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Ultra-processed foods and risk of all-cause mortality: an updated systematic review and dose-response meta-analysis of prospective cohort studies

Shuming Liang[1†], Yesheng Zhou[1†], Qian Zhang[1], Shuang Yu[1] and Shanshan Wu[1*]

Abstract

Background Ultra-processed food (UPF) consumption has been steadily increasing globally, yet the associated risk of all-cause mortality remains unclear. We aimed to assess the risk of all-cause mortality of UPFs via an updated systematic review and dose-response meta-analysis.

Methods A comprehensive literature search was conducted in PubMed, Embase, and Cochrane Library for studies published until July 2, 2024, in addition to referred studies included in the previous systematic review. Prospective cohort studies assessing the association between NOVA classification-defined UPF consumption and all-cause mortality were included. Dose-response meta-analysis via a random-effect model was used to combine the results with hazard ratio (HR) as an effect measure.

Results Overall, 18 studies with 1,148,387 participants (173,107 deaths) were identified. Compared to the lowest, participants with the highest UPF consumption had a 15% increased risk of all-cause mortality (HR = 1.15, 95% CI 1.09–1.22; $I^2 = 83.0\%$). Furthermore, a 10% higher risk of all-cause mortality was detected with each 10% increment in UPF consumption (HR = 1.10, 95% CI 1.04–1.16; $I^2 = 91.0\%$). Dose-response analysis showed a positive linear association ($P_{\text{dose-response}} < 0.001$). Moreover, subgroups and sensitivity analyses indicated consistent findings, while meta-regression analyses suggested sex distributions partially explained heterogeneity, with a higher risk of all-cause mortality in males.

Conclusions Our updated meta-analysis, incorporating a greater number of newly published cohort studies using NOVA classification with the largest sample size to date, strengthens the evidence linking higher UPF consumption to increased all-cause mortality risk. Strategies such as dietary guidelines and policies for limiting UPF consumption worldwide should be encouraged.

Systematic review registration PROSPERO CRD42023467226.

Keywords Ultra-processed food, Mortality, Dose-response, Systematic review, Meta-analysis

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Introduction

Ultra-processed foods (UPFs) are industrial products made from multiple ingredients and minimal whole foods, often containing additives like colorants, flavor enhancers, sugars, fats, salt, and preservatives [1]. Among all definitions of UPFs to date, the NOVA classification system has been considered the most specific, coherent, clear, comprehensive, and workable, which categorizes foods into four groups based on their processing level: unprocessed or minimally processed foods, processed culinary ingredients, processed foods, and UPFs [2]. Given their low nutritional quality and high energy density, UPFs are typically convenient (ready-to-eat/heat), affordable, and hyper-palatable meals [3]. In recent decades, UPF intake has been consumed increasingly globally, constituting over 50% of dietary energy in the USA and the UK, while ranging from 16 to 30% in low- and middle-income countries like Colombia and Mexico [4]. However, the widespread consumption of UPFs has raised substantial health concerns [5].

Previous meta-analyses have indicated an elevated risk of all-cause mortality associated with higher UPF intake [5–7]. These analyses, however, were limited by the small number of included studies, inclusion for cross-sectional or case-control studies, only assessed high versus low categories of UPF, and a predominant focus on Western developed countries. Meanwhile, the results of recent large-scale prospective cohort studies are still currently controversial, with three studies indicating a null association [8–10]. Hence, with a recently growing number of cohort studies conducted in diverse regions, it is necessary to further synthesize this evidence to re-evaluate the effect of UPF consumption on the risk of all-cause mortality.

Therefore, in this updated systematic review and dose-response meta-analysis, we aimed to comprehensively evaluate the effects of UPF intake on the risk of all-cause mortality. We hypothesized higher UPF consumption could increase the risk of all-cause mortality.

Methods

This systematic review and meta-analysis were registered on PROSPERO (CRD42023467226) and conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist (Additional file 1), updating the results of the systematic review and meta-analysis published in 2023 [6].

Data sources and searches

A comprehensive literature search was conducted in PubMed, Embase, and the Cochrane Library. The search was performed for studies published from January 1, 2022, to July 2, 2024, without any restrictions on language. The search keywords included "ultra-processed foods," "food, processed," "UPF," "UPFs," "death," "mortality," and "all-cause mortality" (detailed search strategy was listed in Additional file 2: Table S1). Additionally, references included in prior meta-analyses were also examined to uncover potentially relevant articles. All searches were independently performed by two investigators (SML and SSW).

Study selection

Studies were included if they met the following criteria: (i) the study design was a prospective cohort; (ii) all participants were adults at baseline; (iii) UPF consumption was evaluated with food items categorized according to the NOVA classification [2]; (iv) the outcome was all-cause mortality; and (v) effect estimates were provided in adjusted hazard ratio (HR) with 95% confidence interval (CI), and/or sufficient data to derive these estimates. Studies were excluded if (i) they were abstracts, reviews, comments, letters, reports, or editorials; (ii) the exposure was limited to specific foods such as cookies, bread, chips, beverages, etc.; or (iii) without available all-cause mortality data. If more than one study was conducted based on the same cohort, we included the study with the largest sample size or the longest follow-up duration. A flowchart regarding the study selection process is presented in Fig. 1. All screenings were independently performed by two investigators (SML and SSW) with Cohen's Kappa of 0.91.

Data extraction and quality assessment

Two investigators (YSZ and SML) independently extracted data from eligible studies using a standardized data extraction form, with Cohen's Kappa of 0.89. The following information was extracted: first author, publication year, country and cohort, follow-up duration, number of total participants and deaths, age and sex at baseline, dietary assessment tool, UPF intake measurement, adjusted HR and 95% CI, and covariates used for adjustments in the multivariable analyses. Any disagreements regarding data extraction were resolved by consensus involving a third author (SSW).

The Newcastle-Ottawa Scale (NOS) for cohort studies was used to assess the quality of the included studies, including three domains: selection of study groups/participants, comparability of the groups, and the assessment of exposure/outcome of interest [11]. Based on this 9-point scale, the studies were classified as good quality (8–9 points), fair quality (5–7 points), and poor quality (< 5 points). One author conducted the initial assessment, and a second author checked for accuracy, with any disagreement adjudicated by a third author (SSW).

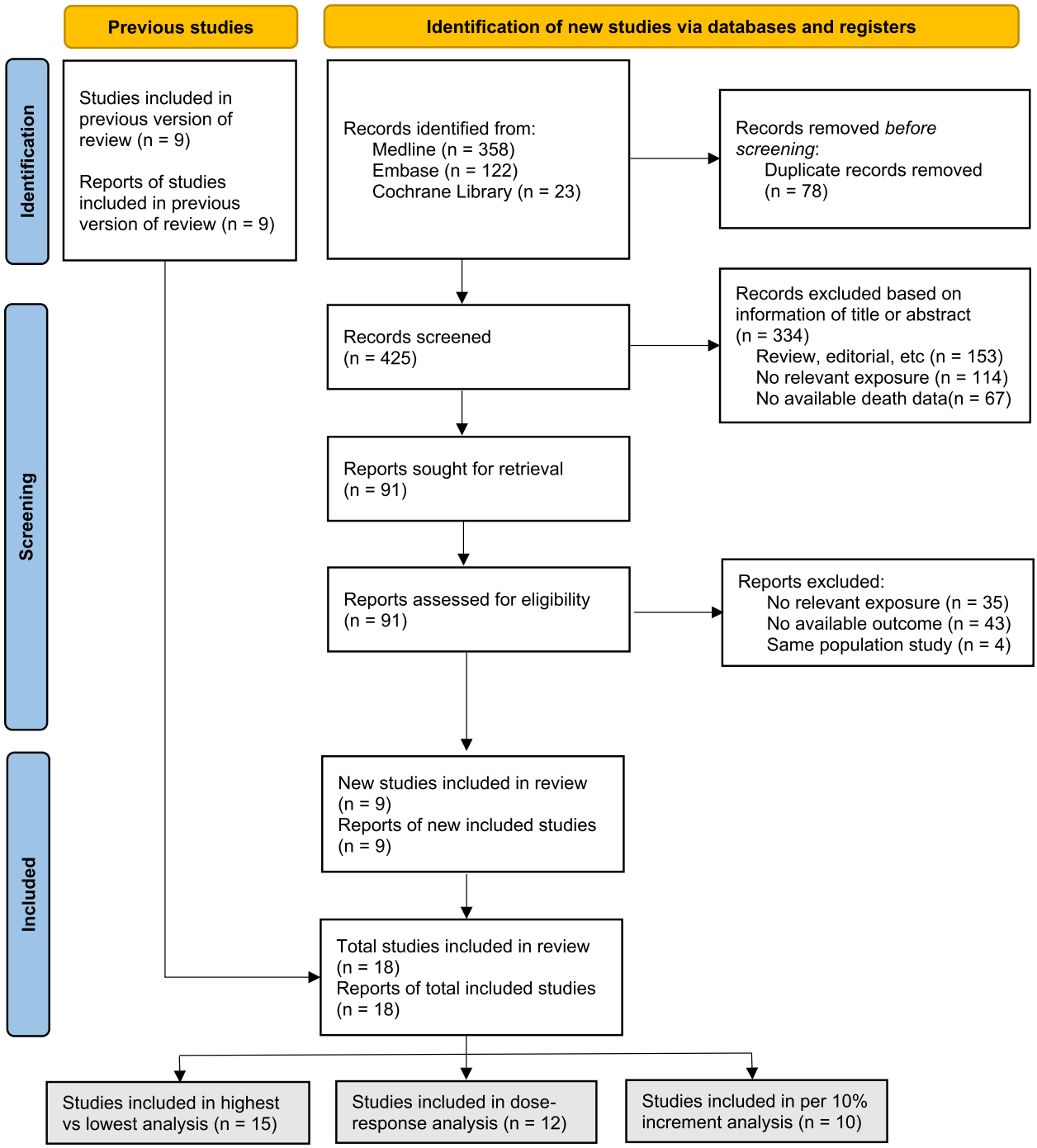

Fig. 1 Flow diagram of study selection

Data synthesis and analyses

Pooled HRs and 95% CIs for all-cause mortality were calculated by comparing the highest versus the lowest categories of UPF intake and for each 10% increase in UPF consumption. Due to anticipated heterogeneity between observational studies, effect estimates were calculated using the DerSimonian-Laird random-effects model [12]. Heterogeneity was assessed using the *I*-squared statistic and Cochrane *Q* test, with $I^2 > 50\%$ and a *P* value < 0.05 indicating substantial heterogeneity [13].

A dose-response meta-analysis was further conducted to estimate the HRs for different proportions of UPFs in

total energy/weight intake. Specifically, the study-specific linear trends between exposure and outcome were first estimated using the method described by Greenland and Longnecker [14, 15]. The estimated linear trends were then pooled with random-effects meta-analysis. The proportions of UPFs in total energy or weight intake were assumed to be equivalent. Additionally, "servings per day" and "consumption in g/1000 kcal" were converted into "proportion of total weight/energy intake" with 50 g considered equivalent to one serving [16]. For the estimation of UPF consumption in closed interval categories, the midpoint value of the interval was taken. For open-ended exposure categories, the lowest dose group was assumed to have a lower boundary of 0, whereas the highest dose group was assumed to be 1.5 times the adjacent interval.

Sensitivity analysis was conducted via the leave-one-out strategy (i.e., removing each study from the analysis and recalculating pooled HR) to test the robustness of the results and the impact of individual studies on heterogeneity. Subgroup and meta-regression analyses were performed to detect the potential sources of heterogeneity by mean age ($<52, \geq 52$ years), male proportion ($<44, \geq 44.0\%$), dietary assessment tool (food frequency questionnaire (FFQ), other), measurement of UPFs (proportion of total weight/energy intake, other), sample size ($<5000, \geq 5000$), mean follow-up duration ($<12, \geq 12$ years), region (USA, other), publication year ($<2023, \geq 2023$), and NOS quality score (<9, 9). Publication bias was evaluated through funnel plots and Begg's test [17, 18].

All analyses were performed using R version 4.4.1 (Institute for Statistics and Mathematics, Vienna, Austria). A two-sided $P<0.05$ was considered statistically significant.

Results

Study characteristics

A total of 18 prospective cohort studies, published between 2019 and 2024, were included, involving 1,148,387 participants and 173,107 mortality cases (Fig. 1). The average follow-up duration was 14.5 years, with a mean age of 52.1 years and a male proportion of 42.1%. These studies were conducted in the USA ($N=5$) [8, 19–22], Spain ($N=4$) [23–26], Italy ($N=2$) [27, 28], France ($N=1$) [29], the Netherlands ($N=1$) [9], Korea ($N=1$) [10], Brazil ($N=1$) [30], and multiple countries ($N=3$) [31–33], as shown in Table 1. The follow-up duration of the studies ranged from 7.1 to 34.0 years.

Daily UPF consumption was self-reported via questionnaire or interview across all studies. Specifically, 14 studies used an FFQ [8–10, 20–22, 24–28, 30–32], 3 used 24-h dietary records [19, 29, 33], and 1 employed a computer-based dietary history to assess the type and amount of food intake at baseline [23]. UPF exposure was quantified using "proportion of total weight/energy intake" ($n=13$) [8, 10, 20, 22, 23, 25–29, 29–31, 33], "servings per day" ($n=3$) [21, 24, 32], "consumption in g/1000 kcal" ($n=1$) [9], and "times per day" ($n=1$) [19]. The included studies were all of high quality based on the NOS (Additional file 2: Table S2).

UPF consumption and risk of all-cause mortality

Overall, 15 studies (144,212 cases and 1,016,461 participants) were included for the highest versus lowest analysis [8–10, 19, 21–24, 26, 27, 29, 31–33]. Compared to the lowest, participants with the highest UPF consumption had a 15% increased risk of all-cause mortality (HR = 1.15, 95% CI 1.09–1.22, $I^2=83.0\%$, $P_{\text{heterogeneity}}<0.01$; Fig. 2). The results of sensitivity analysis suggested that our findings were generally stable and consistent (Additional file 2: Fig. S1). Furthermore, no publication bias was detected, as indicated by funnel plots (Additional file 2: Fig. S3) and Begg's test ($P=0.373$).

As for each 10% increment in UPF intake, 10 studies (67,995 cases and 458,481 participants) were included [8, 20, 22, 25, 26, 28–32]. Our findings revealed that a 10% higher risk of all-cause mortality was detected with each 10% increment in UPF consumption (HR = 1.10, 95% CI 1.04–1.16, $I^2=91.0\%$, $P_{\text{heterogeneity}}<0.01$; Fig. 3). Similarly, sensitivity analysis suggested the robustness of the findings (Additional file 2: Fig. S2). No publication bias was detected by funnel plot (Additional file 2: Fig. S4) and Begg's test ($P=0.592$).

The dose-response meta-analysis, which included 12 studies, revealed a significantly positive linear association between the proportion of UPFs in total weight/energy consumption and all-cause mortality ($P_{\text{dose-response}}<0.001$, Fig. 4).

Subgroup and meta-regression analyses

For highest versus lowest and per 10% increment of UPF consumption, subgroup analysis demonstrated consistently greater risk of all-cause mortality across all subgroups of age, sex, dietary assessment tool, measurement of UPF, sample size, mean follow-up duration, region, publication year and NOS quality score, with HRs ranging from 1.11 to 1.24 for highest versus lowest and 1.04–1.15 for per 10% increment of UPF consumption (Table 2).

Meta-regression analysis suggested that sex might have contributed to the observed heterogeneity specifically in the highest versus lowest consumption analysis ($P=0.019$), with a higher risk of all-cause mortality in males (Table 2). Conversely, differences in age, region, and other factors did not significantly impact

Table 1 Characteristics of the included studies

ID	Author	Publication year	Country	Study design	Follow-up years	Age (years)	Male (%)	Sample size	Deaths	UPF measure
1	Blanco-Rojo R [23]	2019	Spain	Cohort	7.7	46.9	49.5	11,898	440	Proportion of total energy intake
2	Rico-Campa A [24]	2019	Spain	Cohort	10.4	37.6	39.1	19,899	335	Servings/day
3	Kim H [19]	2019	USA	Cohort	19.0	41.8	47.8	11,898	2451	Times/day
4	Bonaccio M [27]	2021	Italy	Cohort	8.2	55.0	47.6	22,475	1216	Proportion of total weight intake
5	Schnabel L [29]	2019	France	Cohort	7.1	56.7	26.9	44,551	602	Proportion of total weight intake
6	Juul F [20]	2021	USA	Cohort	20.2	53.9	44.9	3003	713	Proportion of total weight intake
7	Ferreiro CR [25]	2021	Spain	Cohort	27.0	30.5	48.9	4679	450	Proportion of total energy intake
8	Orlich MJ [31]	2022	USA and Canada	Cohort	7.46	59.3	35.1	77,437	9293	Proportion of total energy intake
9	Dehghan M [32]	2023	Multicenter	Cohort	10.2	50.1	41.5	138,076	9227	Servings/day
10	Vellinga RE [9]	2023	Netherlands	Cohort	18.2	50.0	24.0	38,261	4697	Consumption in g/1000 kcal
11	Bonaccio M [28]	2023	Italy	Cohort	11.6	65.2	60.7	1065	308	proportion of total weight intake
12	Zhao Y [33]	2024	USA and United Kingdom	Cohort	13.5	57.1	45.9	357,835	44,324	Proportion of total weight intake
13	Fang Z [21]	2024	USA	Cohort	34.0	64.9	34.6	114,064	48,193	Servings/day
14	Wang L [8]	2023	USA	Cohort	12.2	52.4	40.1	77,060	17,895	Proportion of total weight intake
15	Torres-Collado L [26]	2024	Spain	Cohort	18.0	46.2	44.8	1538	312	Proportion of total weight intake
16	Mekonnen TC [22]	2024	USA	Cohort	16.8	65.6	47.0	96,607	28,700	Proportion of total weight intake
17	Silva FM [30]	2023	Brazil	Cohort	8.0	52.0	45.6	14,465	495	Proportion of total weight intake
18	Kityo A [10]	2023	Korea	Cohort	10.6	52.0	34.2	113,576	3456	Proportion of total weight intake

Abbreviations: *UPF* Ultra-processed food

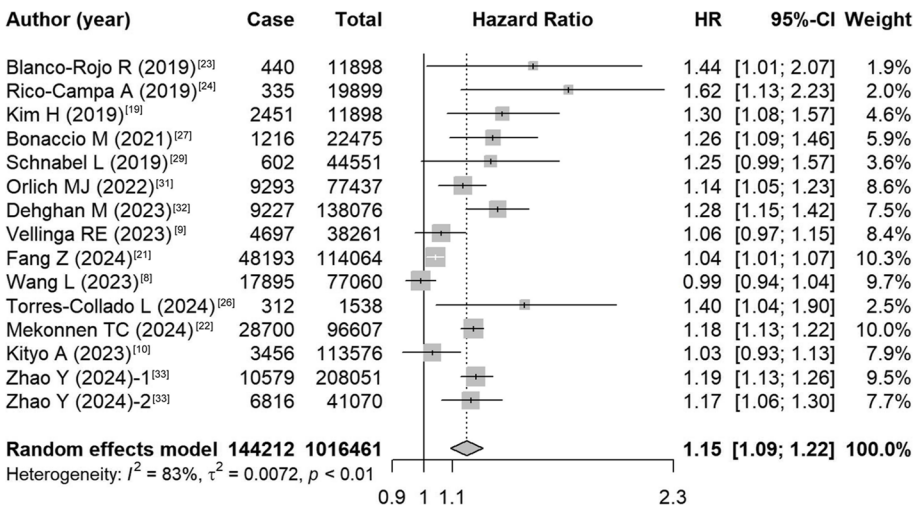

Fig. 2 Forest plot of the association between UPF intake and the risk of all-cause mortality, comparing the highest and lowest categories

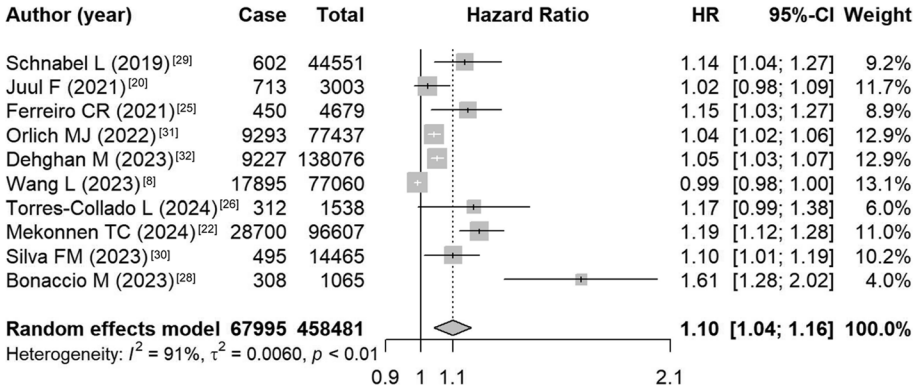

Fig. 3 Forest plot of the association between UPF intake and the risk of all-cause mortality, per 10% increment in UPF intake. A 10% higher risk of all-cause mortality was detected with each 10% increment in UPF consumption. Note: Meta-analysis was constructed using a random-effects model. Abbreviations: UPF, ultra-processed food; HR, hazard ratio; CI, confidence interval

heterogeneity in either the highest versus lowest analysis or the per 10% increment of UPF consumption analysis. Additionally, there seemed greater risk of all-cause mortality in studies with a small sample size and a relatively young population.

Discussion

This meta-analysis comprehensively investigated the association between UPF consumption and the risk of all-cause mortality based on the latest prospective cohort studies. Our findings consistently demonstrated that greater exposure to UPFs, whether measured as higher versus lower consumption or per 10% increment, was associated with a higher risk of all-cause mortality in a relatively older population.

In line with previous meta-analyses [5–7], our findings further supported the positive association between UPF consumption and the risk of all-cause mortality. Compared to the lowest UPF intake group, meta-analyses based on 7, 6, and 5 prospective cohort studies indicated that the highest UPF intake group increased the risk of all-cause mortality by 21%, 21%, and 29%, respectively [5–7]. These results were higher than the findings of our study (15%). Additionally, a meta-analysis of 4 prospective cohort studies revealed a 15% increase in all-cause mortality risk for each 10% increment in UPF intake, whereas our study observed a 10% increase [5]. In another meta-analysis of 9 cohort studies, each additional daily serving of UPFs was linked to a 2% increase in all-cause mortality risk [6]. Linear positive dose-response associations were also observed in the present study, similar to the findings of prior meta-analyses [5, 6].

The mechanism linking UPF intake to a higher risk of all-cause mortality remains inconclusive. However, several potential factors may explain this positive association. Firstly, high UPF consumption typically involves

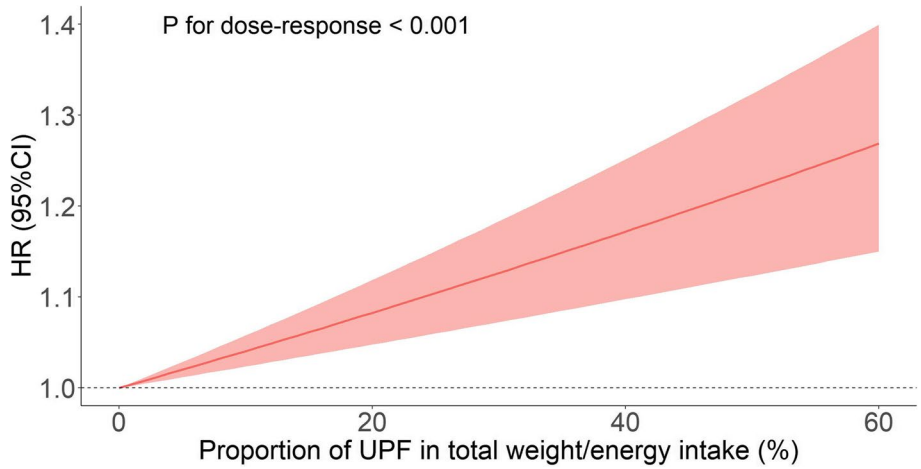

Fig. 4 Linear dose-response relationship between UPF intake and the risk of all-cause mortality. A significantly positive linear association between proportion of UPFs in total weight/energy consumption and all-cause mortality was detected. Note: A total of 12 studies were included in the dose-response analysis. The proportions of UPF in total energy or weight intake were assumed to be equivalent. Additionally, "servings per day" and"consumption in g/1000 kcal" were converted into "proportion of total weight/energy intake" with 50 grams considered equivalent to one serving. Abbreviations: UPF, ultra-processed food; HR, hazard ratio; CI, confidence interval

higher fat, salt, and carbohydrate intake, all of which have been shown to increase the risk of cardiovascular events and other chronic non-communicable diseases by promoting inflammation levels, oxidative stress, thrombosis, or other pathological processes [4]. Secondly, food additives including emulsifiers, sweeteners, colorants, and micro- and nanoparticles, are commonly added to UPFs, which have been shown to affect the gut microbiome, leading to reduced diversity and shifts in bacterial populations, such as more harmful *Shigella* and fewer beneficial *Lachnospira* and *Roseburia* [34]. This may impair gut function, contribute to metabolic diseases, and thus lead to other adverse outcomes. Thirdly, individuals who consume unhealthy diets are also likely to engage in unhealthy lifestyles, including excessive smoking and alcohol consumption, as well as a lack of physical activity. All of which are high-risk factors for cardiovascular events and mortality [35–38]. Lastly, the health effects of UPFs could be linked to their organoleptic properties, which may lead to an increased eating speed and a delay in satiety signals, resulting in higher overall food intake and poor health outcomes [39]. All of these may ultimately contribute to the increased risk of all-cause mortality.

Moreover, a higher risk of all-cause mortality was observed in males than females, which might be due to sexual differences in diet, lifestyle factors, and comorbidities. However, owing to the obtained aggregated data rather than individual-level data, we could not further investigate the effect of these factors on this sexual difference. Further pooled analysis based on individual-level data remains needed to confirm these findings.

The findings of this research suggest a potential need for dietary guidelines and policies aimed at reducing UPF consumption, although further investigation is required to establish robust causal links. Promoting healthy dietary patterns remains a critical public health goal for maintaining overall population health and extending lifespan. Preliminary insights from policy experiments in early-adopter regions indicate that strategies such as front-of-pack labeling, taxation, and marketing restrictions could reduce UPF consumption by up to 30% [40]. However, comprehensive research is needed to further refine these policies and evaluate their broader health impacts. Furthermore, these strategies should be carefully considered, particularly for regions with lower socioeconomic status, who may rely on UPFs owing to affordability and convenience. Implementing subsidies for healthier foods and improving access to fresh produce could help ensure equitable policy outcomes [41].

The present meta-analysis possessed several strengths. Firstly, it incorporated a greater number of newly published studies, particularly studies with null association, with more than 1 million participants, thereby providing the most comprehensive evidence regarding this topic. Secondly, all included studies were prospective cohort studies, with UPF assessment using the most specific, coherent, and clear NOVA classification system, avoiding reverse causation and misclassification bias in our methodology. Thirdly, not only highest versus lowest, but also per 10% increment of UPF consumption, as well as dose-response relationship were evaluated. Hence, this comprehensive assessment provided a deeper understanding of the mortality effect of UPF intake. Lastly, substantial

Table 2 Subgroup analyses for the association between UPF intake and all-cause mortality

Subgroups	Highest versus lowest UPF intake					Per 10% increment of UPF intake				
	No. of studies	HR (95%CI)	I^2 for heterogeneity (%)	I^2 for heterogeneity, meta-regression	*P* value between subgroups	No. of studies	HR (95%CI)	I^2 for heterogeneity (%)	I^2 for heterogeneity, meta-regression	*P* value between subgroups
All studies	15	1.15 (1.09–1.22)	83.0	–	–	10	1.10 (1.04–1.16)	91.0	–	–
Mean age (years)										
< 52	7	1.24 (1.12–1.37)	60.5	82.8	0.078	3	1.09 (1.02–1.18)	53.8	95.5	0.911
≥ 52	8	1.11 (1.05–1.18)	88.0			7	1.11 (1.02–1.20)	91.7		
Male (%)										
< 44.0	8	1.11 (1.03–1.19)	78.1	71.0	0.019	4	1.04 (1.00–1.08)	93.4	94.9	0.068
≥ 44.0	7	1.19 (1.16–1.23)	0.0			6	1.16 (1.06–1.27)	79.9		
Dietary assessment tool										
FFQ	10	1.13 (1.06–1.21)	85.9	80.9	0.159	9	1.10 (1.03–1.17)	91.2	96.9	0.714
Other	5	1.20 (1.15–1.25)	0.0			1	1.14 (1.04–1.27)	–		
Measurement of UPFs										
Proportion of total weight/ energy intake	10	1.15 (1.08–1.22)	80.1	82.2	0.850	9	1.11 (1.04–1.19)	90.2	95.5	0.550
Other	5	1.19 (1.04–1.35)	83.7			1	1.05 (1.03–1.07)	–		
Sample size										
< 5000	8	1.22 (1.09–1.35)	62.5	85.8	0.321	6	1.15 (1.05–1.26)	74.6	96.3	0.205
≥ 5000	7	1.13 (1.06–1.21)	90.3			4	1.06 (0.99–1.14)	95.2		
Mean follow–up (years)										
< 12	8	1.20 (1.11–1.29)	56.0	82.7	0.188	5	1.13 (1.01–1.26)	78.1	94.3	0.671
≥ 12	7	1.12 (1.04–1.20)	89.5			5	1.09 (1.00–1.18)	90.1		
Region										
USA	6	1.11 (1.04–1.20)	89.2	82.7	0.186	4	1.05 (0.98–1.13)	93.4	94.1	0.133
Other	9	1.20 (1.11–1.30)	64.2			6	1.15 (1.06–1.24)	75.4		
Publication year										
< 2023	6	1.24 (1.14–1.36)	26.8	81.8	0.048	4	1.07 (1.01–1.13)	58.0	95.7	0.541
≥ 2023	9	1.12 (1.05–1.19)	87.8			6	1.14 (1.02–1.26)	93.5		
NOS quality score										
< 9	5	1.11 (1.00–1.24)	77.5	74.6	0.106	4	1.14 (0.95–1.38)	93.0	95.6	0.970
9	10	1.18 (1.12–1.24)	54.9			6	1.10 (1.04–1.16)	73.6		

Abbreviations: *UPF* Ultra-processed food, *HR* Hazard ratio, *CI* Confidence interval, *NOS* Newcastle-Ottawa Scale. "–" unavailable

subgroup analysis, meta-regression, and sensitivity analyses were conducted, verifying the robustness of our positive associations.

However, several limitations should be considered. Firstly, as all the included studies were observational, causality could not be inferred due to potential residual confounding and reverse causality. Confounding factors, such as socioeconomic status and access to healthcare, require further control because they affect an individual's ability to access healthy foods and healthcare services, potentially leading to unrecognized or untreated health issues and, consequently, increasing mortality risk. Secondly, recall bias and misclassification of UPF consumption may be inevitable owing to the nature of dietary assessment and self-reported dietary data. Nevertheless, we confirmed the positive findings both in different dietary assessment tools and different UPF measurements. Further studies incorporating multiple cycles of self-reported dietary data may reduce this bias. Thirdly, the composition of UPFs varied across studies, depending on the specific types of food processing involved, which may also affect the effect measure. Lastly, due to the high heterogeneity among studies, relatively older participants, and the fact that most studies were conducted in developed countries, caution should be made when interpreting and generalizing the results to individuals with other age groups and undeveloped countries.

Conclusions

In the present study, higher UPF consumption was associated with a higher risk of all-cause mortality, with a significant dose-response relationship. Strategies such as dietary guidelines and taxation policies for limiting UPF consumption worldwide should be encouraged. Future epidemiological studies in low- and middle-income countries, as well as experimental studies, are necessary to confirm our findings and elucidate the underlying mechanisms.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13643-025-02800-8.

Additional file 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist.

Additional file 2. Supplementary Figure S1. Sensitivity analysis for the association between UPF intake and the risk of all-cause mortality, comparing the highest and lowest categories. Supplementary Figure S2. Sensitivity analysis for the association between UPF intake and the risk of all-cause mortality, per 10% increment in UPF intake. Supplementary Figure S3. Funnel plot for studies included in the association between UPF intake and the risk of all-cause mortality, comparing the highest and lowest categories. Supplementary Figure S4. Funnel plot for studies included in the association between UPF intake and the risk of all-cause mortality, per 10% increment in UPF intake. Supplementary Table S1. Number of citations by each database searched. Supplementary Table S2. Quality assessment of included studies according to the Newcastle-Ottawa Scale for cohort study.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

Authors' contributions

SSW designed the study. SML and YSZ drafted the manuscript. SML and SY conducted eligible study selection and data extraction. YSZ analyzed and verified the data. SSW revised the manuscript. SSW, QZ, YSZ, SML, and SY interpreted the results, incorporated comments from the co-authors, and finalized the manuscript. All authors approved the final version of the paper.

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Data availability

No additional data is available.

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare that they have no competing interests.

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References

1. Monteiro CA, Cannon G, Levy RB, Moubarac J-C, Louzada ML, Rauber F, et al. Ultra-processed foods: what they are and how to identify them. Public Health Nutr. 2019;22:936–41.
2. Monteiro CA, Cannon G, Moubarac J-C, Levy RB, Louzada MLC, Jaime PC. The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr. 2018;21:5–17.
3. Martini D, Godos J, Bonaccio M, Vitaglione P, Grosso G. Ultra-processed foods and nutritional dietary profile: a meta-analysis of nationally representative samples. Nutrients. 2021;13. Available from: https://pubmed.ncbi.nlm.nih.gov/34684391.
4. Lane MM, Gamage E, Du S, Ashtree DN, McGuinness AJ, Gauci S, et al. Ultra-processed food exposure and adverse health outcomes: umbrella review of epidemiological meta-analyses. BMJ. 2024;384:e077310.
5. Suksatan W, Moradi S, Naeini F, Bagheri R, Mohammadi H, Talebi S, et al. Ultra-processed food consumption and adult mortality risk: a systematic review and dose-response meta-analysis of 207,291 participants. Nutrients. 2021;14. Available from: https://pubmed.ncbi.nlm.nih.gov/35011048.
6. Yuan L, Hu H, Li T, Zhang J, Feng Y, Yang X, et al. Dose-response meta-analysis of ultra-processed food with the risk of cardiovascular events and all-cause mortality: evidence from prospective cohort studies. Food Funct. 2023;14:2586–96.
7. Taneri PE, Wehrli F, Roa-Díaz ZM, Itodo OA, Salvador D, Raeisi-Dehkordi H, et al. Association between ultra-processed food intake and all-cause mortality: a systematic review and meta-analysis. Am J Epidemiol. 2022;191:1323–35.
8. Wang L, Pan XF, Munro HM, Shrubsole MJ, Yu D. Consumption of ultra-processed foods and all-cause and cause-specific mortality in the Southern Community Cohort Study. Clin Nutr Edinb Scotl. 2023;42:1866–74.

9. Vellinga RE, Boomgaard I, M A Boer J, Schouw YT, Harbers MC, Verschuren WMM, et al. Different levels of ultraprocessed food and beverage consumption and associations with environmental sustainability and all-cause mortality in EPIC-NL. Am J Clin Nutr. 2023;118:103–13.
10. Kityo A, Lee S-A. The intake of ultra-processed foods, all-cause, cancer and cardiovascular mortality in the Korean Genome and Epidemiology Study-Health Examinees (KoGES-HEXA) cohort. PLoS One. 2023;18:e0285314.
11. Wells G, Shea B, O'Connell D, Peterson je, Welch V, Losos M, et al. The Newcastle–Ottawa Scale (NOS) for assessing the quality of non-randomized studies in meta-analysis. Available online: https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed 23 Sept 2024.
12. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials. 1986;7:177–88.
13. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21:1539–58.
14. Greenland S, Longnecker MP. Methods for trend estimation from summarized dose-response data, with applications to meta-analysis. Am J Epidemiol. 1992;135:1301–9.
15. Orsini N, Bellocco R, Greenland S. Generalized least squares for trend estimation of summarized dose–response data. Stata J. 2006;6:40–57.
16. Han MA, Zeraatkar D, Guyatt GH, Vernooij RWM, El Dib R, Zhang Y, et al. Reduction of red and processed meat intake and cancer mortality and incidence: a systematic review and meta-analysis of cohort studies. Ann Intern Med. 2019;171:711–20.
17. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. Biometrics. 1994;50:1088–101.
18. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315:629–34.
19. Kim H, Hu EA, Rebholz CM. Ultra-processed food intake and mortality in the USA: results from the Third National Health and Nutrition Examination Survey (NHANES III, 1988–1994). Public Health Nutr. 2019;22:1777–85.
20. Juul F, Vaidean G, Lin Y, Deierlein AL, Parekh N. Ultra-processed foods and incident cardiovascular disease in the Framingham Offspring Study. J Am Coll Cardiol. 2021;77:1520–31.
21. Fang Z, Rossato SL, Hang D, Khandpur N, Wang K, Lo C-H, et al. Association of ultra-processed food consumption with all cause and cause specific mortality: population based cohort study. BMJ. 2024;385:e078476.
22. Mekonnen TC, Melaku YA, Shi Z, Gill TK. Ultra-processed food consumption and risk of chronic respiratory diseases mortality among adults: evidence from a prospective cohort study. Eur J Nutr. 2024;63:1357–72.
23. Blanco-Rojo R, Sandoval-Insausti H, López-Garcia E, Graciani A, Ordovás JM, Banegas JR, et al. Consumption of Ultra-Processed Foods and Mortality: A National Prospective Cohort in Spain. Mayo Clin Proc. 2019;94:2178–88.
24. Rico-Campà A, Martínez-González MA, Alvarez-Alvarez I, Mendonça R de D, Fuente-Arrillaga C, Gómez-Donoso C, et al. Association between consumption of ultra-processed foods and all cause mortality: SUN prospective cohort study. BMJ. 2019;365:l1949.
25. Romero Ferreiro C, Martín-Arriscado Arroba C, Cancelas Navia P, Lora Pablos D, Gómez de la Cámara A. Ultra-processed food intake and all-cause mortality: DRECE cohort study. Public Health Nutr. 2021;25. Available from: https://pubmed.ncbi.nlm.nih.gov/34348832.
26. Torres-Collado L, Rychter A, González-Palacios S, Compañ-Gabucio LM, Oncina-Cánovas A, García de la Hera M, et al. A high consumption of ultra-processed foods is associated with higher total mortality in an adult Mediterranean population. Clin Nutr Edinb Scotl. 2024;43:739–46.
27. Bonaccio M, Di Castelnuovo A, Costanzo S, De Curtis A, Persichillo M, Sofi F, et al. Ultra-processed food consumption is associated with increased risk of all-cause and cardiovascular mortality in the Moli-sani Study. Am J Clin Nutr. 2021;113:446–55.
28. Bonaccio M, Di Castelnuovo A, Costanzo S, Ruggiero E, Esposito S, Persichillo M, et al. Ultraprocessed food consumption is associated with all-cause and cardiovascular mortality in participants with type 2 diabetes independent of diet quality: a prospective observational cohort study. Am J Clin Nutr. 2023;118:627–36.
29. Schnabel L, Kesse-Guyot E, Allès B, Touvier M, Srour B, Hercberg S, et al. Association between ultraprocessed food consumption and risk of mortality among middle-aged adults in France. JAMA Intern Med. 2019;179:490–8.
30. Silva FM, Giatti L, Fonseca M de JM, Brant LCC, Diniz M de FHS, Molina MDCB, et al. Consumption of ultra-processed foods and eight-year risk of death from all causes and noncommunicable diseases in the ELSA-Brasil cohort. Int J Food Sci Nutr. 2023; Available from: https://pubmed.ncbi.nlm.nih.gov/37821803.
31. Orlich MJ, Sabaté J, Mashchak A, Fresán U, Jaceldo-Siegl K, Miles F, et al. Ultra-processed food intake and animal-based food intake and mortality in the Adventist Health Study-2. Am J Clin Nutr. 2022;115:1589–601.
32. Dehghan M, Mente A, Rangarajan S, Mohan V, Swaminathan S, Avezum A, et al. Ultra-processed foods and mortality: analysis from the Prospective Urban and Rural Epidemiology study. Am J Clin Nutr. 2023;117:55–63.
33. Zhao Y, Chen W, Li J, Yi J, Song X, Ni Y, et al. Ultra-processed food consumption and mortality: three cohort studies in the United States and United Kingdom. Am J Prev Med. 2024;66:315–23.
34. Whelan K, Bancil AS, Lindsay JO, Chassaing B. Ultra-processed foods and food additives in gut health and disease. Nat Rev Gastroenterol Hepatol. 2024;21:406–27.
35. Fransen HP, Boer JMA, Beulens JWJ, Wit GA, Bueno-de-Mesquita HB, Hoekstra J, et al. Associations between lifestyle factors and an unhealthy diet. Eur J Public Health. 2017;27:274–8.
36. Jha P, Peto R. Global effects of smoking, of quitting, and of taxing tobacco. N Engl J Med. 2014;370:60–8.
37. Rehm J, Rovira P, Llamosas-Falcón L, Shield KD. Dose-response relationships between levels of alcohol use and risks of mortality or disease, for all people, by age, sex, and specific risk factors. Nutrients. 2021;13. Available from: https://pubmed.ncbi.nlm.nih.gov/34444809.
38. Zhao Y, Hu F, Feng Y, Yang X, Li Y, Guo C, et al. Association of cycling with risk of all-cause and cardiovascular disease mortality: a systematic review and dose-response meta-analysis of prospective cohort studies. Sports Med Auckl NZ. 2021;51:1439–48.
39. Pagliai G, Dinu M, Madarena MP, Bonaccio M, Iacoviello L, Sofi F. Consumption of ultra-processed foods and health status: a systematic review and meta-analysis. Br J Nutr. 2021;125:308–18.
40. Popkin BM, Barquera S, Corvalan C, Hofman KJ, Monteiro C, Ng SW, et al. Towards unified and impactful policies to reduce ultra-processed food consumption and promote healthier eating. Lancet Diabetes Endocrinol. 2021;9(7):462–70.
41. Valizadeh P, Ng SW. Promoting healthier purchases: ultraprocessed food taxes and minimally processed foods subsidies for the low income. Am J Prev Med. 2024;67:3–14.

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