Sleep Medicine Reviews 57 (2021) 101430

Contents lists available at ScienceDirect

Sleep Medicine Reviews

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

CLINICAL REVIEW

Association between diet and sleep quality: A systematic review

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ARTICLE INFO

Article history:
Received 31 January 2020
Received in revised form
8 September 2020
Accepted 9 September 2020
Available online 16 January 2021

Keywords:
Sleep
Healthy diet
Fruit
Vegetable
Sugar-sweetened beverages
Mediterranean diet
Systematic review
Evidence

SUMMARY

Dietary habits are considered a leading behavioral risk factor for human health. There is growing scientific evidence suggesting that diet and sleep may be related. The aim of this study was to review the evidence of association between diet and sleep quality. A systematic search in electronic databases PubMed, Embase, Scopus, and the Cochrane Central Register of Controlled Trials was conducted from their inception to November 2019. Studies investigating parameters of diet quality (including dietary patterns or individual healthy/unhealthy foods) and sleep quality (assessed through self-reported or objective methods) were included. The NIH Quality Assessment Tools were used to evaluate the study quality. Twenty-nine studies were reviewed: in summary, consumption of healthy foods was associated with better sleep quality, while higher intake of processed and free-sugar rich foods was associated with worse sleep features. Despite a certain consistency between studies have been observed, the overall poor-to-fair quality of study design (mostly represented by cross-sectional investigations) does not allow to conclude a causal relation. However, diet-related variables are associated with sleep quality, but further studies are needed to corroborate this finding.

Introduction

There is convincing evidence that sleep quantity and quality affect human health: inadequate sleep duration and quality has been associated with increased risk of cancer [1], cardiovascular outcomes [2], diabetes [3] and all-cause mortality [4]. Moreover, long-term changes in sleep quality and architecture have been related to cognitive impairment, including dementias and Alzheimer's disease [5]. Within the context of behavioral factors affecting human health, the interrelation between sleep and diet has been hypothesized about 30 years ago: habitual sleep duration has been generally associated with higher calorie intake and either absolute or relative intake of nutrients or foods [6,7]. Among the potential mechanisms proposed to explain the impact of sleep on dietary intake, extended hours of wakefulness may favour the opportunity to increase eating frequency (i.e., unhealthy snacking), alter the time of intake (i.e., late evening or night feeding) [8], while physiologically sleep deprivation has been demonstrated to affect appetite- (i.e., leptin and ghrelin) and metabolic-related (i.e., cortisol, insulin sensitivity and growth hormones) hormonal homeostasis [9,10]. These hypotheses would also provide the rationale explaining the relation between sleep duration and higher obesity rates [11]. Besides its influence on metabolic disorders through increased risk of obesity, some recent research focused on the role of sleep toward diet quality, showing a general association between short sleep duration and lower diet quality as well as irregular eating behaviors [12]. When considering dietary patterns, individuals sleeping less hours have been reported to follow a diet of lower quality [13,14].

In addition to the aforementioned mechanisms, an intriguing hypothesis includes the possibility of an opposite relation between diet and sleep quality. Some recent overviews of the scientific literature provided interesting insights on the potential association between diet and sleep [15,16]. As recently pointed out [17], despite increasing evidence linking diet to sleep quality and sleep features, previous studies have inconsistently included diet in the analysis of

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https://doi.org/10.1016/j.smrv.2021.101430
1087-0792/

Abbreviations

5-HT	5-hydroxytryptamine
AHEI	Alternative Healthy Eating Index
CHDI	Chinese Healthy Diet Index
CRP	C-reactive protein
DADOS	Deporte ADOlescencia y Salud
DASH	Dietary Approach to Stop Hypertension
DHA	docosahexaenoic acid
DII	Dietary Inflammatory Index
DTAC	Dietary Total Antioxidant Capacity
PGE2	prostaglandin E2
EPA	eicosapentaenoic acid
FFQ	food frequency questionnaire
GABA	gamma-aminobutyric acid
GI	glycaemic index
ISCOLE	International Study of Childhood Obesity, Lifestyle and the Environment
ISI	Insomnia Severity Index
KYRBS	Korea Youth Risk Behavior Web-based Survey
LPS	lipopolysaccharides
MAILES	Men Androgen Inflammation Lifestyle Environment and Stress
MEAL	Mediterranean healthy Eating, Aging and Lifestyle
NF-κB	nuclear factor kappa-light-chain-enhancer of activated B cells
ORAC	oxygen radical absorbance capacity
PSPSI	Paediatric Sleep Problem Survey Instrument
PSQI	Pittsburgh Sleep Questionnaire Index
SCFAs	short chain fatty acids
ULSAM	Uppsala Longitudinal Study of Adult Men

the relation between sleep and human health. As diet is an important determinant of health itself, it is crucial to assess to what extent the relation between diet and sleep may be a confounder or a mediating factor for their effects on health. Several mechanisms have been associated with the sleep–wake cycle, including i) neuroendocrine regulation through neurotransmitters, such as serotonin (5-hydroxytryptamine, 5-HT), gamma-aminobutyric acid (GABA), orexin, melanin-concentrating hormone, acetylcholine, galanin, noradrenaline, and histamine (for instance, following modification of circadian rhythm) [18], and ii) neuroinflammatory processes that alter the normal functionality of the brain and increase the risk of developing neurodegenerative disorders [19]. Consequently, nutritional and dietary aspects that influence or modulate the aforementioned mechanisms may have downstream effects on sleep.

Up to date, two systematic summaries of evidence from observational and intervention studies investigating the potential role of dietary macronutrient composition specifically on sleep duration showed inconclusive results suggesting that the dietary macronutrient profile alone may not play a strong role on sleep [20,21]. Another systematic review focused on the potential bidirectional association between sleep and dietary intake in 0–5 year old children [22]. However, no systematic summary of evidence investigating the relation between diet-related variables as exposure and sleep quality features as outcome has been conducted so far. Therefore, the aim of this study was to systematically review the existing evidence of association between diet and sleep quality in school-age children, adolescents and adults.

Methods

The design, analysis, and reporting of this study followed the PRISMA checklist (Table S1).

Study selection

A literature search in PubMed, Embase, Scopus, and the Cochrane Central Register of Controlled Trials was conducted from inception to November 2019. The following search strategy was used for PUBMED and adapted to the other databases: (((diet OR dietary OR nutrition OR dietary patterns OR food OR nutritional)) AND (sleep OR sleep quality)) AND (observational OR prospective OR longitudinal OR cohort OR cross-sectional OR nested OR intervention OR trial OR clinical study) restricted to humans only. No restriction on study design was applied, thus we considered for inclusion all studies conducted on humans with cross-sectional, prospective, or clinical intervention design. In order not to overlap with existing reviews and to provide an original research question, we focused our search on studies investigating quality features of the diet (i.e., dietary patterns/regimens or consumption of healthy/unhealthy foods) rather than providing quantitative approaches; thus, studies investigating/comparing total energy intake or macronutrient ratios were not included in this systematic review. Inclusion criterion was also the presence of a quantitative or qualitative assessment of sleep quality parameters assessed either with polysomnography or questionnaire tools; studies conducted solely on sleep duration were not considered. Other exclusion criteria were the following: studies conducted in infants and toddlers (<3 years old); studies conducted in subgroup populations of patients with pre-existing chronic conditions; and studies with multiple intervention procedures (i.e., dietary advices plus physical activity) or no clear definition of the dietary intervention. Reference lists of studies retrieved were also analysed in order to retrieve additional pertinent studies fulfilling the above criteria. Two independent reviewers (JG and GG) performed the electronic search and evaluated the studies for inclusion/exclusion; discordance on eligibility was discussed and solved with agreement between reviewers.

Data extraction

Data were abstracted from each identified study by using a standardized extraction form. The following information was collected: 1) first author name; 2) year of publication; 3) study cohort name; 4) country; 5) number of participants; 6) sex of participants; 7) age range or mean of the study population at baseline; 8) dietary exposure; 9) sleep quality assessment; and 10) main results.

Quality assessment

The overall study quality was scored by means of the "NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies" and the "NIH Quality Assessment Tool for Controlled Intervention Studies" (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). These tools allow the rater to assign a three-level quality score ("good", "fair", or "poor"), based on the consideration of 14 items. The tool for observational studies evaluates the following: research question, study population (2 items), groups recruited from the same population and uniform eligibility criteria, sample size justification, exposure assessed prior to outcome measurement, sufficient timeframe to see an effect, different levels of the exposure of interest, exposure measures and assessment, repeated exposure assessment, outcome measures, blinding of outcome assessors, follow-up rate, and statistical analyses. The tool for controlled intervention studies evaluates the following: described as randomized, treatment allocation (2 items), blinding (2 items), similarity of groups at baseline, dropouts (2 items), adherence, avoidance of other interventions, outcome measures assessment, power calculation, pre-specified outcomes, and intention-to-treat analysis.

Results

Studies description

A total of 1703 studies have been identified through the search strategy (Fig. 1). Out of these, after examination of title (n = 1459) and abstracts (n = 193) and full-texts (n = 22), 29 studies have been finally included for the review. The main characteristics and quality results for the studies included are presented in Table 1. A total of 25 studies had an observational design (only one with prospective design) and four were clinical intervention trials. Four studies were conducted in US, eight in Europe, one in South America, four in Middle-East countries, six in Eastern Asian countries, five in Australia, and one multinational. Diet-related variables explored in the studies included quality features through investigation of individual food groups (n = 9), dietary patterns (n = 18), and carbohydrate quality (high glycaemic index diets) (n = 2). The majority of the studies investigated sleep quality through administration of the Pittsburgh Sleep Questionnaire Index (PSQI) (n = 11) or other validated instruments taking into account various features related to sleep (n = 4); other studies explored clinical features related to sleep quality, such as actigraphy or polysomnography (n = 9); finally, seven studies assessed subjective evaluation of sleep quality through self-evaluation. Based on the NIH Quality Assessment Tools, half of the studies achieved a “fair” quality, while the other half scored “poor” quality and only one study had good description of methodology, outcomes report and discussion: most of the studies had proper description of methods and selection of the study population, while the main limitation was lack of prospective

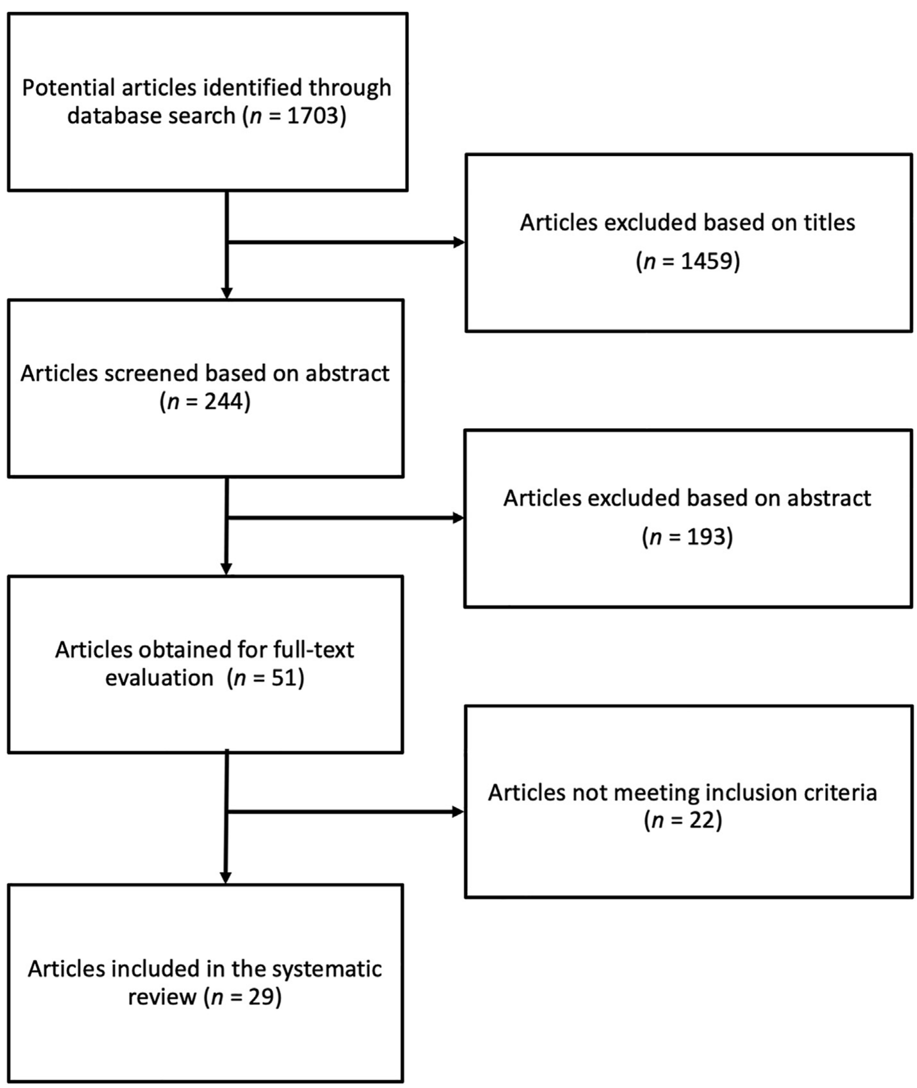

Fig. 1. Study selection process.

Table 1
Main characteristics of observational and intervention studies included in the systematic review.

Authors, reference number	Cohort name, country	Sample size	Mean age or range, gender	Dietary exposure or intervention	Sleep quality assessment	Main results	NIH quality score
Observational studies							
Abshirini et al., 2018 [46]	NR, Iran	400	about 56 y, F	Dietary total antioxidant capacity	Self-report questionnaire	Inverse relation between the dietary total antioxidant capacity and occurrence of sleep problems together with other related somatic and psychological symptoms, such as hot flushes and sweating, anxiety, and exhaustion.	Fair
Adelantado-Renau et al., 2019 [42]	DADOS, Spain	269	13.9 ± 0.3 y, MF	Mediterranean diet	PSQI, Spanish version, actigraphy	Positive correlation between adherence to the Mediterranean diet and sleep quality.	Poor
Campanini et al., 2017 [38]	Seniors-ENRICA, Spain	1500	>60 y, MF	Mediterranean diet	Self-report questionnaire	Mediterranean dietary pattern associated with lower risk of variation in sleep duration (>2 h) and of poor sleep quality.	Good
Cao et al., 2017 [30]	Jiangsu Nutrition Study, China	1492	≥20 y, MF	Dietary soy isoflavone	Self-report questionnaire	Persistent high intake of isoflavone associated with a reduced risk of daytime falling asleep in women, but not men.	Fair
Cao et al., 2017 [47]	MAILES, Australia	784	35-80 y, M	Dietary patterns	PSG and self-reported symptoms	High intake of vegetables, fruits, and legumes inversely associated with sleep onset, no other associations found.	Fair
Castro-Diehl et al., 2018 [41]	Multi-Ethnic Study of Atherosclerosis, USA	2068	45-84 y, MF	Mediterranean diet	Actigraphy	Moderate-high adherence to Mediterranean diet more likely to sleep 6–7 vs. <6 h/night and less likely to report insomnia symptoms.	Fair
Chaput et al., 2018 [27]	ISCOLE, Multinational	5873	9-11 y, MF	Sugar-sweetened beverages	Actigraphy	Sugar-sweetened beverages associated with lower sleep duration, while earlier bedtime with lower intake of regular soft drinks and higher intake of energy drinks and sports drinks.	Fair
Faris et al., 2017 [23]	NR, UAE	919	17-25 y, MF	Energy drink consumption	Online questionnaire (PSQI adapted)	41% consuming energy drinks with significant relationship between consumption and sleep quality/patterns.	Poor
Gianfredi et al., 2018 [33]	insomnia, Italy	117	20-43 y, MF	Mediterranean diet	Sleep and Daytime Habits Questionnaire	Frequent consumption of meat, fish, coffee associated with higher odds of various sleep disorders; conversely, frequent consumption of pasta and whole-grain bread inversely associated.	Poor
Godos et al., 2019 [43]	MEAL, Italy	1936	>18 y, MF	Mediterranean diet	PSQI	Increase of 1-point of the Mediterranean diet adherence score associated with 10% higher likelihood of having adequate sleep quality.	Fair
Godos et al., 2019 [44]	MEAL, Italy	1936	>18 y, MF	Dietary Inflammatory Index	PSQI	Higher adherence to a pro-inflammatory diet associated with worse sleep quality and longer sleep latency.	Fair
Hong and Peltzer 2017 [31]	KYRBS, Korea	65,212	15.1 ± 0.02 y, MF	Diet quality	Online single question	Healthy dietary behaviours linked to higher sleep satisfaction; unhealthy dietary behaviours inversely associated with sleep satisfaction.	Fair
Jaussent et al., 2011 [40]	NR, France	5886	≥65 y, MF	Mediterranean diet	Self-report questionnaire	Higher adherence to the Mediterranean diet inversely associated with insomnia symptoms, only in women but not in men.	Poor
Katagiri et al., 2014 [32]	Three-generation Study of Women on Diets and Health survey, Japan	3129	34-65 y, F	Eating habits	PSQI (Japanese version)	Low intake of vegetables and fish, high intake of confectionary, noodles and carbohydrate, consumption of energy drinks and sugar-sweetened beverages, skipping breakfast, and eating irregularly associated with poor sleep quality.	Poor
Kong et al., 2018 [28]	Ningbo Adult Chronic Diseases and Risk Factors, China	5160	17-74 y, MF	Dietary behaviours	PSQI, Chinese version	Soy sauce and alcohol positively associated with poor sleep quality; dark fruits and water positively associated with good sleep quality.	Poor

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Lopes et al., 2019 [45]	NR, Brazil	296	18-60 y, MF	Dietary Inflammatory Index	ESS, PSQI, Chalder Scale, PSG	DII scores associated with apnea severity, daytime sleepiness, and rapid eye movement latency in obese individuals.	Poor
Mamalaki et al., 2018 [39]	HELIAD, Greece	1639	72.7 ± 5.7 y, MF	Mediterranean diet	Sleep Scale from the Medical Outcomes Study	Seep quality, but not sleep duration, associated with higher adherence to the Mediterranean diet, only among individuals aged ≤75 years.	Fair
Marmorstein et al., 2017 [24]	Camden Youth Development Study, USA	127	13.2 ± 0.8 y, MF	Energy drink consumption	Ad-hoc questionnaire (PSQI adapted)	Energy drink interacting with initial insomnia and daytime fatigue, no association for coffee and soda.	Poor
Morrissey et al., 2019 [25]	GSC and GV study, Australia	2253	9-12 y, MF	Different foods consumption	Self-report questionnaire	Sugar-sweetened beverage consumption were shown to increase the likelihood of having more than three sleep problems.	Fair
Nisar et al., 2019 [29]	NR, Pakistan	440	18-24 y, MF	Different foods consumption	PSQI	Soybeans, whole grains, processed meats, leafy greens, dark chocolate, spices, dairy products, products high in fat and sugar, lima beans, and carbohydrates associated with sleep quality.	Poor
Reid et al., 2019 [35]	Multi-Ethnic Study of Atherosclerosis, USA	1813	68.3 ± 9,1 y, MF	Diet quality (AHEI-10)	Type 2 in—home PSG	Moderate-to-severe obstructive sleep apnea associated with lower intake of whole grains, higher intake of red/processed meat, and poor diet quality.	Fair
Rostami et al., 2019 [37]	NR, Iran	488	12-18 y, F	DASH diet	ISI, Iranian version	High adherence to a DASH-style diet associated with lower odds of insomnia.	Poor
van Egmond et al., 2019 [36]	ULSAM Study, Sweden	970	71±1 y, M	Healthy Diet Indicator and Mediterranean diet	Self-report questionnaire	No associations between dietary scores and sleep parameters. Low consumption of milk and dairy products (one of the dietary features of the MD) associated with better subjective sleep initiation.	Poor
Watson et al., 2018 [26]	NR, Australia	287	8-12 y, MF	Sugar consumption	PSPSI	Total sugar consumption not associated with sleep or behavioural domains nor predicting of sleep behaviour problems.	Poor
Wu et al., 2019 [34]	Chinese Urban Adults Diet and Health Study, China	1548	18-75 y, MF	Diet quality (Chinese Healthy Diet Index)	PSQI	Better diet quality (food diversity, higher intake of fruits and fish/seafood, lower eggs consumption, and higher total energy intake), significantly associated with lower risk of poor sleep quality.	Fair
Intervention studies							
Afaghi et al., 2007 [48]	NA, Australia	12	18-35 y, M	High/low GI meal	PSG	Reduced sleep latency in high GI compared with a low GI meal consumed 4 h before bedtime, as well as the same high GI given 1 h before bedtime.	Good
Hansen et al., 2014 [50]	NA, USA	95	21-60 y, M	Fish (Atlantic salmon)	Actigraphy and self-reported sleep quality	Fish group reported better sleep latency than the meat group.	Fair
Jalilolghadr et al., 2011 [49]	NA, Australia	8	8-12 y, MF	High/lowGI drink	PSG	Greater total and NREM arousal index in the first half of night after high GI drink.	Fair
Saito et al., 2017 [51]	NA, Japan	120	20-84 y, MF	Zinc-rich oysters/zinc yeast- or astaxanthin-enriched food	Actigraphy and PSQI	Zinc-rich food efficiently decreased the time necessary to fall asleep and improved sleep efficiency, whereas zinc-enriched yeast food and astaxanthin oil significantly improved the sleep onset latency.	Good

Abbreviations: AHEI-10 (Alternative Healthy Eating Index-2010); DADOS (Deporte, ADOlescencia y Salud study); DASH (Dietary Approaches to Stop Hypertension); DII (Dietary Inflammatory Index); ESS (Epworth Sleepiness Scale); F (female); GI (glycaemic index); GSC (Great South Coast Childhood Obesity Monitoring Study); GV (Goulburn Valley Health Behaviours Monitoring Study); HELIAD (Hellenic Longitudinal Investigation of Aging and Die study); inSOMNIA (Sleep disOrder&MediterraneaNdIet in Advancement); ISCOLE (International Study of Childhood Obesity, Lifestyle and the Environment); KYRBS (Korea Youth Risk Behavior Web-based Survey); M (male); MAILES (Men Androgen Inflammation Lifestyle Environment and Stress); MEAL (Mediterranean healthy Eating, Lifestyle and Aging study); NA (not applicable); NR (not reported); PSG (polysomnography); PSPSI (Paediatric Sleep Problem Survey Instrument); PSQI (Pittsburgh Sleep Quality Index); ULSAM (Uppsala Longitudinal Study of Adult Men).

design and self-report of the outcome investigated (Table S2). Among intervention studies, two studies scored as "fair" and two as "good": the main limitation was that eligibility criteria were not clearly pre-specified and the participants were not representative sample of general population.

Observational studies on sugar-sweetened/energy/caffeinated drinks

Several studies conducted on younger populations (children or students) often found a relation between consumption of sugar-sweetened beverages, energy and caffeinated drinks and sleep quality outcomes due to the rationale that such beverages may affect the physiologic circadian rhythm and sleep-related features. In a cross-sectional survey conducted on randomly selected college students at the University of Sharjah/United Arab Emirates ($n = 919$), which aimed to establish a relation between energy drinks intake (defined as caffeinated sugar-sweetened beverages) and sleep quality (assessed through the PSQI), the authors found a higher proportion of participants with good sleep quality among non-drinkers and a significant ($r = -0.10$, $P < 0.05$) relationship between the consumption of energy drinks and sleep quality as well as sleep patterns [23]. In the Camden Youth Development Study ($n = 127$; mean age 13.1 years; 68% Hispanic, 29% African American), the association between measures of frequency of caffeinated beverage consumption (energy drinks, coffee, and soda) and sleep quality assessed through the PSQI and the Child and Adolescent Sleep Habits Questionnaire showed that energy drink consumption was inversely correlated with sleep duration ($r = -0.36$, $p < 0.01$) and directly with daytime fatigue ($r = 0.21$, $p < 0.05$) [24]. A study including 2253 students (ages 8.8–13.5) from two monitoring studies across regional Victoria (Australia) aimed to investigate the influence of dietary factors on sleep quality using data on dietary intake validated against dietary recommendations and assessed with the Simple Dietary Questionnaire and sleep quality assessed by considering various sleep-related variables, classified within a 16-item questionnaire (including sleep duration, sleep initiation, and maintenance/waking episodes). The study revealed that, among various dietary factors, sugar-sweetened beverage consumption was associated with having several problems with sleep duration, quality and efficiency (OR = 2.21, 95% CI: 1.32–3.72) [25]. However, results have not been always univocal when considering adherence to the dietary recommendations and sleep features among the young population. For instance, in a sample of 287 Australian children aged 8–12 years, in which the association between dietary sugar and sleep quality has been investigated through administration of a food frequency questionnaire (FFQ) and the Paediatric Sleep Problem Survey Instrument (PSPSI), a validated 30-item tool which assesses sleep problems in school-aged children, only a minority of participants (19%) did not exceed the recommended sugar intake limit, and the analyses showed that total sugar consumption (as a percentage of energy derived from confectionary or sugar-sweetened beverages) was not associated with sleep or behavioural domains (r ranged from −0.07 to −0.08; p ranged from 0.173 to 0.979) nor contributed to the prediction of sleep behaviour problems (p range from 0.16 to 0.80) [26]. Also the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE), a multinational study conducted on children ($n = 5873$; aged 9–11 years), investigated the relation between sugar-sweetened beverages and sleep quality including sleep duration, sleep efficiency and bedtime assessed by 24 h, waist-worn accelerometer. The study showed that children regularly consuming sugar-sweetened beverages had lower sleep duration while earlier bedtime was associated with lower intake of regular soft drinks and higher intake of energy drinks and sports drinks: however, the association between sleep efficiency and all types sugar-sweetened beverage consumption was not significant while children consuming specifically cola or soft drinks were less likely to meet sleep duration recommendation of 9–11h/night (OR = 0.79, 95% CI: 0.71–0.88) [27].

Observational studies on individual food groups

Several studies assessed the role of individual food groups on sleep quality through dietary recalls, administration of FFQ, or direct questions on food consumption. Among studies investigating the relation between individual food groups and sleep quality assessed through PSQI, a survey on 5160 participants from the 2015 Ningbo Adult Chronic Diseases and Risk Factors Survey (China) reported that intake of soy sauce (OR = 1.02, 95% CI: 1.00, 1.04; beta = 0.022, $p = 0.001$) and alcohol (OR = 1.44, 95% CI: 1.16, 1.80; beta = 0.217, $p = 0.005$) were positively associated with poor sleep quality, while consumption of dark fruits (beta = −0.394, $p = 0.001$) and water (beta = −0.246, $p = 0.001$) were positively associated with good sleep quality [28]. Interesting results on soy have been also reported by a study conducted on 440 medical students, aged 18–24 years, chosen through non-probability consecutive sampling from Karachi, Pakistan, investigated to test the association between individual food consumption and sleep quality; the PSQI was used to measure sleep quality and a self-administered questionnaire was used to measure the frequency of food consumption: significant associations with better sleep quality were found for certain foods, including soybeans (OR = 2.51, 95% CI: 1.13–5.61), lima beans (OR = 6.57; 95% CI: 1.62–26.7), and papaya (inversely associate, OR = 0.40; 95% CI: 0.18–0.85) [29]. Also another study investigated soy isoflavone intake in relation with sleep parameters in a longitudinal analysis conducted on Chinese adults aged 20 years and older from the Jiangsu Nutrition Study followed up for 5 years ($n = 1474$): the results showed that individuals with higher consumption of soy isoflavone had lower risk of long sleep duration and reduced risk of daytime falling asleep, despite the latter association was significant in women (OR = 0.20, 95% CI: 0.06–0.68) but not men, while no consistent association between soy isoflavone intake and short sleep duration was found [30].

Among investigations evaluating more general "healthy" dietary behaviors, a study was conducted on 65,212 students (mean age 15.1 years) participating to the Korea Youth Risk Behavior Web-based Survey (KYRBS) in which participants were asked about food consumption and self-rated sleep satisfaction. Healthy dietary behaviors (including fruit, vegetable, and milk consumption) were reported to be linked to higher sleep satisfaction while, on the contrary, unhealthy dietary behaviors (intake of caffeine, soft drinks, sweet drinks and fast food consumption) were inversely associated with sleep satisfaction [31]. The diet and sleep quality of 3129 female workers aged 34–65 years were analyzed by means of a self-administered diet history questionnaire and the PSQI, in a cross-sectional study conducted in Japan: poor sleep quality was associated with low intake of vegetables (p for trend 0.002) and fish (p for trend 0.04) and high intake of confectionary (p for trend 0.004), noodles (p for trend 0.03), and sugar-sweetened beverages ($p < 0.001$) [32].

A cross-sectional survey of nursing students of the University of Perugia, Italy, participating to the InSOMNIA study ($n = 117$, age 20–43 years), was conducted to assess the potential relation between dietary variables and sleep disorders: insomnia symptoms included difficulty in initiating sleep, difficulty in maintaining sleep, non-restorative sleep, early morning awake, and insomnia with diurnal symptoms. The authors reported various associations between frequent (>3 times/week) consumption of meat, fish, coffee and higher odds of various sleep disorders; conversely, the frequent consumption of pasta and whole-grain bread was inversely associated [33].

Observational studies on diet quality indices

Some studies provided a more comprehensive and complete approach by evaluating the characteristics of the whole diet though assessing the adherence with healthy dietary guidelines or principles. A cross-sectional study conducted among urban adults from eight Chinese cities from the Chinese Urban Adults Diet and Health Study (n = 1548) investigated sleep quality using the PSQI and assessed diet quality through administration of a semi-quantitative FFQ and calculation of the Chinese Healthy Diet Index (CHDI): the study showed that better diet quality, featuring greater food diversity, higher intake of fruits and fish, along with higher seafood consumption, lower eggs consumption, and higher total energy intake, was significantly associated with lower risk of poor sleep quality (OR = 0.62, 95% CI: 0.43−0.88) [34]. Participants of the Multi-Ethnic Study of Atherosclerosis (MESA, n = 1813) undergoing type 2 in−home polysomnography (which included measurement of reductions in slow-wave sleep, REM sleep, and apnea-hypopnea index) and investigated for diet quality through the Alternative Healthy Eating Index (AHEI), had a high prevalence (about one third) of moderate-to-more severe obstructive sleep apnea, which was associated with lower intake of whole grains (beta = −0.20, p = 0.005), higher intake of red/processed meat (beta = −0.43, p = 0.001), and poor overall diet quality (beta = −1.26, p = 0.019) [35]. An older male population from Sweden (*n* = 970; mean aged 71 years old) participating to the Uppsala Longitudinal Study of Adult Men (ULSAM) has been investigated in a study testing for the association between higher adherence to the Mediterranean dietary pattern or to the Healthy Diet Indicator (based on recommendations from the World Health Organization on saturated fatty acids, polyunsaturated fatty acids, proteins, total carbohydrates, sucrose, fiber, fruit and vegetables, cholesterol, and fish intake) and sleep disturbances [36]; the study showed null results, with no significant associations between the dietary patterns investigated and either sleep initiation or maintenance problems [36].

Observational studies on a priori-derived dietary patterns

Another strategy to assess quality-features rather than quantity of a diet was to apply *a priori*-derived scores evaluating the level of adherence to dietary patterns developed through evidence from the scientific literature. Amongst the most important *a priory* defined dietary patterns, the Dietary Approach to Stop Hypertension (DASH) and the Mediterranean dietary pattern have been the most studied in relation to health so far. The DASH diet is characterized by a high consumption of vegetables, fruits, whole grains, low-fat dairy, nuts and legumes, and limited amounts of red or processed meat, sweets, and sugar-sweetened beverages. To date, only one cross-sectional study exploring the effect of DASH diet on sleep has been conducted [37]. The study randomly recruited 488 adolescent girls aged 12−18 years old from different regions of Iran and assessed insomnia through the Insomnia Severity Index (ISI) questionnaire, consisting of seven questions. The authors reported that high adherence to a DASH-style diet was not associated with lower odds of insomnia compared to lower adherence (OR = 0.54, 95% CI: 0.27−1.09) despite a significant trend over quintiles of adherence was found (p for trend = 0.03) [37].

In contrast, several studies have been conducted to test whether Mediterranean dietary pattern is associated with sleep features. The Mediterranean diet is referring to a traditional dietary pattern adopted by southern Italian individuals in the ‘60s and characterized by high consumption of plant-based foods (i.e., fruit, vegetable, legumes and nuts) and whole-grain cereals, moderate consumption of fish and dairy foods as sources of animal protein, low consumption of meat-products; other peculiar features of this dietary pattern were daily intake of extra virgin olive oil and (red) wine during the meals. A prospective cohort study was conducted on nearly 1500 older adults living in Spain followed-up for 2.8 years and monitored for their sleep duration and indicators of poor sleep quality: the authors found that individuals more adherent to the Mediterranean dietary pattern had a lower risk of a variation in sleep duration of more than 2 h (for increase, OR = 0.54, 95% CI: 0.34−0.85; for decrease, OR = 0.58, 95% CI: 0.35−0.95) and were also at lower risk of poor sleep quality (OR = 0.68, 95% CI: 0.47−0.99) [38]. Another study investigating sleep duration and quality in relation to adherence to the Mediterranean diet on a sample of 1639 adults aged ≥65 years from the Hellenic Longitudinal Investigation of Aging and Diet: dietary habits were recorded through a 69-item FFQ, sleep measures were collected through administration of the Sleep Scale from the Medical Outcomes Study, consisting of 12 self-reported items, and the Sleep Index II, consisting of nine questions related to sleep quality (the higher the score, the lower the quality) [39]. The study showed that sleep quality, but not sleep duration, was directly associated with higher adherence to the Mediterranean diet (beta = −0.087, p = 0.001 and beta = −0.019, p = 0.486, respectively); when the analysis was stratified by age groups, results were particularly significant among individuals aged ≤75 years [39]. Accordingly, it has been shown in a sample of 2673 men and 3213 women aged 65 years and older living in France participating to the 3C Study, that higher adherence to the Mediterranean diet was inversely associated with insomnia symptoms (such as difficulty initiating and maintaining sleep as well as morning awakening), despite the association was significant in women (OR = 0.80, 95% CI: 0.64−1.00) but not in men (OR = 0.93, 95% CI: 0.69−1.26) [40]. Actigraphy-measured sleep duration and self-reported insomnia symptoms have been also investigated in a cohort of 2068 individuals participating in the Multi-Ethnic Study of Atherosclerosis: compared with individuals who reported low adherence to the Mediterranean diet, those with a moderate-high adherence were more likely to sleep 6−7 vs. <6 h/night (OR = 1.43, 95% CI: 1.08−1.88) and less likely to report insomnia symptoms occurring with short sleep (OR = 0.65, 95% CI: 0.45−0.93); noteworthy, individuals with an unchanging adherence reported fewer insomnia symptoms compared with those with decreasing adherence (OR = 0.61, 95% CI: 0.45−0.82) [41]. A national three-year longitudinal research project, DADOS (Deporte, ADOlescencia y Salud, investigated the relation between sleep parameters and adherence to the Mediterranean diet in 269 Spanish adolescents (aged 13.9 ± 0.3 years): adherence to the Mediterranean diet was assessed using KIDMED, a 16-item tool focusing on the main dietary characteristics of the diet, while sleep quality was assessed through the PSQI; the study showed positive correlations between adherence to the Mediterranean diet and sleep quality (r = 0.120, p < 0.05) but not duration [42]. Lately, we performed an observational study investigating the relation between adherence to the Mediterranean diet and sleep quality evaluated with the PSQI on a sample of nearly 2000 individuals recruited in Southern Italy participating to the Mediterranean healthy Eating, Aging and Lifestyle (MEAL) study; the report revealed that a total of 1314 individuals (67.9% of the cohort) had adequate sleep quality and increase of 1-point of the Mediterranean diet adherence score was associated with 10% higher likelihood of having adequate sleep quality (OR = 1.10, 95% CI: 1.05−1.16) and various sleep features, including sleep duration (OR = 1.07, 95% CI: 1.02−1.12), latency (OR = 1.07, 95% CI: 1.02−1.12), efficiency (OR = 1.06, 95% CI: 1.01−1.12), and lack of day dysfunction (OR = 1.04, 95% CI:

1.00–1.09); interestingly, when the analyses were stratified by weight status, the association between sleep quality and high adherence to the Mediterranean diet was observed only among normal/overweight individuals but not in obese participants [43].

We hypothesized that there might have been a potential role of the antioxidant potential of the diet. Consequently, we calculated the Dietary Inflammatory Index (DII), a literature-derived score that has been developed to evaluate the inflammatory potential of the diet based on the effect of dietary parameters on inflammatory cytokines and we found that individuals with higher adherence to a pro-inflammatory diet were more likely to have worse sleep quality (OR = 0.73, 95% CI: 0.61–0.88), sleep duration (OR = 0.79, 95% CI: 0.66–0.93) and latency (OR = 0.85, 95% CI: 0.72–1.00) [44]. Among other studies exploring the same research question, a cross-sectional study conducted in patients diagnosed with severe obstructive sleep apnea (n = 296) aiming to evaluate the potential role of a pro-inflammatory diet in predicting sleep pattern showed that the DII scores were significantly associated with apnea severity, daytime sleepiness, and predicting rapid eye movement latency in obese individuals; however, no significant associations were found between DII scores and the other sleep parameters investigated [45]. Finally, another study investigating the relation between the antioxidant potential of the diet toward sleep issues has been conducted on 400 postmenopausal women who referred to municipality health houses and health centers in south Tehran, Iran [46]. In the study, the dietary total antioxidant capacity (DTAC) was calculated using Nutrient Data Laboratory of US Department of Agriculture database, which estimated TAC using the oxygen radical absorbance capacity (ORAC) method for 100 g of selected foods, and expressed it as micromole of Trolox equivalents (micromol TE/100 g), while information on sleep quality was recorded using the Menopause Rating Scale questionnaire. Results of the study revealed an inverse relation between the DTAC and occurrence of sleep problems together with other related somatic and psychological symptoms, such as hot flushes and sweating, anxiety, and exhaustion [46].

Observational studies a posteriori-derived dietary patterns

Only one study has been conducted by testing for *a posteriori*-derived dietary patterns: in a cohort of community dwelling Australian men (n = 784, age 35–80 years) participating to the Men Androgen Inflammation Lifestyle Environment and Stress (MAILES) study, sleep parameters measured through polysomnography and self-reported sleep symptoms (including daytime sleepiness, sleep quality, sleep onset latency, apnoea hypopnea index, and total sleep duration) were tested for association with *a-posteriori* derived dietary patterns retrieved after administration of a 167-item FFQ; the study showed that a prudent dietary pattern characterized by high intake of vegetables, fruits, and legumes was inversely associated with sleep onset compared with a Western dietary pattern characterized by high intake of processed meat, snacks, red meat and take-away foods (beta = −6.34, 95% CI: −11.57, −1.11 min); however, no associations were found between dietary patterns and other sleep outcomes [47].

Clinical intervention studies on glycaemic index

The clinical intervention studies were characterized by a more rigorous methodology for assessing the effect of a dietary exposure (having control groups for comparison) but were limited by a lower number of participants and generally explored relatively acute effects on sleep quality features. To investigate the role of carbohydrate quality in sleep onset, a group of researchers studied the effect of glycaemic index (GI) and meal time on sleep in 12 healthy men volunteers (aged 18–35 years). The participants were administered standard, isocaloric meals of either low GI or high GI rice, 4 h or 1 h before their usual bedtime, after familiarization night followed by three test nights in random order 1 week apart. The intervention led to a significant reduction in the mean sleep onset latency in high-GI (9.0 ± 6.2 min) compared with a low-GI (17.5 ± 6.2 min) meal consumed 4 h before bedtime; the high-GI meal given 4 h before bedtime showed a significantly shortened sleep latency compared with the same meal given 1 h before bedtime (9.0 ± 6.2 min compared with 14.6 ± 9.9 min; $P < 0.01$); no effects on other sleep variables were observed [48]. Another study was conducted on eight children, which underwent three nights of full polysomnography study, one familiarization and two test nights consecutively: on the test nights, 1 h before bedtime, the children were given randomly a low GI or high GI milk drink. Interestingly, the mean of total arousal index in the first half of night after the high GI was greater than that of low GI drink; moreover, also NREM arousal index in the first half of night after the high GI was higher than that after low GI drink, even though other sleep parameters were not affected by the GI of the drink [49]. The results of these intervention studies suggest that GI may play a role in shortening sleep onset latency and increasing the number of arousals during sleep.

Clinical intervention studies on food groups

Other studies investigated the role of specific “healthy” foods in improving sleep quality. A total of 95 male sexual offenders (mean age 42 years, range 21–60) residing at a secure forensic inpatient facility in the US were randomly assigned into two groups; one group that would have to eat *fish* (portion size 150–300 g) three times a week and one group that would have to eat *meat* (e.g., chicken, pork, beef) meals three times a week for a period for six months (September–February); data concerning sleep latency, sleep efficiency, actual sleep time, and actual wake time actigraphs from the Actiwatch Activity Monitoring Systems were investigated; moreover, sleep diaries investigating sleep quality and daily functioning were also collected [50]. The fish group reported better sleep latency than the meat group (23.30 ± 20.38 vs. 30.89 ± 18.93 min, $p < 0.05$); while no substantial differences between groups were found, a worsening of sleep latency (19.37 ± 19.45 min vs. 30.89 ± 18.93 min, $p < 0.05$), efficiency (69.64 ± 7.1 min vs. 75.84 ± 6.47 min, $p < 0.05$) and actual wake time (107.49 ± 31.1 min vs. 83.63 ± 25.71 min, $p < 0.05$) was observed between pre-post tests in the meat group [50]. In order to investigate the potential effects of zinc in the regulation of sleep, and astaxanthin, an antioxidant abundant in seafoods able to chelate minerals and promote zinc absorption, a placebo-controlled parallel group trial has been conducted on 120 healthy Japanese subjects divided into four groups: placebo, zinc-rich food (two types of shellfish), zinc- and astaxanthin-rich foods (shellfish and krill oil), and placebo supplemented with zinc-enriched yeast and astaxanthin oil; their night activity was recorded by actigraphy for 12 weeks to assess total sleep time, sleep onset latency, wake after sleep onset, sleep efficiency, frequency and duration of nocturnal awakenings, and number of body positional changes [51]. The results of the PSQI were not significantly different between groups; however, the zinc-rich food group efficiently decreased the time necessary to fall asleep (−6.46 ± 12.29 vs. 2.78 ± 10.55, $p = 0.032$) and improved sleep efficiency compared with the placebo group (3.78 ± 7.80 vs. −1.74 ± 4.94; $p = 0.025$), whereas the group that ingested zinc-enriched yeast and astaxanthin oil significantly improved the sleep onset latency (−8.57 ± 8.38 vs. 2.78 ± 10.55, $p = 0.004$) [51].

Discussion

The present study aimed to investigate the current state of evidence for the association between exposure to diet-related variables and sleep quality outcomes: several studies showed a potential relation between healthier dietary patterns or individual food groups and sleep quality. There was no univocal definition of “healthy” diet, but some general characteristics were common to all dietary patterns reviewed, including high intake of plant-derived foods, including fruit and vegetable, whole-grains and legumes, olive oil and seafood as main sources of fats (i.e., in the Mediterranean diet) and low consumption of processed and free sugar-rich foods (i.e., sugar-sweetened beverages). Concerning dietary fats, there were several studies showing a potential benefits of seafood, a large body of evidence has been provided for the role of omega-3 fatty acids for brain health: docosahexaenoic acid (DHA) represents one of the most important structural components of neuron membranes responsible for their stability and neuronal homeostasis also affecting serotoninergic, noradrenergic and dopaminergic neurotransmission; eicosapentaenoic acid (EPA) is capable of modulating both metabolic and immune process, which may reduce pro-inflammatory cytokines, such as arachidonic acid (AA, an n-6 PUFA) level on cell membrane and prostaglandin E2 (PGE2) synthesis [52]. Dietary omega-3 fatty acids have been suggested to influence brain health through several potential mechanisms, including the neuroendocrine modulation of the serotoninergic and dopaminergic transmission, the synthesis of neurotrophic factors and the release of anti-inflammatory cytokines such as Transforming Growth Factor-β1 [53].

Also, carbohydrates may play an important role on sleep quality: however, rather than mere quantity, the reviewed studies pointed that type of carbohydrates may be a more important target for future studies. In fact, high-glycemic index carbohydrates stimulate glucose entry into the blood and facilitates a greater insulin response, which mediates the uptake of large neutral amino acid into muscle, but not tryptophan that is largely bound to plasma albumin, leading ultimately to higher availability for serotonin synthesis [54]. However, excessive chronic consumption of added simple sugars have been shown to be associated with cognitive impairments, especially worsened hippocampal memory function; this relation might be mediated by neuroinflammation in the hippocampus, which is especially pronounced in the high sugar/low fat condition [55]. In contrast, complex carbohydrates not digestible by human enzymes and broken down by the intestinal flora leading to production of short chain fatty acids (SCFAs) as a by-product of their fermentation; SCFAs (including acetate, propionate, and butyrate) have shown anti-inflammatory effects that can be transmitted also to the brain through pathways involving neuronal and glial signaling and immune system activation [56]. Altered intestinal flora (“*dysbiosis*”) may lead to increased permeability of the intestinal mucosa (“*leaky gut*”); as a result, bacterial components, such as lipopolysaccharides (LPS) from the bacterial cell wall, bind on circulating macrophages and monocytes, which in turn stimulate an inflammatory response with rise in circulating pro-inflammatory cytokines [57].

Protein quality (i.e., amino-acid composition) is also another dietary feature that might be related to sleep quality [58]. Tryptophan is among the most studied amino-acids because is a precursor of serotonin and melatonin, both implicated in sleep regulation [59]. Also L-ornithin may play a role on sleep quality by reducing stress-induced activation of the central nervous system mediated by the GABA receptor [60]. Finally, protein quality (i.e., animal vs. plant protein) may contribute to the inflammatory potential of the diet as a result of the different utilization by gut microbiota of derived peptides produced after protein digestion, which in turn may result in dysbiosis and rise in inflammatory biomarkers [61]: conversely, substitution of animal by vegetable proteins led to changes in the microbiota and improvement in antioxidant status in people with chronic disease [62].

Another hypothesis that could be derived from the results of the present systematic review is that healthy and unhealthy dietary patterns potentially playing a role against (or in favor of) low-grade subclinical inflammation may, in turn, have an impact on neuroinflammatory phenomena [63]. In fact, recent research demonstrated that there is a bidirectional link between sleep and inflammation and oxidative stress. It has been showed that sleep disturbances and extreme long sleep duration may be associated with higher levels of c-reactive protein (CRP) and IL-6, while short sleep duration only with IL-6 [64]. It has been demonstrated that individuals with sleep disorders are prone to increased oxidative damage and impaired antioxidant defense, and that the magnitude of changes is associated with severity of disorders [65]. Several dietary factors have been hypothesized to influence systemic inflammation, mainly through pro- or anti-inflammatory cytokine release and regulation of nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) signaling pathway [66]. Up to date, several mechanisms that underline sleep-inflammation cross-talk have been hypothesized, implicating dysregulation of inflammatory balance, partially caused by the over-activation of microglia in central nervous system [67], dysfunction of different neurotransmitters, intracellular signaling, gene transcription, reduced synaptic plasticity and hippocampal neurogenesis, and epigenetic changes that in turn can contribute to short-term and long-lasting imbalances of neuronal function and behavior [68]. Plant-based foods are key sources of antioxidant vitamins and (poly)phenols, which have been shown to exert neuroprotective effects through regulation of inflammatory and oxidative response damage [69]. Similarly, healthy fats, such as mono and certain polyunsaturated fatty acids, like omega-3 fatty acids, exert anti-inflammatory and neuroprotective effects improving cognitive functions [70]. On the contrary, processed foods and highly caloric foods have been shown to pro-inflammatory cytokine release and therefore worsen inflammatory state. In example, food sources of refined carbohydrates may negatively affect dietary glycemic index and load, which in turn may induce acute inflammatory response [71]. Similarly, consumption of processed meat products, has been associated with production of biomarkers of inflammation [72].

Nutritional factors may finally affect the circadian rhythm leading to modification in sleep quality [73]. Albeit not directly investigated in this review, there is evidence that dietary factors may affect adiponectin levels, a hormone involved in glucose regulation and fatty acid oxidation: following consumption of certain foods (i.e., coffee and tea) or as consequence of intermittent fasting, adiponectin influence the circadian system and may play a role in sleep quality [74]. Moreover, adiponectin levels have been also associated with anxiety, mood and stress-related affective disorders [75]. Circadian rhythm has been shown to respond to some bioactive compounds, such has dietary polyphenols (i.e., hydroxycinnamic acids in coffee and flavonoids in tea), which may regulate circadian clock genes and leptin secretion, another hormone that helps to regulate energy balance by inhibiting hunger [76,77]. Alterations in the sleep–wake cycle lead to fluctuation of gut microbiota taxonomic configurations, which in turn may play a role in physiological stress induction and sleep-related outcomes [78]. Moreover, circadian rhythm also influence levels of Brain-Derived Neurotrophic Factor, a neurotrophin regulating neuronal survival, growth, and plasticity, which has been related to mental health and neurodegenerative disorders, as well as with insomnia [79–81].

The results summarized in the present systematic review should be considered in light of some limitations. First, the most of studies included had a across-sectional design, and thus it is not possible to identify a causality or directionality between dietary exposure and sleep quality. Moreover, diversity and a limited number of studies was available for each dietary exposure not allowing to state convincing level of the evidence and perform quantitative analysis. Second, about a half of the studies scored as poor quality, mainly due to the tools used to measure sleep quality (solely few studies used actigraphy or polysomnography). Future studies with a prospective design, optimally measuring sleep features using valid tools and not only self-reported symptoms are needed to better understand the real impact of dietary factors toward sleep quality and establish dietary recommendations.

Conclusions

The general quality of the studies conducted so far is poor-to-fair, taking into accounting that the majority of studies had a cross-sectional design, which does not allow to clearly define cause—effect relations. Thus, there is currently insufficient evidence available to conclude whether it is possible to modulate or influence sleep quality through interventions on dietary habits nor on individual components of the diet. However, the findings are promising and an association between certain dietary factors and sleep quality has been shown. It is important to better understand the potential molecular mechanisms relating nutrition with brain health that may lead to increased sleep quality. Future research should provide evidence from larger prospective cohort studies to individualize potential candidates among dietary patterns and individual foods or molecules, while clinical intervention studies should confirm the retrieved associations. Preclinical studies could focus on molecular mechanisms and novel pathways. Finally, interventions on the gut microbiota may be a useful tool to explore the role of the gut—brain axis in sleep quality and disorders.

Practice Points

- Healthy diets, rich in plant-derived foods and seafood as well as low in processed and free sugar-rich foods, are associated with sleep quality.
- The dietary characteristics underlined suggest a potential role of inflammation and gut—brain axis in affecting sleep quality.

Research Agenda

Better designed studies are needed to strengthen the conclusions:

- Prospective cohort with proper follow-up and use of adequate tools to collect data on dietary exposure and sleep quality are warrant.
- Randomized controlled trials on larger samples and with objective methods to evaluate sleep quality are needed to confirm the results from observational studies.
- Preclinical and clinical studies focusing on the role of inflammation and gut microbiota in affecting sleep quality may provide final evidence for the hypothesized mechanisms.

Funding

This study was partially supported by a fund from the Italian Ministry of Health "Ricerca Corrente" (RC n. 2751594) (Drs. Ferri, Caraci and Godos).

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smrv.2021.101430.

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