieving this target. Weight problems and obesity are also prevalent in most of the EU member states with estimates of 51.6 % of the EU's population (18 and over) being overweight in 2014 [9]. Only 14% of the EU population consumes 5-a-day or more with 34.4% not eating fruit and vegetables on a daily basis.

Tea has a range of bioactive constituents, particularly flavonoids, including flavan-3-ols (catechins), such as particularly in green tea, Epigallocatechin Gallate (EGCG) and epicatechin-3-gallate, and particularly in black tea, theaflavins and thearubigins generated during aeration, all of which have become well known as antioxidants. Tea also contains caffeine which like L-theanine, has been found to be associated with health and wellness benefits. Overall, thanks to these constituents, tea possesses significant antioxidant and anti-inflammatory activity as well as cardiovascular and neuroprotective properties. Several research investigations, epidemiological studies, and meta-analyses suggest that tea and its bioactive polyphenolic constituents, caffeine and L-theanine have numerous beneficial effects on health, including the maintenance of cardiovascular, metabolic, immune and cognitive health. In drinking tea for centuries, people have instinctively linked it with a 'feel good factor', health and wellness without having the underpinning scientific evidence.

Tea can have positive impacts on health for all age groups. While studies on such areas as cognitive function and bone health have focused on the elderly, the preventative effects of tea can start much earlier and for children 4 years of age and above and young adults, tea can be consumed as a low calorie, healthy alternative to carbonated soft drinks etc.

The aim of this review is to gather and collate evidence on tea in relation to aspects of health and wellness. When considering these potential outcomes, it is important to appraise the totality of research evidence in relation to tea. Whilst Randomised Controlled Trials (RCTs), systematic reviews and meta-analyses in human beings are the gold standard for causal evidence, observational studies can suggest important health links, whilst laboratory studies can provide information about potential mechanisms of tea ingredients. Due to the high consumption of tea in the European region, including the UK, and throughout the world, even small effects on human health, which may be suggested not only in clinical studies, but also in observational studies, can have large implications for public health and wellness.

Methods

The National Centre for Biotechnology Information (NCBI) search engine (PubMed) was used to extract relevant publications. English-

language human studies published between January 2000 (month start) and January 2021 (month start) were screened. Publications were included if they used tea (*Camellia sinensis*) and studied a named health outcome.

The search terms "Tea", "Black Tea", "Green Tea", "*Camellia sinensis*" and/or "Health", "Wellness", "Disease", "Pregnancy", "Children", "Teenagers" and "Old Age", "Polyphenols", "Flavonoids", "Caffeine", "Theanine", "Catechins" were used. The initial database search was restricted to human studies, including epidemiological studies. Meta-analyses and systematic reviews were included. To probe potential mechanisms for health outcomes, a secondary search for laboratory studies using the same search terms was applied.

Findings

In this paper, we consider the definitions of health and wellness. According to the World Health Organisation, health is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

Wellness is linked to health, and like the WHO definition of health, definitions of wellness incorporate physical, mental and social (or spiritual) well-being. In evaluating research on tea, we have been mindful of this all-encompassing model of health and wellness, and whilst we have considered the potential impact of tea consumption on disease, we have used a health and wellness lens to evaluate our findings rather than a disease-based focus.

Mood, mental health and cognitive health

One of the keys to health and wellness is mood and mental health. For centuries tea drinkers have testified to both the relaxing and calming qualities of tea, elevating *Camellia sinensis* to a role beyond quenching thirst. The early spread of tea from ancient China to Japan was linked to tea's ability to help with meditation and the first tea gardens were in temple grounds. Whilst these mental health benefits are well understood by tea drinkers, scientific research is now beginning to elucidate these effects and their potential mechanisms.

An early trial in 75 healthy men found that 6 weeks' tea consumption reduced cortisol levels in response to a stressful task compared to placebo with a relative increase in subjective relaxation during the post-task recovery period [10]. L-theanine, an amino acid found in both black and green tea and to a greater extent in black than green tea (24.2 ± 5.5 mg vs 7.9 ± 3.8 mg) [11] may, alongside caffeine, be responsible for the mood responses to tea. It needs to be noted here that this study did not include matcha, a powdered green tea that is known to have higher L-theanine contents than standard green teas [12]. A double-blind, placebo-controlled, crossover study in 34 adults aged 18-40, found that subjective stress response to a multi-tasking cognitive stressor was significantly reduced one hour after consumption of a drink containing L-theanine [13]. The salivary cortisol response to the stressor was reduced three hours after the drink. No treatment-related cognitive performance changes were observed. A 2020 systematic review, which included 9 peer-reviewed studies, also indicated the stress and anxiety reducing effects of L-theanine, albeit in supplement form, in doses of 200-400 mg daily [14].

More recent evidence suggests that the combination of L-theanine and caffeine is linked with mood and cognition. A 2017 review of 49 human intervention studies evaluating research on the psychoactive effects of L-theanine, caffeine and EGCG found that L-theanine and caffeine have clear beneficial effects on sustained attention, memory, and suppression of distraction. Moreover, L-theanine was found to lead to relaxation by reducing caffeine induced arousal [15]. Caffeine

(at doses from 40 mg) was found to mainly improve performance on demanding long-duration cognitive tasks and self-reported alertness, arousal, and vigour. L-theanine alone improved self-reported relaxation, tension, and calmness starting at amounts of 200 mg. L-theanine and caffeine combined were found to particularly improve performance in attention-switching tasks and alertness, but to a lesser extent than caffeine alone.

A 2017 meta-analysis (which included 21 studies, four of which were randomised controlled trials, 12 were cross-over studies, four were cross-sectional studies and one was a cohort study) provided evidence that green tea reduces anxiety and has cognitive benefits (e.g. benefits in memory and attention) and brain function (e.g. activation of working memory seen in functional magnetic resonance imaging) [16]. These beneficial green tea effects on cognition were observed under the combined influence of both caffeine and l-theanine, whereas separate administration of either substance was found to have a lesser impact; this suggests that the mental and cognitive benefits cannot be attributed to either L-theanine or caffeine alone but to the combination, which is found in both black and green tea.

Catechins present in tea, including Epigallocatechin Gallate (EGCG), may also contribute to the mood enhancing and relaxing effects of tea. A double-blind, placebo controlled crossover study evaluated the effect of 300 mg EGCG or matched placebo in human volunteers. EGCG administration was associated with a significant overall increase Electroencephalogram (EEG) readings and increased self-rated calmness whilst reducing self-rated stress [17], suggesting that participants in the EGCG study arm may have been in a more relaxed and attentive state after consuming EGCG.

Tea consumption has also been associated with reduced risk of depression in epidemiological studies. Studies in this field mainly come from Asian societies, mostly evaluating green tea and many focus on older people. A longitudinal study in Chinese older people found that frequent and consistent tea drinking significantly reduced depressive symptoms [18]. Similar findings have emerged from a Korean population with those who habitually drank green tea 21% less likely to develop depression over their lifetime than those who did not drink tea [19]. A meta-analysis of 11 studies involving 22,817 participants with 4,743 cases of depression found a reduced risk of depression with higher tea consumption, with every three cups of tea daily consumption associated with a 37% decrease in risk [20].

Further research has shown that constituents found in all major tea types, predominantly L-theanine, polyphenols (and polyphenol metabolites), are capable of functioning through multiple biochemical signalling pathways simultaneously to collectively reduce the risk of depression [21]. For example, several compounds in tea influence dopaminergic activity and the gut brain axis [21]. Black tea theaflavins and EGCG are potent anti-inflammatory agents *via* down-regulation of nuclear factor kappa-light-chain-enhancer of activated B cells (NF- κ B) signaling [22]. NF- κ B is a protein complex involved in cellular responses to stress and inflammation, and controls transcription of DNA, cytokine production and cell survival [23].

Epidemiological studies also show that long term habitual consumption of tea might reduce the risk of dementia. Again, many of these studies have been conducted in Asian populations and evaluating green tea. A meta-analysis of 26 observational studies indicated that tea consumption could reduce risk of cognitive disorders by 35% (Odds Ratio (OR)=0.65, 95% Confidence Interval (CI)=0.58-0.73) with population subgroup analysis showing main associations in Chinese people [24]. One study in Chinese people over the age of 55 years in

Singapore, for, example, found that those who drank as little as one cup of tea per week performed better at memory and information processing tasks than did non-tea drinkers. This protective effect was not limited to any particular type of tea; black, oolong and green tea were associated with better cognitive performance [25].

Of note, is a recent longitudinal UK study 676 people aged 85 years and older in the North East of England, who did not suffer from dementia, measured cognitive function (memory, speed and attention) at baseline. Higher tea consumption was associated with significantly better attention (focused and sustained attention), and psychomotor speed (complex tasks only) over five-year follow-up. There was no association between tea consumption and global cognitive function, memory or performance on simple speed tasks over time [26]. The findings from this large study suggest the potential benefits of older people continuing to drink tea throughout their life.

Cardiovascular health

The consumption of tea (*Camellia sinensis*), both black and green, has been associated with the promotion of cardiovascular health. A 2013 Cochrane review of 11 RCTs and 821 participants (which did not look at cardiac outcomes), found that black tea produced statistically significant reductions in cardiovascular risk factors including Low-Density Lipoprotein (LDL) cholesterol: Mean Difference (MD)-0.43 mmol/L, 95% Confidence Interval (CI)-0.56 to -0.31) and blood pressure (Systolic Blood Pressure (SBP): MD-1.85 mmHg, 95% CI-3.21 to -0.48; Diastolic Blood Pressure (DBP): MD-1.27 mmHg, 95% CI-3.06 to 0.53) over six months. Green tea was also found to produce statistically significant reductions in total cholesterol (MD-0.62 mmol/L, 95% CI-0.77 to -0.46), LDL cholesterol (MD-0.64 mmol/L, 95% CI-0.77 to -0.52) and blood pressure (SBP: MD-3.18 mmHg, 95% CI-5.25 to 1.11; DBP: MD-3.42, 95% CI-4.54 to -2.30). When both tea types were analysed together, they showed favorable effects on LDL cholesterol (MD-0.48 mmol/L, 95% CI-0.61 to -0.35) and blood pressure (SBP: MD-2.25 mmHg, 95% CI-3.39 to -1.11; DBP: MD-2.81 mmHg, 95% CI-3.77 to -1.86) [27]. Whilst the changes were small, small changes can have a large impact on public health. More recent studies have continued to show promising findings on cardiovascular risk factors. A meta-analysis of 10 studies involving 811 participants found that black tea significantly lowered LDL cholesterol (MD-0.12 mmol/L 95% CI:-0.23, -0.008 mmol/L; P=0.036). No remarkable change was detected in total cholesterol (MD-0.05 mmol/L; 95% CI:-0.17, 0.06 mmol/L; P=0.363) or HDL cholesterol (MD-0.03 mmol/L; 95% CI:-0.08, 0.02 mmol/L; P=0.236) [28]. In a further meta-analysis, black tea reduced LDL cholesterol (MD-0.14 mmol/L (95% CI, -0.25 to -0.04 mmol/L; P=0.005) in healthy participants and not in those with coronary artery disease [29]. In the recent UK Biobank Study, compared with non-consumers of tea, higher tea consumption was associated with lower total and LDL cholesterol and higher HDL cholesterol [30].

Possible mechanisms for the cholesterol lowering effects of black and green tea may be that tea catechins (Epigallocatechin-3-Gallate (EGCG) and Epicatechin-3-Gallate (ECG)) limit cholesterol absorption in the intestine, improve antioxidant status and contribute to the regulation of cholesterol metabolism related genes, for example targeting Low-Density Lipoprotein Receptor (LDLR), and down regulating Microsomal Triglyceride Transfer Protein (MTTP) and Apolipoprotein B (APOB), thereby regulating the synthesis of cholesterol [31].

In a meta-analysis of 24 short term trials (1697 subjects) green tea significantly reduced blood pressure [32]. Green tea appears to have a

slightly greater effect on blood pressure lowering than black tea, but black tea is not without positive impact [33]. In terms of mechanisms for blood pressure regulation, data from laboratory studies have shown that tea components and their secondary metabolites have important roles in relaxing smooth muscle contraction, enhancing endothelial nitric oxide synthase activity, reducing vascular inflammation, inhibiting rennin activity, and anti-vascular oxidative stress [34]. However, the exact molecular mechanisms of these activities remain to be elucidated.

With regard to cardiovascular outcomes, both black and green tea have been associated with reduced risk of mortality from all cardiovascular diseases, although the association with black tea consumption was not statistically significant in this analysis [35]. An increase of one cup of green tea each day could decrease the risk of Cardiovascular Disease (CVD) mortality by 5% and an increase of three cups daily has been associated with a 27% reduced risk of coronary artery disease, an 18% lower risk of stroke and a 26% reduced risk of cardiac death [36]. A meta-analysis of data from 39 prospective cohort publications found that both black and green tea reduce risk of CVD [37]. One serving (~230 ml) increase in daily tea consumption (estimated 280 mg and 338 mg total flavonoids/d for black and green tea, respectively) was associated with an average 4% lower risk of CVD mortality, a 2% lower risk of CVD events, a 4% lower risk of stroke.

Metabolic health

Tea consumption is associated with metabolic health in some, but not all, studies [38,39]. Two cups of tea daily have been linked with reduced risk of type 2 diabetes mellitus. In a dose response meta-analysis (which included 16 cohorts from 15 articles that reported 37,445 cases of diabetes among 545,517 participants), the risk of type 2 diabetes was reduced by 15% when tea consumption exceeded four cups daily [38]. Tea consumption also reduced the incidence of type 2 diabetes in a further meta-analysis (involving 18 studies with information on 457,922 participants) [39]. Polyphenols in all types of tea, particularly phenolic acids, have been highlighted as the likely contributors to metabolic health [40]. Tea appears to protect metabolic health *via* several possible mechanisms, including enhancing insulin action, ameliorating the insulin resistance, activating insulin signaling pathway, protecting islet β -cells, scavenging free radicals, and decreasing inflammation [41].

Bone health

Tea consumption (both black and green) has the potential to protect bone health, maintaining or improving Bone Mineral Density (BMD) and protecting against osteoporosis. A meta-analysis of four cohort, one case-control, and eight cross-sectional studies with 12,635 cases indicated a potential trend that tea consumption might result in higher Bone Mineral Density (BMD) at the femoral neck, Ward triangle, greater trochanter, lumbar spine, and hip than non-tea consumption, and might prevent bone loss [42]. A meta-analysis of two prospective cohort studies, four case-control studies, and 11 cross-sectional studies found the total odds ratio (OR) of osteoporosis for the highest *versus* the lowest categories of tea consumption was 0.62 (95% CI, 0.46-0.83) [43]. EGCG, one of the polyphenols found in tea, has the capacity to promote the survival of osteoblasts and increase formation of mineralised bone [44].

Associations have also been found between all types of tea consumption and risk of hip fracture [45]. Compared to no tea consumption, 1-4 cups of tea per day was found to reduce the risk of hip fracture by 28% (0.72; 95% CI 0.56-0.88 for 1-2 cups/day), 37% (0.63; 95% CI 0.32-0.94 for 2-3 cups/day), and 21% (0.79; 95% CI 0.62-

0.96 for 3-4 cups/day). In a further meta-analysis (involving 195,992 individuals with 9,958 cases of hip fractures from 14 studies, including six cohort and eight case-control studies), there was no association between tea and fracture overall [46].

Immune health

There is some, albeit preliminary, evidence, highlighted in a review, that tea can impact immune health by having protective effects against infections of the upper respiratory tract and in inhibiting the growth of periodontal bacteria [47].

Tea contains a number of active compounds, principally flavonoids, including catechins, and the amino acid L-theanine, that may beneficially impact the immune system. A narrative review highlighted laboratory studies that showed reduced viral replication with theanine-related compounds derived from black tea [48]. A laboratory study indicated that theaflavin derivatives in black tea and catechin derivatives in green tea could inhibit HIV-1 entry into cells [49].

In a human study, green tea consumption, with a minimum of one to two times a week, was shown to be protective in a 2009 French pandemic of influenza [50]. A 5-month randomised double blind controlled study of 200 healthcare workers in Japan found that capsules containing green tea catechins and theanine reduced clinically defined influenza infection [51]. Gargling of tea has also been evaluated in some studies. A 2016 meta-analysis of five Randomised Controlled Studies (RCTs) (1890 participants aged 16-83 years) found that participants who gargled with tea or its ingredients had a 30 per cent reduced risk of influenza infection than did those who gargled with water/placebo or no gargle [52].

Tea polyphenols are under preliminary study as potential candidates for prophylaxis of COVID-19. A review of laboratory studies [53] showed that EGCG and theaflavins, especially theaflavin-3,3'-digallate (TF3) interact with receptors for binding sites on SARS-Cov-2 with some docking studies further indicating the activity of these polyphenols against COVID-19 [54,55].

Body weight

Tea has been associated with maintenance of healthy body weight and weight loss, particularly in mechanistic studies. In a 2008 12-week RCT amongst 60 Thai adults with a Body Mass Index (BMI)>25 following a standardised diet in which the intervention group drank green tea and the control group did not, the green tea group lost 3.3 kg more than the control group by week 12 ($p<0.05$). Measures of energy expenditure and fat oxidation were increased, suggesting a mechanism for this weight loss [56].

Whilst green tea has been the type of tea most frequently associated with weight management, black tea consumption may also contribute to weight control. One study of 111 people found that drinking three cups of black tea each day for three months significantly inhibited weight gain and reduced waist circumference, compared to drinking a caffeine-matched control beverage [57].

Drinking tea may help to promote healthy weight by reducing the quantity of calorific beverages consumed. The polyphenol content of tea may also contribute in that these compounds could act in the stimulation of fat oxidation, inhibition of fat cell differentiation and as antioxidants and anti-inflammatories [58]. In the 2020 green Mediterranean diet study, the inclusion of 3-4 cups of green tea daily improved intra-hepatic fat loss [59].

Gut health

Tea is a rich source of polyphenols and can be considered as a prebiotic. The polyphenols in tea are typically broken down in the large intestine by gut microbiota and changed into secondary metabolites which are available for absorption into the systemic circulation [60]. In general [61], polyphenol-rich diets boost levels of beneficial bacteria, including *Lactobacillus*, *Faecali bacteria* and *Bacteroides*, and decrease potentially pathogenic species such as *E. coli* and *Enterobacter cloacae*. In turn, the more favourable microbiota profile enhances polyphenol bioavailability leading to improved markers of metabolic and cardiovascular health.

Green tea majors in Epigallocatechin-3-Gallate (EGCG), epigallocatechin, epicatechin and gallic acid gallate, while the dominant polyphenols in black tea are the theaflavins and thearubigins. Polyphenols in both green and black teas are known to interact with the gut microbiota. In a systematic review of 24 studies (6 human trials, 18 mechanistic studies), the largest body of evidence related to green tea with 4-5 cups daily (1000 ml) reported to increase proportions of Bifidobacteria. The mechanistic studies indicated that both green and black tea polyphenols improved bacterial diversity and increased Bacteroidetes whilst reducing Firmicutes [62].

Tea throughout the life stages

Children and adolescents: Tea both black and green is a healthy drink to consume throughout life from childhood (4 years and above) to older age. Habitual tea consumption has been associated with better mental health, cognitive health, cardiovascular health, metabolic health, bone health, immune health and gut health.

Caffeinated drinks have attracted some attention for consumption in children. A meta-analysis of 109 studies found that children and adolescents should limit daily caffeine consumption to 2.5 mg/kg (-1) body weight day (-1), equating to one or two cups of tea or one small cup of coffee [63]. However, lower contributors of caffeine, such as tea, may be more appropriate for children 4 years and above because they contribute to daily hydration, fluid intakes and provide flavonoids. By contrast, caffeinated soft drinks may be less suitable options for children as a result of their acidity, higher caffeine content, presence of added sugar (in some cases) and absence of bioactive compounds.

During pregnancy: Black and green tea is safe to consume during pregnancy and contribute to hydration as well as the health benefits described above. UK NHS guidelines state that caffeine should be limited to 200 mg daily during pregnancy. One cup of tea (190 ml) provides 40-50 mg caffeine. Provided guidelines on caffeine are followed during pregnancy, tea is likely to be a much healthier option than caffeinated, sugary drinks and also alcoholic drinks.

Iron nutrition: With regards to iron nutrition, the absorption of iron is influenced by a number of factors including the amount of iron consumed and the form of iron (haem or non-haem) consumed. Haem iron (found in animal foods) is more bioavailable than non-haem iron (found in plant foods). However, a healthy well-balanced diet will contain a variety of sources of iron. A diet devoid of animal foods will generally also contain vitamin C which helps the absorption of non-haem iron from plant-based sources of iron. Some studies have found no relationship between tea intake or polyphenol intake and iron status [64]. In one study [65] the strongest dietary association with iron status (measured by serum ferritin) was a positive association with haem iron intake (animal foods) and not non-haem iron intake (plant-based sources).

A review of 16 studies [66] concluded tea consumption does not appear to affect iron status in populations consuming mixed and varied diets. Iron absorption from a meal containing non-haem iron can be optimised by leaving one hour after the meal before drinking tea [67].

Moderate maternal tea consumption has also been associated with reduced risk of acute leukaemia in the child [68].

Adults: Tea has been studied for its impact on several age-related health and well-being issues, including cardiovascular and metabolic health, bone health and brain health, mostly in middle aged to older adults (40-85 years). Whilst significant evidence is derived from epidemiological studies, evidence from clinical studies is promising. Of note for older people is that in the recent longitudinal North East of England study [26] higher tea consumption was associated with significantly better attention (focused and sustained attention), and psychomotor speed (complex tasks only) over five-years follow-up.

Tea has also been associated with reduction in mortality risk. In a meta-analysis of 18 studies, green tea consumption was significantly inversely associated with CVD and all-cause mortality, whereas black tea consumption was significantly inversely associated with all cancer and all-cause mortality [69]. In a systematic review of 22 prospective studies from 24 articles (reporting data on 856,206 individuals), an increase in tea consumption by three cups per day was associated with a 27% reduced risk of CHD, 26% reduced risk of cardiac death, 18% reduced risk of stroke, 24% reduced risk of total mortality, but had little or no effect on stroke mortality [70]. Both black and green teas were associated with reduced total mortality with an increase in one cup of black tea or one cup of green tea reducing the risk of total mortality by 3% and 4% respectively. The maximum reduction in mortality was found at two to three cups daily.

In a further meta-analysis, synthesis of data from 39 prospective cohort studies indicated that each cup increase in daily tea consumption was associated with a 1.5% risk reduction in mortality, an average 4% lower risk of CVD mortality, a 2% lower risk of CVD events, a 4% lower risk of stroke mortality [37]. Subgroup meta-analysis results showed that the magnitude of association was larger in elderly individuals for both all-cause mortality (8% risk reduction; pooled adjusted RR: 0.92; 95% CI: 0.90, 0.94; P<0.0001 and CVD mortality (11% risk reduction RR: 0.89; 95% CI: 0.83, 0.96; P=0.001).

Also, of value for elderly individuals is that tea consumption (both black and green) has the potential to protect bone, maintaining or improving Bone Mineral Density (BMD) and protecting against osteoporosis. By maintaining bone density and promoting the survival of osteoblasts tea may also reduce the risk of hip fractures.

Discussion

Tea has been consumed for thousands of years for emotional and social health and wellness. It is only in recent decades, however, that these benefits have started to become explainable on the basis of scientific evidence. There is a growing body of evidence looking at tea and aspects of health and wellness throughout life from infancy to old age. In 1990 Medline records around 300 papers published on the subject of tea whilst in 2020 over 3000 publications were recorded in the same data base.

A significant proportion of the evidence on tea and health and wellness is derived from epidemiological studies with fewer Randomised Controlled Trials (RCTs). Whilst RCTs are considered to be the gold standard for evaluating clinical outcomes, epidemiological

studies can evaluate the health and wellness impacts of tea drinking, which was our main objective in this review.

In terms of health and wellness, this review has identified a wealth of evidence for *Camellia sinensis* in mood, mental health and cognitive health, cardiovascular health, metabolic health, body weight, bone health, immune health and gut health. Whilst green tea is frequently highlighted for its health benefits, there is a large body of evidence for black tea with studies appearing to indicate that drinking 3-4 cups of black tea daily could help to maintain health and wellness throughout life. The flavonoids present in both black and green tea are considered to be key contributors to these health benefits, although evidence shows that the amino-acid L-theanine may also make an important contribution [15].

Tea consumption has been found to improve mood and reduce physiological stress response with a reduction in blood cortisol levels [11-13]. Whilst caffeine has been thought to be the main contributor to the mood improvement effects of tea, our findings indicate that L-theanine, an amino acid present in black tea and green tea, with recent evidence showing that it is found in black tea in greater concentrations, may be a key bioactive responsible for mood and mental health improvement. This review also shows the potential benefits of L-theanine on memory and alertness with an ability to act in concert with caffeine but to dampen the stimulant spike of caffeine and induce relaxation [15]. Tea has also been shown to have an antidepressant action with meta-analysis indicating a 37% reduction in depression in people drinking three cups of tea daily [20]. Findings from a large UK study in which higher tea consumption was associated with better memory [26] suggest the benefits of tea on brain health in older age.

Cardiovascular health benefits of tea are demonstrated in the peer reviewed literature. Green tea is highlighted for its cardiovascular benefits, often at the expense of black tea which is not without benefits in terms of reducing cardiovascular risk factors such as LDL cholesterol and blood pressure [28,30,33]. Whilst reduction in risk does not necessarily translate into reduced mortality or disease, in terms of cardiovascular mortality, meta-analysis of 32 studies has indicated that a one cup increase (~ 230 ml) in daily tea (either black or green) consumption has been associated with an average 4% lower risk of CVD mortality, a 2% lower risk of CVD events, a 4% lower risk of stroke [37].

Emerging evidence also shows that tea consumption is associated with improved mental health with the polyphenol content thought to contribute to the reduced risk of type 2 diabetes observed in some studies [40] and bone health although not all findings are consistent. Some preliminary evidence also indicates a benefit of tea drinking on bone health. Although not all findings are consistent, a meta-analysis of 14 studies found that 2-3 cups of tea daily has been associated with a 37% decrease in hip fracture [45]. Given the high prevalence of obesity in the UK and the popularity of black tea, it is not surprising that tea is attracting increasing attention for a potential impact on body weight. Tea, with or without milk, is a low calorie beverage and whilst green tea has attracted most research attention in the area of body weight, preliminary evidence also suggests that three cups of black tea each day can inhibit weight gain [57].

The impact of tea on gut health and immune health is also an area of increasing interest, partly due to the COVID-19 pandemic. Polyphenols in both black and green tea interact with the gut microbiota and are broken down in the gastrointestinal tract. Preliminary evidence

indicates that tea polyphenols improve gastrointestinal bacterial diversity, shifting it in a healthier direction [56] which can potentially benefit immune function. Theaflavin compounds derived from black tea have been shown in preliminary research to reduce viral replication [48].

Overall data collated for this review implies benefits in terms of health and wellness from consuming 2-4 cups of tea each day. It is important to note as whilst the manufacture of black tea does have some chemically different end points (e.g., 7-membered benzotropolone ring structures in theaflavins formed from the polymerisation of catechins at the aeration (formerly the fermentation)) stage the vast majority of the phenolics in tea are based on a flavonoid structure. In all types of tea, once consumed, metabolised and absorbed the active 'fragments' may be structurally similar hence they will have similar health promoting benefits.

The benefits of tea consumption are present at all stages of life from infancy to old age and long-term tea consumption promotes long term wellbeing. People are living longer and the risk of developing cardiovascular disease and cognitive impairments increase with age. Obesity, a global trend increasingly starts in childhood and is a known risk factor in developing type 2 diabetes, as well as increased fatality from COVID-19 [71].

Tea is a potentially health and wellness promoting beverage, particularly when consumed without sugar. Whilst this has been known for centuries by those who choose to drink tea, the findings in this review concur with this long held traditional view. This review also points to the need for ongoing tea research in the areas of gut health and its link to immune health and the possibility of reducing infection. Findings from the large English study [26] which suggest a benefit of regular tea drinking in older people on cognitive health should be followed up with further studies.

This review is limited by the fact that much of the data on the health benefits of tea are derived from epidemiological studies which show associations rather than the causes and effects of controlled intervention trials. While these types of human studies overall show heterogeneity and risk of bias, three cups of tea daily, as part of a healthy habitual dietary pattern, may be associated with health and wellness throughout life.

Conclusions

Tea has been consumed for centuries for its relaxing and social benefits. However, research increasingly shows that consuming tea *Camellia sinensis* throughout life from childhood to older age offers health and well-being benefits including hydration, mental and cognitive health benefits, cardiovascular health, metabolic health, bone health, gut health and immune health.

Overall, it appears that both black and green tea consumption in amounts of 2-4 cups daily is beneficial for health and wellbeing throughout the lifecycle. Whilst the flavonoid compounds in tea have attracted most attention in relation to these health and well-being benefits due to their anti-oxidant, anti-inflammatory and cell signalling functions, L-theanine and caffeine in combination contribute significantly to cardiovascular and metabolic health throughout adulthood.

Including three cups of black tea daily as part of a healthy lifestyle strategy could help to preserve and improve physical and mental health from pregnancy and childhood, through the teens and adulthood into old age.

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Conflicts of interest

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