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Moving Beyond Nutrients-Tea Flavonoids and Human Health is it Time to Consider Food-Based Bioactive Guidelines?

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Abstract

Flavonoids are a diverse group of natural compounds with flavan-3-ols being a predominant subgroup within these. Tea is one of the best sources of flavonoids and flavan-3-ols including the arubigins. Whilst flavonoids are not regarded as 'essential' to human health their bioactive properties influence health. Given this, there has been growing interest in the movement towards the development of dietary recommendations for bioactive compounds such as flavonoids in tea made from the leaves of *Camellia sinens*. In the United States the Academy of Nutrition and Dietetics in 2022 convened an expert scientific panel concluding that we should be moving towards a food-based dietary recommendation for flavan-3-ols, with 400-600 mg/d appearing to confer cardiometabolic protection. Intakes from dietary surveys indicate that habitual intakes of flavanol-3-ols are variable, ranging from 33 mg/d (non-tea drinkers) to 698 mg/d (tea drinkers) and depend on the inclusion of dietary sources providing these such as tea and citrus fruits. Given this, the inclusion of such dietary sources may help to plug gaps between habitual intakes and these benchmarks thought to offer cardiometabolic protection. Ongoing research, uniformity of sub-classes of flavonoids measured and use of biomarkers will aid future movements towards food-based guidelines for bioactives.

Keywords: Flavonoids; Flavan-3-Ols; Dietary Guidelines; Bioactive Compound; Tea; Health; Nutrition Trends

Introduction

Bioactives are food components that can impact positively on health [1]. Bioactive compounds from the diet can encompass thousands of phytochemicals, all from different families, amongst which the polyphenols are one of the most notable [2]. It is now well recognised that bioactives can target blood pressure, endothelial health, serum lipids, inflammation, oxidative stress and the gut microbiome [3]. Given this, there has been growing interest towards the development of dietary recommendations for certain bioactives [1,3,4].

Polyphenols can be classified into flavonoids and non-flavonoids [5,6]. Within the branch of 'flavonoids' it is the 'flavan-3-ols' that represent the most interesting and complex subclass of flavonoid [2,6]. Flavan-3-ols, sometimes referred to as 'flavanols' or 'catechins' are a particular group of bioactive compounds that have increasingly been found to impact on health but are not yet formally considered within dietary guidelines [7]. According to chemical structure there are many subclasses of flavonoids, but it is the flavan-3-ols that appear to be the most highly consumed subclass of flavonoid [4].

Given the growing evidence base around bioactives, polyphenols (flavonoids and non-flavonoids) and within the flavonoid sector flavan-3-ols the present paper aims to focus in on flavan-3-ols in particular. It focuses on habitual intakes of flavan-3-ols, evidence on tea flavan-3-ols and health and describes whether now is the time to commence movements towards the compilation of dietary recommendations for certain bioactives recommendations that as of yet do not formally exist.

Dietary Sources & Metabolism

Flavonoids are bioactive compounds found in abundance in foods of plant origin and can be found as glycosides (sugars) and aglycones (non-sugars) [8,9]. They contribute to plant growth and development and plant flowers, leaves, roots, stems, and fruits are renowned for their high flavonoid profiles [10,11]. These typically provide the colour and flavour to foods, fruits and vegetables [9]. In 2018 the United States Department of Agriculture (USDA) released a database including data on 506 food items from five subclasses of flavonoids, including flavan-3-ols [12]. Table 1 summarises key data from this report. Overall, flavan-3-ols are abundantly present in teas, apples, berries, and pears. In the case of black tea thearubigins are a principal flavan-3-ol, providing 81.3 mg/100 g (70%) of the total flavan-3-ols [12].

Using data from 49 human studies the mean bioavailability of flavan-3-ols has been found to be moderate (31±23%) [13]. Intra and

Table 1: Dietary Sources of Flavan-3-Ols.

NDB Database Number	Food Source	Total flavan-3-ols (mg/100g)
14355	Tea, black, brewed, prepared with tap water	115
99068	Tea, green, brewed, flavoured	54
99071	Tea, oolong, brewed	50
99582	Tea, white, brewed	69
14096	Wine, table, red	11
09003	Apples, raw, with skin (*Malus domestica*)	9.3
09236	Peaches, raw	9.2
09252	Pears, raw	6.8
09016	Juice, apple, canned or bottled, unsweetened, without added ascorbic acid	6.0
09302	Raspberries, raw	5.8
09316	Strawberries, raw	4.6
09176	Mangos, raw	1.7
14194	Cocoa mix, powder, prepared with water	1.3
09148	Kiwifruit, green, raw	0.4

Note: The main flavan-3-ols determined were: (+)-Catechin, (+)-Gallocatechin, (-)-Epicatechin, (-)-, Epigallocatechin, (-)-Epicatechin 3-gallate, (-)-Epigallocatechin 3-gallate, Theaflavin, Theaflavin 3-gallate, Theaflavin 3'-gallate, Theaflavin 3,3'-digallate, Thearubigins.

Source: Adapted from Haytowitz, et al. (2022) [61] and USDA (2018) [12].

inter-source differences in bioavailability also exist with this reported to be 25% after tea consumption [13]. From a metabolic stance a large proportion of ingested flavan-3-ols are not absorbed in the large intestine thus these become available to colonic microbiota [14]. It is here that they metabolise flavan-3-ols to yield microbial metabolites that may are proposed to have a role in disease prevention and management [14]. Intestinal microbiotas play a central role in food flavonoid metabolism and ongoing research is key to understanding the mechanisms behind 'how' these compounds exert health effects [15]. A systematic review of 24 publications [16] has previously identified that up to 1000 mL green tea daily (4-5 cups) could increase proportions of Bifidobacterium with mechanistic research implying that black, oolong, Pu-erh and Fuzhuan teas could modulate microbial diversity and the ratio of Firmicutes to Bacteroidetes.

A variety of other authors and studies have looked at the composition of tea brews made from black and green teas. Lakenbrink, et al. (2000) [17] found that a typical UK consumer brew of black tea delivered 137-141 mg flavanoids per serving (235 ml) using an estimation method based on total polyphenol x 0.86='total flavanoids'. Astill, et al. (2001) [18] showed that a number of factors affected the delivery of total polyphenols to the brew (bag weight, brew time etc). They found that a standardised brew and commercially available black tea bags gave around 188-305 mg total polyphenols per serving. Green tea gave lower values of 171-194 mg total polyphenol per serving driven primarily by lower tea bag weights (2 g green *vs* 3.12 g black tea per bag).

Methods

The present publication was a narrative (discussion-based) review. The National Centre for Biotechnology Information (NCBI) database search engine (PubMed) was used to search for and extract relevant publications. English-language publications were chosen only. To obtain data on intakes the search terms "flavonoids" and "flavan-3-ols" combined with "intakes" were used. A restriction to human studies was applied. The most current and relevant studies were included. Intake studies were only included if a measurable daily intake was reported (Table 2). References lists were also searched for relevant publications.

To assess impacts on health an additional PubMed search was undertaken and restricted to meta-analysis publications from the last 5-years. The terms 'flavonoids', 'flavan-3-ols' and 'health' were first applied. A second search was then undertaken using the same search terms with the key term 'tea' also added. Abstracts were screened for relevance and 14 key publications identified (Table 3).

Habitual Intakes

Several surveys in Europe and Western regions have determined habitual dietary intakes of flavonoids, with some reporting specific intakes for flavanol-3-ols and/or their percentage contribution to total flavonoid intakes. As seen in table 2 most surveys use dietary recalls or food frequency questionnaires to determine these. In Europe mean total flavonoid intakes are documented to range from 313 mg/day to 428 mg/day [19,20]. Interestingly, dietary contributors to flavonoid intakes vary regionally. For example, tea provides most flavonoids in the European Union (and in the United Kingdom) whilst fruits and fruit products are predominant contributors in Southern Europe [19,21].

Several studies have been published in the USA, mainly using data from the National Health and Nutrition Examination Survey (NHANES). In general, mean flavonoid intakes in the UDS range from 190 to 345 mg/day [22-26]. Earlier work by Song and Chun (2008) [27] separated out mean flavonoid intakes for tea and non-tea consumers reporting these to be 698 and 33 mg/day, respectively.

Murphy, et al. (2019) [28] undertook a cross-sectional study with 1183 middle-aged Australians finding that women aged 39-65 years had higher flavonoid intakes than men of the same age (660 versus 566 mg/day, respectively). Thearubigins comprised 58% of the flavonoid intake [28]. Data from the Australian Raine Study Gen 2 [29] derived flavonoid intakes from a 212-item FFQ which were 210 mg/day and 200 mg/day at ages 14 and 17 years, thus reducing 10 mg/day (5%) with age.

Data from the Korean National Health and Nutrition Examination Survey (KNHANES) found mean total flavonoids intakes to be 318 mg/day [30] Another Korean analysis of dietary flavonoid intake using data from 11,474 adults who completed 24-hour recalls and found that green tea for catechins and black tea (thearubigins) were both single food items that contributed to more the 50% of the intake of certain flavonoids [31].

Key surveys have also reported mean daily intakes for flavan-3-ols [19,21-22,25,32]. These vary between publications. For example, a European analysis by Vogiatzoglou, et al. (2015) found that gallated flavan-3-ols (53±12 mg/d) were the main contributor to flavonoids [19]. Knaze, et al. (2012) [21] reported highest flavan-3-ol intakes amongst health-conscious UK males (436 mg/d), 378 mg/d amongst UK females and lowest intakes in Greek men and women (161 and 125 mg/d respectively). In the USA [22] daily flavan-3-ol intakes are reported to range from 542 mg/d amongst tea consumers to 98 mg/d amongst non-consumers [22]. In Spain flavan-3-ols comprised 10% [20], Korea 17% [30], the USA 81-83% [24,26] and Australia up to 92% of total daily flavonoids [33]. Data analysed from the highly-regarded EPIC study [32] comprised of 36,037 adults aged 35-74 years who

Table 2: Flavonoid/Flavan-3-Ol Intakes – Key Surveys Undertaken In European and Westernised Regions (Food Sources Only).

Country & Reference	Sample Size	Age	Methodology	Mean Flavonoid Intake (mg/D)	Flavan-3-Ol Intake (mg/d)	Main Flavonoid Food Source(S)
Europe Vogiatzoglou, et al. (2015) [19]	n≈30,000	18–64 y	EFSA/ FLAVIOLA Food Composition Database data	428 mg/d.	53 mg/d (Gallated flavan-3-ols, mainly)	Tea was the main source of total & monomeric flavonoids in the EU (mean: 66 mg/d). In Southern Europe main contributors were fruits & fruit products
Europe Zamora-Ros, et al. (2013) [32]	n=36 037	35-74y	24-h dietary recall	TR intakes ranged from 0.9 mg/day in men from Navarra & San Sebastian to 532.5 mg/day in UK men.	NR	TR contributed <5% to the total flavonoid intake in Greece, Spain and Italy but in the UK constituted 48% of the total flavonoids
Europe Knaze, et al. (2012) [21]	n=36 037	35-74y	24-h dietary recall	NR	436 mg/d - M, health conscious, UK 378 mg/d – F, UK 161 mg/d – M, Greek 125 mg/d – F, Greek	Tea was the main contributor of total flavan-3-ols in the UK. Non-citrus fruits (apples/pears) were the highest contributors in other regions
Spain Zamora-Ros, et al. (2010) [20]	n=40,683	35-64 y	Computerized version of a validated diet history method	313 mg/day	10% flavan-3-ols	The main sources of total flavonoid intake were apples (23%), red wine (21%), unspecified fruit (12.8%), and oranges (9.3%)
USA Vieux, et al. (2020) [22]	n=17,506 NHANES 2011-2016	9y+	2-d of dietary recalls	219 mg/d 610 mg/d tea consumers 141 mg/d non-consumers	174 mg/d 79% of total flavonoids 542 mg/d tea consumers 98 mg/d non-consumers	Time trend analyses showed that flavonoid intakes & tea intakes did not change from 2011 to 2016
USA Kim, et al. (2016) [23]	n = 8833 NHANES 1999-2002 n = 9801 NHANES 2007-2010	19y+	24-h dietary recall	202 mg/d 200 mg/d	NR	Tea was the main food source of flavonoids
USA Sebastian, et al. (2015) [24]	n = 5420 NHANES 2007-2008	≥ 20 y	24-h dietary recall	251 mg/d	81% of flavonoids	Tea was the primary source (81%) of flavonoid intake
USA Bai, et al. (2014) [25]	NR	Adults	24-h dietary recall	345 mg/day	192 mg/day (most abundant flavonoid class).	Tea, wine, beer, citrus fruits, and apples were the most important sources
USA Song & Chun (2008) [27]	n = 8809	-	24-h dietary recall	698 mg/d tea consumers 33 mg/d non tea consumers		Daily total flavonoid intake of tea consumers was over 20 times that of tea non-consumers
USA Chun, et al. (2007) [26]	n=8809 NHANES 1999-2002	-	24-h dietary recall	190 mg/d	Flavan-3-ols (83%)	The greatest daily mean intake of flavonoids was from the following foods: tea (156 mg), citrus fruit juices (8 mg), wine (4 mg), and citrus fruits (3 mg)
Australia Kent, et al. (2020) [29]	n=883	14y and 17-y	212-item FFQ	210 mg/day 14 y 200 mg/d 17 y		Fruit juice was the major contributor to total flavonoid intake
Australia Murphy, et al. (2019) [28]	n=1183	39-65y	215-item FFQ	626 mg/d overall 566 mg /d M 660 mg/d F	Thearubigins accounted for 58% of the flavonoid intake	Flavan-3-ols, predominantly thearubigins from tea, were the main flavonoid consumed by Australians
Korea Jun, et al. (2016) [30]	n=33 581	≥ 19 years	24-h dietary recall	318 mg/d	17% from flavan-3-ols	Major food groups contributing to flavonoid intake were fruits (54·4%), vegetables (20·5%), legumes & legume products (16·2%) & beverages & alcohols (3·1%)
Korea Kim, et al. (2015) [31]	n=11,474	≥ 19 years	24-h dietary recall	107 ± 1.47 mg/d		Kimchi was the major food source, followed by green tea, persimmons, and soybeans

Key: y: year/s, d: day; hr: hour, NHANES: National Health and Nutrition Examination Survey, F: Female, M: Male; NR: Not Reported, TR: Thearubigins.

Table 3: Meta-Analysis Studies Published (last 5 years).

Health Outcome of Focus	Association/Main Findings	Author(s)
Antidiabetic and Anti-Inflammatory Agents	Potential antidiabetic and anti-inflammatory effects	Shamsudin, et al. (2022) [40]
Breast cancer	No association	Nasr, et al. (2023) [62]
Blood pressure (tea flavonoids)	Possible use of this tea as an active compound to promote CV health, mostly when used for longer duration (>7 days) and in men	Ma, et al. (2021) [35]
Cardiovascular disease	Lower risk	Micek, et al. (2021) [41]
Cardiometabolic health (flavan-3-ols)	Potential beneficial effect on cardiometabolic outcomes, but there was heterogeneity	Raman, et al. (2019) [37]
CHD risk	Lower risk	Fan, et al. (2022) [42]
Circulating levels of adiponectin and leptin	Increased circulating adiponectin & decreased leptin levels	Liu, et al. (2022) [63]
Diabetes (flavan-3-ols)	Beneficials effects for protection against T2DM	Guo, et al. (2019) [38]
Prostatitis	May be clinically beneficial	Guan, et al. (2019) [64]
Risk of CVD and All-Cause Mortality (tea flavonoids)	Lower risks of CVD and all-cause mortality among adults	Chung, et al. (2020) [36]
Skeletal Muscle Health	Potential tool for the prevention of muscle loss	Munguia, et al. (2022) [43]
Stroke (flavan-3-ols)	Higher intakes associated with a lower risk of stroke	Li, et al. (2022) [39]
Total and cause-specific Mortality	Potential protective role against total and cause-specific mortality	Mazidi, et al. (2020) [45]
Treating viral acute respiratory tract infections	Potential role for the common cold, influenza, COVID-19, acute non-streptococcal tonsillopharyngitis, acute rhinosinusitis, acute bronchitis, bronchial pneumonia, and upper RTIs	Yao, et al. (2022) [44]

completed 24-hour dietary recalls reported that thearubigin intakes ranged from 0.9 mg/day in men from Spain (Navarro) to 533 mg/day for men in the U.K. High levels of variation may be attributed to variation in black tea intakes.

It should be considered that variations in dietary assessment methods, study populations recruited, different dietary habits attributed to cultures and reporting bias may have contributed to variations in reported flavonoid and flavan-3-ol intakes between studies. Studies also recorded different subclasses of flavonoids and tended to collate these in different ways.

Flavonoids and Health

There has been an emergence of health studies focusing on the role (s) of flavonoids and flavonoid sub-classes, including flavan-3-ols. Meta-analysis publications are useful where there are large volumes of information and considered more highly regarded than individuals studies [34]. Given this, a PubMed search was undertaken restricted to meta-analysis publications from the last 5-years. The terms 'flavonoids', 'flavan-3-ols' and 'health' were first applied. A second search was then undertaken using the same search terms with the key term 'tea' also added. Abstracts were screened for relevance and 14 key publications identified (Table 3).

Tea Flavonoids and Health

As shown in table 1 a range of health outcomes have been investigated. Two meta-analysis papers focused specifically on tea flavonoids [35,36]. Ma, et al. (2021) [35] undertook a meta-analysis of 13 Randomised Controlled Trials (RCTs) finding that black tea supplementation significantly reduced systolic blood pressure ($p=0.04$) and diastolic blood pressure ($p=0.01$), especially in males and when used for >7 days compared with controls. Another publication by Chung, et al. (2020) [36] found a dose-response link between risk of Cardiovascular Disease (CVD) and tea consumption. Data analysed from 39 prospective cohort studies showed that each cup (237 ml) increase in daily tea consumption (around 280 mg and 338 mg of total flavonoids for black and green tea daily, respectively) corresponded to an average 4% reduced risk of CVD mortality, a 4% lower risk of stroke, a 2% reduced risk of CVD events, and a 1.5% reduced risk of all-cause mortality [36].

All Flavonoids and Health

Three meta-analysis studies focused on flavonoid subclasses and reported data on flavan-3-ols and health [37-39]. Compelling findings from Raman, et al. (2019) [37] as evidenced from 156 RCTs found that flavan-3-ols were associated with significant improvements in acute/chronic flow-mediated dilation, systolic and diastolic blood pressure, total cholesterol, and triglycerides [37]. Within the same meta-analysis analysis of the 15 prospective cohort studies showed that highest compared with lowest flavonoid intakes in four studies corresponded to as 13% reduced risk of CVD mortality and in two studies a 19% reduction in risk of chronic health disease incidence [37]. Li, et al. (2022) analysed data from 10 prospective cohort studies (n=387, 076) finding that a 200 mg/day increment of flavan-3-ols corresponded to a 14% reduction in stroke risk [39]. Regarding diabetes Guo and colleagues (2019) [38] found that a 68 mg daily increment of flavan-3-ols was associated with 6% reduction in Type 2 Diabetes Mellitus (T2DM) risk.

Several other health outcomes have also been studied and collated in meta-analysis research. Flavonoids in general have been associated with anti-diabetic and anti-inflammatory effects [40], a lower risk of cardiovascular disease [41], coronary heart disease [42], potential compounds for prevention of skeletal muscle loss [43] and treating viral Respiratory Tract Infections (RTIs) [44]. A meta-analysis of 16 studies has also found that flavonoid consumption was significantly and inversely linked to total and cardiovascular disease mortality risk [45].

Related Recommendations

It has recently been proposed that our food chains are comprised of both essential and non-essential components and that greater attention should now begin to be paid to the 'non-essential' i.e., bioactives that are increasingly being linked to improved health [46]. In the United States an expert panel was convened by the Academy of Nutrition and Dietetics in 2022 [4]. Conclusions drawn were largely based on findings from the influential meta-analysis published by Raman, et al. (2019) [37] which was powered by data from 156 RCTs and 15 cohort studies. Overall, after collating evidence it was concluded that: "The recommendation of 400–600 mg/d for flavan-3-ols to improve cardiometabolic health is based on beneficial effects observed across a range of disease biomarkers and endpoints". It was also concluded that increased consumption of dietary flavan-3-ols could help improve blood pressure, blood sugar levels and cholesterol concentrations [4]. It is noted that this recommendation is higher than the European Food Safety Authority (EFSA) health claim set at 200 mg/d for cocoa-flavanols [47]. When developing this recommendation safety limits were also considered. Assessments of green tea catechin measuring upper intake limits for flavan-3-ols have not reported and do not anticipate any adverse effects for intakes up to 800 mg/day [48]. Italian researchers have also comprised dietary recommendations for atherosclerosis prevention in the general population and within these tea consumption is listed as being associated with reduced atherosclerosis [49].

Some countries also appear to be transitioning towards the inclusion of tea within food-based dietary guidelines. As shown in table 4 across Europe there are deviations in food-based dietary guidelines for water and whether these include tea, or not. For example, in the Netherlands [50] the ingestion of 1.5 to 2 litres of water/day is advised and within this the consumption of 3 cups of black or green tea advised daily. Other regions such as Austria and Bulgaria are more generic and simply say that water can be derived from other sources such as tea [50]. The Japanese food guide spinning top also has similar guidance and recommends drinking plenty of water or tea [51].

Discussion

Nutrients, such as vitamins, minerals, protein, and essential fatty acids all have dietary intake recommendations, but these do not exist for bioactives [52]. These recommendations are based on the amounts needed to avoid a deficiency in key nutrients that may lead to poor health outcomes. There is now a pool of thought that we should be encompassing bioactives as components that are valuable for promoting improved health [46]. Bioactives such as flavonoids have not traditionally been regarded as essential components for health, rather 'non-essential' food components [46,53]. Nevertheless, there is growing scientific support for flavonoids and particular sub-classes such as flavan-3-ols to have potential dietary recommendations [46]. In 2021 a 4-step framework was proposed to facilitate the movement towards such recommendations [53]. In short, this included 1) characterizing the bioactive and quantifying intakes, 2) evaluating safety, 3) quantifying the causal relationship between the named bioactive and relevant health marker and 4) translating the evidence into a quantified bioactive intake statement [53]. Without the movement towards evidence-based guidelines for bioactives such as flavonoids consumers may utilise information from sources that are lacking in standards and rigour [53]. For example, a systematic review of 91 studies identified that there was large variability in the methods used to quantify and evaluate polyphenol intakes which may attribute to some of the discrepancies in intakes reported between studies [54].

In deriving a science-based guideline for governments that translates to ease of consumer understanding we need to understand better the delivery of tea flavonoids to the consumer e.g., flavonoids per serving. As in the present publication there are variations in the literature. Based on USDA data delivery of 400-600 mg flavonoids per day would need (assuming whole cups) 2-3 cups of black or 3-5 cups of green tea. As modelled in table 5 Lakenbrink, et al. (2000) [17] would suggest 3-5 cups of black tea and Astill, et al. (2001) [18] would suggest 2-4 cups per day black tea or 3-4 cups green tea per day. The work by Lakenbrink, et al. (2000) [17] which analysed the flavonoid composition of four commercial tea bag products also revealed that flavonoids comprised 93 to 94% of total phenolics and depending on brewing times the contribution of tea to UK adult average flavonol intakes was projected to be up to 80%. Astill, et al. (2001) [18] also found that final tea infusion compositions were influenced by growing environments, manufacturing conditions, variety, size and particle size (grade) of tea leaves, whether tea in a teabag and the material and construction of the tea bag.

The present narrative review has shown that evidence in this field is building. Flavonoid intakes, as evidenced by meta-analytical studies are now associated with an array of health benefits. The prominent meta-analysis by Raman, et al. (2019) [37] implies the beneficial effect of flavan-3-ol intakes on cardiometabolic markers of health including systolic and diastolic blood pressure, flow-mediated dilation, lipid profiles, CVD mortality and chronic heart disease incidence. Wider health effects appear to include anti-diabetic and anti-inflammatory effects [40], prevention of skeletal muscle loss [43], RTIs [44] and reduced total and cardiovascular disease mortality risk [45]. It has also been observed how daily tea intake as part of a healthy habitual dietary pattern could be associated with reduced risks of CVD and all-cause mortality in adult populations [36].

Table 4: Current Recommendations Related To Beverages.

Country	Recommendation	Reference Source
United States (Academy of Nutrition and Dietetics)	"The recommendation of 400–600 mg/d for flavan-3-ols to improve cardiometabolic health is based on beneficial effects observed across a range of disease biomarkers and endpoints"	Crowe-White, et al. (2022) [4]
Italy (Dietary recommendations for prevention of atherosclerosis)	Regarding beverage consumption tea is associated with a reduced atherosclerosis risk	Riccardi, et al. (2022) [49]
Austria	At least 1.5 l per day. Moderate consumption of coffee, tea, and other caffeinated beverages (3-4 cups per day) is acceptable	European Commission (2021) [50]
Bulgaria	1.5-2 l per day (6-8 glasses) of water or other drinks such as tea	European Commission (2021) [50]
Netherlands	1.5-2 l water per day. Daily 3 cups of green or black tea	European Commission (2021) [50]
Japan	Drinking plenty of water or tea	Food and Agriculture Organization of the United Nations (2023) [51]

Table 5: Projected Number Of Cups Of Tea Required To Deliver Flavonoid Recommendations.

Source	Flavonoids (mg/100ml)	Flavonoids (mg/serving)	Total Polyphenols Per Serving	Cups Required For Delivery (400 mg/d)	Cups Required For Delivery (600 mg/d)
USDA [12]	115 (black)	270	-	1.5	2.2
USDA [12]	54 (green)	127	-	3.2	4.7
Lakenbrink, et al. (2000) [17]	-	137	-	2.9	4.4
Lakenbrink, et al. (2000) [17]	-	141	-	2.8	4.3
Astill, et al. (2001) [18]	-	-	188	2.1	3.2
Astill, et al. (2001) [18]	-	-	305	1.3	2.0
Astill, et al. 2001) [18]	-	-	171	2.3	3.5
Astill, et al. (2001) [18]	-	-	194	2.1	3.1

It is also important to compare gaps between recent recommendations and habitual intakes. For example, we have seen how the U.S. Academy of Nutrition and Dietetics now recommends 400–600 mg/d for flavan-3-ols to improve cardiometabolic health [4]. In contrast habitual intakes of flavan-3-ols are highly variable. For example, in Europe intake of 53 mg/d gallated flavanol-3-ols have been reported [19]. In stark contrast much higher intakes of up to 698 mg/d have been reported in the U.S amongst tea consumers-levels that were 20 times higher than that of non-consumers of tea [27]. Zamora-Ros, et al. (2013) [32] also reported that thearubigin intakes ranged from 0.9 mg/day in men from Navarra and San Sebastian in to 533 mg/day for UK males. Such high levels of variation may be attributed to variation in black tea intakes.

These discrepancies may be attributed to varying assessment methods used to decipher flavan-3-ol intakes [1,7,55]. Underreporting is plausible with multiple automated self-administered 24-h recalls and 4-d food records now being found to out compete food frequency questionnaires in terms of generating best intake estimates [56]. When comparing intakes from Western regions without tea ingestion versus the Academy of Nutrition and Dietetics recommendations, wider gaps appear apparent. This indicates that tea ingestion could be valuable contributor to such recommendations.

UK Movements

The UK Eatwell guide was published by Public Health England in 2016 [57]. As present hydration guidance is that we should aim to drink 6 to 8 glasses of fluid daily. Within this it is stated that water, lower fat milk and sugar-free drinks such as tea all count [57]. An updated report outlining UK Government Dietary Recommendations was also published by Public Health England in 2016 [58]. Government recommendations have been compiled for energy, macronutrient, vitamins, and minerals but no advice as of yet is available for bioactives [58]. The Scientific Advisory Committee on Nutrition (SACN) covers scientific aspects of nutrition and health and advises UK government organisations and the Office for Health Improvement and Disparities [59]. SACN's terms of reference focus on 1) nutrient intakes and status, 2) nutrient content of individual foods and advice on individual nutrients and diet as a whole i.e., the definition of what constitutes a balanced diet, 3) monitoring and surveillance of aspects mentioned, 4) nutritional issues affecting wider public health policy issues including conditions such as cardiovascular disease, cancer, diabetes, oral health, osteoporosis and obesity and 5) research requirements for the factors mentioned [59]. There are also subgroups and working groups thus there could be potential scope to form a working group around bioactives. This could be undertaken from the perspective that they are 'consumed' by the UK population and intakes could influence some of the SACN listed risk factors, with cardiovascular diseases being one of these.

Finally, for UK wide and global movements towards bioactive recommendations wider use of standardised flavonoid databases and uniformity in approaches used to analyse, report, and develop flavonoid interventions would help this field to move forwards [1]. Future research is needed from both an analytical perspective and large-scale epidemiological stance to accurately assess levels and intakes of flavonoids from dietary sources using suitable biomarkers, with particular focus on tea derivatives of flavonoids. For example, urinary levels of catechin and epicatechin have recently been identified as a potential short-term nutritional marker of flavan-3-ols [60] although this would not be applicable to thearubigins from black tea consumption. As this data begins to build the movement towards future dietary recommendations for tea flavonoids then becomes more plausible. It is important that research in this field continues to advance to underpin potential future recommendations and policies in this advancing field [3].

Conclusions

The movement towards developing dietary recommendations for bioactives has been gaining momentum, especially in the United States with the Academy of Nutrition and Dietetics advising 400-600 mg/d flavan-3-ols for cardiometabolic health. Intake data shows that habitual intakes of flavan-3-ols are variable and certain foods and beverages, such as tea, appear to be a predominant contributor to these. Available data shows some variation but 400-600 mg of flavan-3-ols could be provided through the consumption of 2-5 cups of black tea or 3-4 cups green tea based on commercially available UK tea. Ongoing research is needed to continue the advancement of science in this field. In the meantime, tea is an important provider of flavan-3-ols with promising cardiometabolic and wider health benefits.

Declaration

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