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Research article

Association between yogurt and dietary supplements containing probiotic consumption with sleep disturbance in US adults: Results from NHANES, 2009–2018

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ABSTRACT

Purpose: Sleep disorders are common globally. Probiotics may improve human microbial diversity, offering potential benefits for sleep disturbances by enhancing sleep quality and reducing disorders. We aimed to use a population-based study to investigate the association between yogurt (a probiotic food) and probiotic consumption with sleep disturbances in US adults.
Methods: A total of 49,693 adults from the 2009–2018 National Health and Nutrition Examination Survey (NHANES) were included in the analyses. Sleep disorders and sleep duration were assessed according to the Sleep Disorders Questionnaire. The Dietary Questionnaire evaluated yogurt and dietary supplements containing probiotic consumption. After adjusting for confounding factors, weighted multivariable logistic regression and subgroup analyses were used to assess the association between yogurt and probiotic consumption and sleep status.
Results: Of the study cohort, 3535 (14.24 %) participants consumed yogurt and/or dietary supplements containing probiotics. The prevalence of sleep disorders was 16.22 %. Only 53.51 % of the participants achieved the recommended amount of sleep (7–9 h), with 6.10 % and 33.48 % having excessive and insufficient sleep duration, respectively. Weighted Logistic regression models indicated a significant association of probiotic intake with a decreased risk of sleep disturbances compared with those without yogurt or probiotic consumption after adjustments. (For sleep disorders: OR: 0.96, 95 % CI 0.94–0.98, $P < 0.001$; for sleep duration: OR: 0.98, 95 % CI 0.96–1.00, $P = 0.081$) Moreover, the effect size of the probiotic intake on sleep was especially significant in sex, race, and BMI subgroups.
Conclusion: The present study first indicated that yogurt and probiotic consumption were associated with a reduced risk of sleep disturbances in US adults, particularly among males, whites,

Abbreviations: **WHO**, World Health Organization; **SCFAs**, Short-chain fatty acids; **NHANES**, National Health and Nutrition Examination Survey; **BMI**, Body Mass Index; **OR**, Odds Ratio; **CI**, Confidence Interval.

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and those with a normal BMI. Incorporating yogurt or probiotics into the diet could serve as a public health strategy for improving sleep disturbances, though further investigation into the underlying mechanisms is needed.

1. Introduction

Sleep is an essential physiological process for life activities and plays a major role in body homeostasis. Due to lifestyle changes and increased pace of life, sleep disorders have become a widespread public health issue [1–3]. According to the World Health Organization (WHO), about one-third of the population experiences insomnia symptoms, and about 10–15 % suffer from chronic sleep disorders [4]. In addition, middle-aged people are particularly susceptible to short sleep among all age groups [5]. The consequences of sleep deprivation are far-reaching, leading to progressive impairments of memory, language, and cognition, as well as sensory perception and emotion [6–8]. Sleep deprivation has been associated with numerous health issues, including obesity, hypertension, diabetes, depression, increased mortality, and dysregulation of the gut microbiome [9–12].

As the second genome of the human body, the gut microbiome contains approximately 100 trillion microorganisms. It possesses the potential to influence brain homeostasis via the microbial-gut-brain axis under both physiological and pathological conditions [13,14]. Accumulating evidence indicates a pivotal role of the gut microbiome in sleep disorders. Both self-reported and objectively measured sleep quality positively correlate with gut microbial diversity and Firmicutes to Bacteroidetes ratio [11]. Sleep deprivation exacerbated microbiome dysbiosis and systemic inflammation [15]. At the same time, changes in the gut microbiome affect sleep through immunomodulatory and metabolic mechanisms, inducing further comorbidities [16]. Moreover, specific dietary components that affect microbiome composition are also known to influence sleep [17]. Probiotic supplementation prevented sleep deprivation-induced cognitive dysfunction in rats by enhancing the production of short-chain fatty acid (SCFA) and maintaining microglial homeostasis [18].

According to the International Scientific Association for Probiotics and Prebiotics (ISAPP), “probiotics” refers to live microorganisms that confer a particularly abundant in fermented dairy products like yogurt [19]. Evidence showed that the supplementation of probiotics increased the amount of “beneficial bacteria”, significantly relieving anxiety, depression, and insomnia [20–22]. Therefore, many clinical dietary supplements contain probiotics to maintain the health of the host by the regulation of the gut microbiome [23]. A Recent study suggested that daily consumption of *Lactobacillus plantarum* PS128 as a dietary supplement for 30 days increased the levels of dopamine and serotonin in the serum, which in turn improved sleep efficiency during the deep sleep stage and arousal times [24]. Studies have confirmed that probiotics improve sleep by modulating the autonomic nervous system, stimulating the secretion of sleep cytokines, and inhibiting inflammation [25–27]. Although increasing evidence indicates the potential benefits of probiotics in sleep disorders, no large cross-sectional studies have explicitly investigated the association between probiotic intake and sleep status.

This study aimed to assess the relationship between yogurt and dietary supplements containing probiotics and the prevalence of sleep disorders and sleep duration in a large-scale cohort of participants in the National Health and Nutrition Examination Survey (NHANES), 2009–2018.

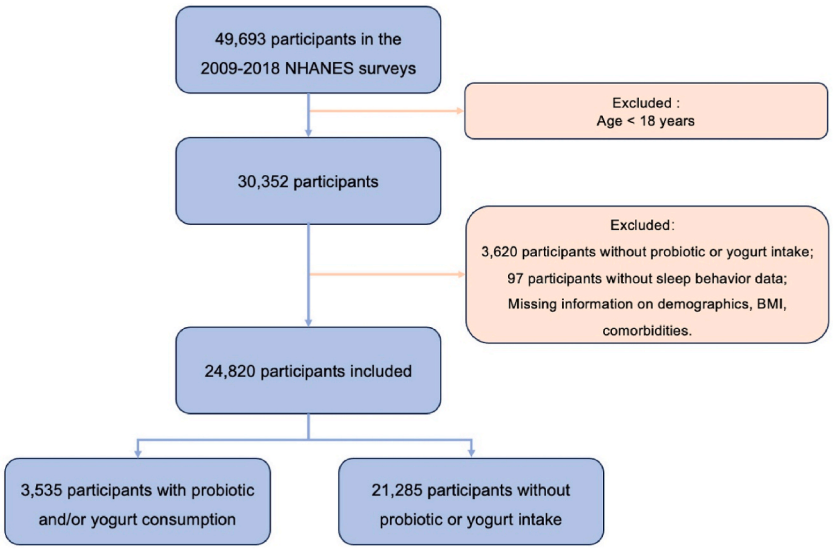

Fig. 1. Flowchart of the study population.

2. Material & methods

2.1. Study design and population

NHANES is a national research survey designed to collect demographic, socioeconomic, dietary, and health-related information in the United States. Annually, a nationally representative sample of about 5000 people takes part in the survey. NHANES was approved by the NHANES Institutional Review Board and the NCHS Research Ethics Review Board (NHANES 2009–2018: Continuation of Protocol #2005-06, Protocol #2011-17, Continuation of Protocol #2011-17, Protocol #2018-01; https://www.cdc.gov/nchs/nhanes/irba98.htm) [28]. All procedures were performed in compliance with relevant laws and guidelines. Supplementary Material 1 contains all the questionnaires given to the participants of this study.

In the present study, 49,693 participants from the NHANES surveys between 2009 and 2018 were included. We excluded participants aged <18 years and those with missing information on yogurt and dietary supplements containing probiotic consumption, sleep behavior (sleep disorders and sleep duration), comorbidities (hypertension, diabetes, and stroke), and covariates (sex, race, education, and body mass index (BMI)). Therefore, a total of 24,820 participants remained in our cohort for analysis (Fig. 1).

2.2. Assessment and definition of yogurt and probiotic consumption

We utilized the Dietary Interview - Individual Foods, First Day and Individual Foods, Second Day to assess yogurt consumption. We

Table 1
Participants' baseline demographic and clinical characteristics.

Variables	Without yogurt and probiotic intake (N = 3535)	Yogurt and probiotic intake (N = 21,285)	*P*-value
Age			<0.001[a]
<45	9079 (46.4 %)	1414 (39.3 %)	
[45, 60)	5211 (27.6 %)	919 (29.3 %)	
≥60	6995 (26.0 %)	1202 (31.0 %)	
Sex			<0.001[a]
Female	10,472 (49.0 %)	2318 (64.5 %)	
Male	10,813 (51.0 %)	1217 (35.5 %)	
Race			<0.001[a]
Mexican American	3226 (9.1 %)	396 (5.4 %)	
Other Hispanic	2219 (6.3 %)	335 (4.5 %)	
Non-Hispanic White	8226 (64.0 %)	1810 (77.3 %)	
Non-Hispanic Black	4953 (12.4 %)	425 (5.1 %)	
Other/multiracial	2661 (8.1 %)	569 (7.8 %)	
Education			<0.001[a]
Below highschool	5176 (16.2 %)	464 (7.5 %)	
Highschool	5052 (24.5 %)	552 (14.6 %)	
College or above	11,057 (59.3 %)	2519 (77.9 %)	
BMI			<0.001[a]
<25	5919 (28.0 %)	1127 (33.9 %)	
[25, 30)	6798 (31.8 %)	1187 (33.4 %)	
≥30	8568 (40.1 %)	1221 (32.7 %)	
Drinkers			<0.001[a]
Heavy drinkers	4018 (32.8 %)	503 (26.0 %)	
Moderate drinkers	7159 (50.7 %)	1443 (59.9 %)	
No drink user	2908 (16.5 %)	396 (14.1 %)	
Smoke			<0.001[a]
Current smokers	4597 (21.0 %)	333 (8.8 %)	
Former smokers	5031 (24.4 %)	851 (26.4 %)	
Never	11,646 (54.6 %)	2350 (64.8 %)	
Hypertension			<0.001
Hypertension	7894 (32.9 %)	1151 (28.6 %)	
Normal	13,391 (67.1 %)	2384 (71.4 %)	
Diabetes			0.044
Diabetes	2908 (10.2 %)	387 (8.7 %)	
Normal	18,377 (89.8 %)	3148 (91.3 %)	
Sleep disorders			0.100
Normal	17,858 (82.4 %)	2937 (80.6 %)	
Sleep disorders	3427 (17.6 %)	598 (19.4 %)	
Sleep duration			0.042[a]
Insufficient	7271 (33.9 %)	1039 (29.4 %)	
Recommend	11,230 (59.9 %)	2052 (66.5 %)	
Excessive	1363 (6.1 %)	151 (4.1 %)	

BMI, Body Mass Index. Mean ± SD for continuous variables, unweighted number (weighted percentage) for categorical variables. *P*-value was calculated by the weighted chi-squared test.

[a] $P < 0.05$.

used the Dietary Supplement Use 30-Day - Individual Dietary Supplements to assess dietary supplements containing probiotics. Supplementary Material 2 describes detailed information on probiotic consumption. The study considered probiotic intake when participants reported consumption of yogurt or probiotic-containing dietary supplements [29].

2.3. Definition of sleep disturbance

Sleep disturbances consist of sleep disorders and sleep duration. The Sleep Disorders Questionnaire addressed the question "Ever told by doctor have sleep disorder?" or "Ever told doctor had trouble sleeping?" to assess sleep disorders. Sleep duration was evaluated through the question "How much sleep do you get (hours)?" or "Sleep hours". Sleep duration was categorized into three categories: insufficient sleep time (<7 h/day), recommended sleep time (7–9 h/day), and excessive sleep time (>9 h/day) [30].

2.4. Assessment of potential covariates

Based on weekly alcohol consumption and binge drinking days in the NHANES Alcohol Use Questionnaire, alcohol users were classified into three categories: no drink users, moderate drinkers, and heavy drinkers [31]. The NHANES Cigarette Use Questionnaire categorized smokers as current smokers (currently smoke somedays), former smokers (used to smoke at least 100 cigarettes but do not currently smoke), or never [32].

2.5. Statistical analysis

Sample weights from the MEC interviews were reweighted to merge ten years of total survey data from the NHANES 2009 to 2018 ($1/5 \times WTMEC2YR_{cycle}$). Continuous variables were presented as mean ± standard deviation (SD), and categorical variables were presented as numbers or percentages. We evaluated the association between probiotic intake and sleep disturbance using multivariable logistic regression models. Model 1 was not adjusted for any factors. Model 2 was adjusted for age, sex, and BMI. Model 3 was adjusted for age, sex, race, education, BMI, smokers, alcohol drinkers, diabetes, hypertension, and stroke. Logistic regression results were expressed as an odds ratio (OR) and a 95 % confidence interval (95 % CI). Analyses were performed with R (version 4.2.0). Statistical significance was determined by $P < 0.05$.

3. Results

3.1. Baseline characteristics according to yogurt and probiotic intake

A total of 24,820 adult participants were included in this analysis, of whom 14.24 % had yogurt and/or probiotic consumption. 4025 (16.22 %) participants reported sleep disorders and higher prevalence in unrecommended sleep duration, with 6.10 % and 33.48 % with excessive and insufficient sleep time, respectively. Females, whites, highly educated, and those with recommended sleep duration exhibited greater consumption of yogurt or dietary supplements containing probiotics. Additionally, the consumption behavior stratified by age, BMI, smoking status, and hypertension was statistically significantly different (all $P < 0.001$). Detailed baseline demographic and clinical characteristics are described in Table 1.

3.2. Associations between probiotic intake and sleep disturbance

As shown in Table 2, three weighted logistic regression models were constructed to evaluate the relationship between yogurt and/or probiotic intake and sleep disturbances. In the unadjusted Model 1, compared to those who did not consume yogurt and probiotics, participants with yogurt and probiotic exposure had a lower incidence of insufficient and excessive sleep duration (OR: 0.94, 95 % CI 0.92–0.98, $P < 0.001$). There was no statistical significance in sleep disorders (OR: 0.95, 95 % CI 0.96–1.00, $P = 0.11$). Model 2 adjusted for age, sex, and BMI, the prevalence of sleep disturbance was significantly lower in the probiotic exposure group (For sleep

Table 2
The association between yogurt and probiotic intake and sleep disturbances.

	Model 1 OR (95 % CI)	*P*-value	Model 2 OR (95 % CI)	*P*-value	Model 3 OR (95 % CI)	*P*-value
Sleep disorders						
No exposure	Reference		Reference		Reference	
Yogurt and probiotic exposure	0.98 (0.96, 1.00)	0.11	0.98 (0.96, 1.00)	0.11	0.96 (0.94, 0.98)	<0.001[b]
Sleep duration[a]						
No exposure	Reference		Reference		Reference	
Yogurt and probiotic exposure	0.94 (0.92, 0.98)	<0.001[b]	0.94 (0.92, 0.96)	<0.001[b]	0.98 (0.96, 1.00)	0.08

OR, odds ratio; CI, confidence intervals.
Model 1: Unadjusted; Model 2: Adjusted for age, sex, and BMI; Model 3: Adjusted for age, sex, race, education, BMI, alcohol use, smoking status, diabetes, hypertension, and stroke.
[a] : Grouping insufficient and excessive sleep time into "Unrecommended sleep duration" for analysis.
[b] $P < 0.05$.

disorders: OR: 0.95, 95 % CI 0.96–1.00, $P = 0.11$; for sleep duration: OR: 0.94, 95 % CI 0.92–0.96, $P < 0.001$). However, following further adjustment for race, education, alcohol use, smoking status, diabetes, hypertension, and stroke (Model 3), yogurt and probiotic intake demonstrated significant protection with sleep disorders (OR: 0.96, 95 % CI 0.94–0.98, $P < 0.001$) rather than sleep duration (OR: 0.98, 95 % CI 0.96–1.00, $P = 0.08$).

3.3. Subgroup analysis

We further explore the association between yogurt and probiotic consumption and sleep disturbances in subgroup age, sex, race, education, and BMI under Model 3. 18.12 % of females consumed yogurt and/or probiotics, compared to 10.12 % of males. However, 17.21 % of females experienced sleep disorders, surpassing the 15.16 % of males. This protective effect of probiotic and/or yogurt intake on sleep disorders was more significant among males ($P = 0.039$; P for interaction = 0.045). And for sleep duration, the significant protection was among Non-Hispanic White ($P < 0.001$; P for interaction = 0.018) and those with normal BMI ($P < 0.001$; P for interaction = 0.023) (Fig. 2).

4. Discussion

This large cross-sectional study investigated for the first time the association between yogurt and dietary supplements containing probiotic consumption and sleep disturbances in US adults (2009–2018). We found that participants with yogurt and/or probiotic intake reported reasonable sleep duration and a low prevalence of sleep disorders after adjustment for covariates. Furthermore, the protective association was also found to be more pronounced among males, Non-Hispanic White, and those with normal BMI.

Previous studies have also shown a positive correlation between sleep and probiotic intake, which is consistent with our study. A meta-analysis of 7 randomized controlled trials showed that daily consumption of *Lactobacillus gasseri* CP2305 increased gut microbiome diversity and significantly improved sleep quality in adults objectively and subjectively [33]. The dosage and form (such as yogurt, a milk-based beverage, beverage, or tablet) of probiotics varied in the meta-analysis and our study. However, all forms of probiotics are beneficial for sleep quality. This is attributed to their shared capacity to provide beneficial microbial communities, thereby improving overall health, including enhanced sleep quality. Irwin et al. [34] assessed the impact of probiotics and paraprobiotics on sleep metrics among adult participants in a systematic review and meta-analysis. The health benefits were more pronounced on subjective sleep scales rather than objective sleep parameters measured by polysomnography or actigraphy, especially with probiotic supplementation lasting 8 weeks or more. Another randomized controlled study involving 32 participants revealed sex-related differences in the effect of yogurt-based probiotics. Specifically, the paraprobiotic CP2305 demonstrated a more pronounced improvement in sleep quality and latency among male students than female students [35]. In the present subgroup analyses, we also found that males were more likely to benefit from probiotic consumption than females. In fact, women encounter distinct sleep challenges during various phases, such as menstruation, pregnancy, and menopause. Hormonal changes, in particular, elevate the risk of sleep disturbances among women more so than men [36,37].

As active microorganisms, probiotics benefit the host by promoting metabolic activity and the diversity of beneficial gut bacteria [38]. Yogurt is a nutrient-dense food commonly containing strain-specific probiotics, the health benefits of yogurt may be attributed to its prebiotic and probiotic properties [39]. Supporting evidence suggests that *Bifidobacterium breve CCFM1025* modulates gut microbiome to regulate sleep by influencing key metabolites and hypothalamus-pituitary-adrenal axis functions [40]. A study in mice

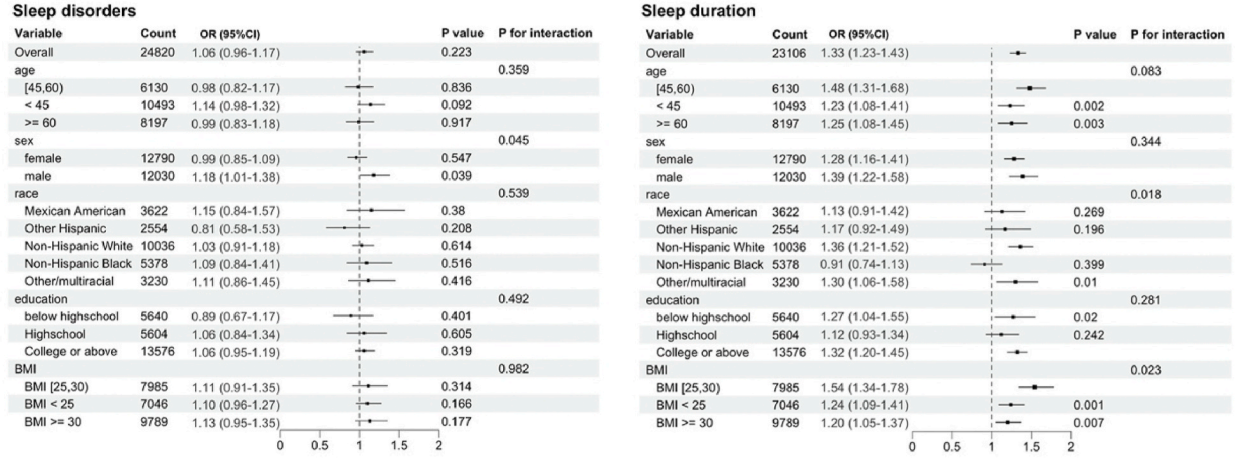

Fig. 2. Association between sleep disturbances with yogurt and probiotic consumption in NHANES subgroups. Logistic regression analyses of the association between sleep disturbances with yogurt and probiotic consumption in subgroup age, sex, race, education, and BMI under Model 3. OR, odds ratio; CI, confidence intervals. Model 3: Adjusted for age, sex, race, education, BMI, alcohol use, smoking status, diabetes, hypertension, and stroke.

found that probiotics significantly reduced central and peripheral inflammation and oxidative stress levels caused by chronic sleep deprivation [41]. In addition, prebiotics regulated the expression of circadian rhythm and clock genes in the gut microbiota of mice [42]. Dietary supplementation with heat-killed SBC8803 resulted in an extended duration of NREM sleep during the resting phase [43]. Besides, supplementation of prebiotics blends in the early stage of life maintained the daytime waking state and naptime in infants, along with the significant increase of the genus Bifidobacterium [44]. Another NHANES study demonstrated that incorporating yogurt into diet was associated with a reduced risk of all-cause mortality [29]. Haarhuis et al. [45] concluded that the most widely applicable probiotic genera for improving sleep are *Lactobacillus, Lacticaseibacillus, Limosilactobacillus, Lactiplantibacillus, Levilactobacillus,* and *Bifidobacterium*. However, further research is needed to explore additional probiotic strains and their key metabolites.

Every individual's microbiome is unique, just as each person will respond differently to different probiotics. Considering the significant individual variability in the microbiome, a standardized administration of probiotics may not yield benefits for every individual. Additionally, it's vital to maximize the comprehensive beneficial impact of probiotic supplements, which includes considerations such as appropriate strain selection, bacterial viability and functionality, optimal dosage and form, intake duration, and effective delivery at the target site [46]. Our study indicated that probiotics play an essential role in decreasing sleep disturbances. However, only 14.24 % of participants reported yogurt and/or probiotic consumption among US adults, indicating significant room for improvement in probiotic food consumption. Appropriate strategies are needed to encourage broader acceptance of probiotic products.

In summary, we conducted a 10-year large cross-sectional survey with nationally representative samples. In addition, we further conducted adjusted logistic regression models and subgroup analyses to eliminate confounding factors such as age, sex, race, BMI, comorbidities, etc. There are also several limitations. First, dietary intake and sleep disturbances in NHANES were assessed by self-report, which might lead to recall and measurement biases. Second, in the absence of detailed information about yogurt and probiotic consumption, such as frequency, amount, and type of bacteria, the magnitude of the association between probiotic consumption and sleep disturbances may have been diluted. Third, the NHANES may collect varying sample information across different years, and researchers' choice of study periods can affect results. Consequently, it is recommended to choose the study period thoughtfully and to use the most updated data. Finally, It was a cross-sectional survey with compromised accuracy and generalizability, rendering us unable to ascertain the sequence of events and causal relationships.

5. Conclusions

In conclusion, our study supports the beneficial association between probiotic supplements or yogurt consumption and sleep disturbances. Furthermore, this protective association was most prominent among males, Non-Hispanic White, and participants with normal BMI. Probiotic intake and yogurt consumption are crucial public health strategies for improving sleep quality. Moreover, future research should focus on developing engineered bacteria to target sleep disorders and understanding the underlying mechanisms behind probiotics and related metabolites.

Data availability statement

Publicly available datasets were analyzed in this study. Data used for this study are available on the NHANES website: https://www.cdc.gov/nchs/nhanes/index.htm.

Ethics statement

Review and approval by an ethics committee were not needed for this study, because the data in this study are from public databases.

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CRediT authorship contribution statement

Rui-zhi Yang: Writing – original draft, Methodology, Funding acquisition, Data curation, Conceptualization. **Shi-zhu Lin:** Writing – original draft, Methodology, Data curation, Conceptualization. **Xi-yuan Xie:** Project administration, Methodology, Data curation. **Yi-jie Tang:** Project administration, Methodology, Data curation. **Jing-xuan Zheng:** Project administration, Methodology, Formal analysis. **Chao-mei Yuan:** Project administration, Methodology, Data curation. **Ya-yi Lin:** Supervision, Project administration, Methodology, Conceptualization. **Xiao-dan Wu:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Kai Zeng:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e35609.

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