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This manuscript is an official IHME collaborator-led paper: “**GBD 2023 IHD & Dietary Risk Factors Collaborators**”

Original article

Burden of ischemic heart disease attributable to suboptimal diet in 204 countries and territories

Running title: Burden of ischemic heart disease attributable to suboptimal diet

GBD 2023 IHD & Dietary Risk Factors Collaborators

ABSTRACT

Ischemic heart disease (IHD) remains a leading cause of death worldwide, with dietary risks being its most significant modifiable factor. However, comprehensive studies examining the global impact of specific dietary components on IHD are notably lacking. Using data from the Global Burden of Disease Study (GBD) 2023, we estimated the mortality and disability-adjusted life years (DALYs) associated with diet-related IHD across 204 countries and territories. Our analysis employed a comparative risk assessment approach to quantify the contribution of various dietary elements to the burden of IHD in populations aged 25 years and older. Specifically, we assessed the relative impact of 13 nutritional factors—ranging from fruits, vegetables, and whole grains to omega-6 polyunsaturated fatty acids, red and processed meats, and sodium—on IHD outcomes. These estimates were further stratified by age, sex, geographic region, and Socio-demographic Index (SDI) to capture disparities across different population groups.

In 2023, suboptimal diet was responsible for 4.08 million IHD deaths and 97.62 million IHD DALYs. The global age-standardized death rate of IHD attributable to suboptimal diet saw a 43.61% (95% uncertainty interval [UI], 33.87-43.61) decrease, while the DALY rate for IHD attributable to suboptimal diet declined by 39.80% (29.10-50.19) from 1990 to 2023. Despite these overall improvements, older population presented with disproportionately high burden of IHD attributable to suboptimal diet, whereas males and females did not show significant disparities. Among dietary components, low intake of nuts and seed (9.95 [95% UI, 2.85 to 16.87] deaths per 100,000 population), low in whole grains (89.22 [4.73 to 13.54]), low in fruits (7.32 [1.55 to 13.35]), and high in sodium (7.14 [0.85 to 17.86]) emerged as the most significant contributors to global diet-related IHD deaths. There were substantial regional disparities in IHD outcomes, with Australasia showing the greatest reduction in IHD death attributable to suboptimal diet between 1990 and 2023 (-77.32%) while central sub-Saharan

Africa did not show significant decrease (13.16%). The burden of diet-related IHD was particularly pronounced in low- and middle-SDI countries, where age-standardized death rates reached 61.95 per 100,000 and DALYs rates 1,503.15 per 100,000. Despite global decreases in diet-related IHD burden, significant age and regional disparities persist, with older populations experiencing substantially higher mortality rates. The nature of dietary risks varies substantially across socioeconomic and geographic contexts: while populations in lower-SDI countries often face challenges related to undernutrition and limited access to protective foods (ie, whole grains, fruits, vegetables, omega-3 fatty acids), higher-SDI countries are more commonly burdened by overconsumption of harmful dietary components (ie, processed meats, sugar-sweetened beverages). By disentangling dietary causes, we identified the portion of the IHD burden that is directly modifiable and preventable through food interventions. Factoring in the regional dynamics in diet may optimize implementation of effective, equitable strategies to lower the global burden of IHD.

Funding: Gates Foundation

Keywords: dietary risks; ischemic heart disease; death; disability-adjusted life years; Global Burden of Disease, Injuries, and Risk Factors Study

INTRODUCTION

Ischemic heart disease (IHD) has remained the leading cause of death globally for more than decades.¹ Despite a modest decline in global age-standardized rates for prevalence and deaths over the past 30 years, the absolute number of IHD cases has increased in most countries.² This trend indicates a growing demand for preventive and therapeutic healthcare interventions. Among various risk factors that could lead to IHD, a suboptimal diet stands out as one of the most significant contributors to the disease.³

Although global food production and caloric availability have improved over time, the public health focus has shifted from food insufficiency to food quality.⁴ This shift underscores global concerns about nutritional insecurity and the disease burden associated with poor dietary patterns.⁵ However, previous studies have emphasized individual dietary components rather than comprehensive dietary patterns, and were predominantly conducted in single-country cohorts, particularly in high-income countries, creating a substantial knowledge gap regarding dietary patterns in low- and middle-income regions.⁶⁻⁸ Furthermore, the lack of geographically representative data on dietary consumption has prevented accurate assessment and comparison of dietary risks across countries or regions, limiting the generalizability of findings.^{6,9,10}

To our knowledge, no previous studies have provided a global overview of regional and demographic variations in dietary risk factors for IHD. To fill this gap, as part of the Global Burden of Disease Study (GBD) 2023, we performed a comprehensive assessment of the IHD burden attributable to suboptimal diet, providing detailed estimates across 204 countries and evaluating the impact of 13 distinct dietary factors. Our primary objective was to quantify IHD mortality and disability-adjusted life years (DALYs)-attributable to dietary risks on a global scale. These findings will help guide the equitable global food resource allocation and implementation of population-level strategies to reduce global IHD burden.

METHODS

Overview

The GBD 2023 offers a comprehensive evaluation of health loss across 375 diseases in 204 countries and territories from 1990 to 2023.¹¹ The study generated key health metrics, including incidence, prevalence, cause-specific mortality, years of life lost, years lived with disability, and DALYs. Rates are presented per 100,000 person-years to enable comparisons across populations. The GBD world population standard was applied to compute age-standardized rates, thereby accounting for variations in age structure across different populations.¹² The GBD 2023 adheres to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER), thereby ensuring methodological transparency. The complete GATHER checklist is available in **Table S1**. The analyses were conducted using Python (version 3.10.4; Python Software Foundation, Wilmington, DE, USA) and R (version 4.2.1; R Foundation, Vienna, Austria). Additional methodological details are provided in the **Supplementary Methods**. This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.¹³

Case definition

IHD and its associated health states were identified using standardized case definitions based on the International Classification of Diseases (ICD), specifically versions 9 (ICD-9) and 10 (ICD-10). GBD study conceptualized IHD as an aggregate of discrete sequelae, encompassing myocardial infarction (MI), stable angina (manifesting as chest pain), and ischemic cardiomyopathy (heart failure resulting from IHD).^{1,11} For the GBD 2023 iteration, the study modeled both the prevalence and incidence of acute MI, as well as the prevalence of chronic IHD. Acute MI was defined in accordance with the fourth universal definition of myocardial

infarction, incorporating both definite and possible cases, and was adjusted to include out-of-hospital sudden cardiac death. Stable angina was operationalized based on the Rose Angina Questionnaire, physician diagnosis, or the use of nitrate medication for chest pain alleviation. Ischemic cardiomyopathy was defined as heart failure resulting from reduced blood supply to the myocardium, typically due to coronary artery disease.^{1,11} Detailed case definitions for each condition are elucidated in the **Table S2** and **Supplementary Methods**.

Data sources for IHD estimates

Mortality estimation was conducted utilizing vital registration data coded according to the ICD-9 and ICD-10, to ensure consistency in disease classification, and verbal autopsy data obtained from household mortality surveys.¹ To ensure data quality, several data sources that did not meet methodological standards or exhibited implausible trends were excluded from the analysis. For non-fatal IHD, incidence and prevalence were derived from a comprehensive array of population-representative data sources.¹¹ These sources were identified through systematic literature reviews and collaborative research efforts, encompassing scientific reports from cohorts and registries, population-based surveys, microdata from registry and cohort studies, and health system administrative records.¹¹ The methodological approach for the systematic review process and the total number of data sources utilized for IHD estimation are delineated in detail within the **Supplementary Methods**.^{1,11}

IHD estimation and modeling strategy

Fatal outcomes (mortality and YLL) were modeled using advanced statistical methodologies to enhance the comparability of mortality data sources. These techniques included the reclassification of nonspecific or unspecified codes, application of noise reduction algorithms,

and utilization of Bayesian geospatial regression software, specifically the Cause of Death Ensemble model (CODem).¹ CODem incorporated location-specific covariates to generate smoothed time trends for 204 countries and territories, leveraging across age, space, and time dimensions.^{1,14} The specific covariates integrated into the ensemble modeling process are detailed in the **Supplementary Methods** and **Table S3**, along with updates regarding the redistribution of deaths.¹

Non-fatal outcomes (prevalence, incidence, and years of healthy life lost due to disability) were modeled using different methodologies tailored to estimate disease burden. A wide array of population-representative data sources was utilized, and disease estimates were generated using the epidemiologic state-transition disease modeling software, DisMod-MR 2.1, developed by the Institute for Health Metrics and Evaluation.¹¹ DisMod-MR 2.1 is well-suited for handling sparse and heterogeneous data, enabling more accurate and reliable estimates across various populations and time periods.¹¹ Additionally, Bayesian meta-regression software, meta-regression—Bayesian, regularized, trimmed (MR-BRT), also from the Institute for Health Metrics and Evaluation, was employed to adjust for study-level variations in measurement methods and case definitions.¹¹ The Fisher scoring correction was used to refine heterogeneity parameters in data-sparse scenarios. Comprehensive modeling methodologies are thoroughly documented in the **Supplementary Methods**.

IHD burden of dietary risks

Among GBD selection criteria for risk factors, 13 dietary risk factors were identified as contributors to IHD burden. These factors include diets low in fruits, vegetables, whole grains, nuts and seeds, fiber, seafood omega-3 fatty acids, omega-6 polyunsaturated fatty acids, and legumes; and diets high in red meat, processed meat, sugar-sweetened beverages, trans fatty

acids, and sodium (**Table S4**). Detailed information on dietary data and data processing methods is presented in the **Table S5** and **Figure S1**. Diet-related IHD was defined as IHD burden attributable to suboptimal dietary intake, quantified using population-attributable fractions (PAFs). Specifically, we combined detailed dietary exposure data at the population level—derived from representative survey and surveillance data, and refined using spatiotemporal Gaussian process regression models (ST-GPR)—with relative risk estimates systematically obtained via Bayesian meta-regression (MR-BRT), accounting for study heterogeneity, publication bias, and study quality (**Tables S6-S21**).¹⁵ This approach ensures robust estimation of diet-attributable IHD by comparing observed dietary exposure levels with theoretical minimum risk exposure levels (TMRELs), representing the counterfactual exposure levels of minimal health risk. TMREL values for dietary risks were determined through comprehensive evaluations of epidemiological and clinical evidence. PAFs were stratified by age, sex, country, and year to enable detailed demographic analyses.^{3,15} Mediation factors were incorporated to adjust for interdependencies among dietary risk factors, thereby avoiding the overestimation of PAFs and isolating the direct effects of each dietary risk. The attributable number of deaths and DALYs for each dietary risk factor was subsequently calculated by the multiplying PAFs by total IHD deaths and DALYs.^{3,15}

Countries were contextualized along the development spectrum through the utilization of the Socio-demographic Index (SDI).^{3,15} SDI is categorized into five levels: low, low-middle, middle, high-middle, and high SDI, reflecting varying levels of development. Detailed definition of the SDI levels was described in **Supplementary Methods**. These levels were used throughout the Results section to highlight disparities across different demographic groups.

Estimating uncertainty

The estimation process systematically incorporated uncertainty at each stage through random sampling from the distribution of possible values for each estimate. A total of 250 draws were used for this process, ensuring robust statistical representation of uncertainty.¹¹ In the aggregation of results across various categories, such as geographical regions or age groups, each sample was treated as an independent entity.^{1,11} The final uncertainty intervals (UIs) for each result were determined by calculating the 2.5th and 97.5th percentiles of the distribution of draws.^{11,16}

Role of the funding source

The funding entity for this research maintained strict non-involvement in all aspects of the study. This includes the conceptualization and design of the research, data collection processes, analytical procedures, interpretation of results, and the composition of the report.

RESULTS

The overall impact of diet on IHD

In 2023, dietary risks were globally responsible for 4.08 million (95% UI, 0.79 to 6.16) IHD deaths and 97.62 million (18.87 to 142.01) DALYs (Tables S22-S35). Compared to 1990, the number of global diet-related IHD deaths increased by 42.58% (95% UI, 14.99 to 67.16) in 2023. However, the age-standardized death rate decreased by 43.61% (95% UI, 33.87 to 43.61) from 80.42 (14.58 to 121.56) per 100,000 population in 1990 to 45.35 (8.86 to 68.60) in 2023. Similarly, the number of global diet-related IHD DALYs increased by 37.16% (95% UI, 9.84 to 62.42) in 2023. The age-standardized DALY rate decreased by 39.80% (95% UI, 29.10 to 50.19) from 1789.55 (308.25 to 2571.62) per 100,000 population in 1990 to 1077.30 (208.07 to 1564.26) in 2023 (Tables S36-38).

In 2023, significant geographical disparities in diet-related IHD burden were observed across the 21 GBD regions (Figure 1). Central Asia exhibited the highest age-standardized rates of diet-related IHD deaths (124.83 [95% UI, 1.75 to 197.08] deaths per 100,000 population), while Oceania presented the highest age-standardized rates of DALYs (2917.78 [406.45 to 4328.53] DALYs per 100,000 population) among adults aged 25 years and older. High-income Asia Pacific region reported the lowest rates (12.20 [95% UI, 4.93 to 18.05] deaths per 100,000 population and 295.95 [134.13 to 412.38] DALYs per 100,000 population). Detailed age-standardized death and DALY rates of diet-related IHD at the country level are available in Table S39.

Burden of IHD attributable to dietary risks according to age and sex

The burden of diet-related IHD was broadly comparable between sexes across all age groups.

Although males consistently exhibited higher point estimates from 1990 to 2023, these differences were not statistically significant. For males, the age-standardized rates of diet-related IHD deaths decreased by 40.34% (95% UI, 28.65 to 51.80) from 98.23 (21.28 to 146.41) in 1990 to 58.60 (13.02 to 88.77) in 2023. Similarly, for females, the age-standardized death rates decreased by 48.21% (95% UI, 37.10 to 59.77) from 64.964 (9.379 to 101.465) in 1990 to 33.642 (5.190 to 53.563) in 2023. Similar patterns were observed for diet-related IHD DALYs (**Tables S37 and S38**).

Among age groups older than 25 years, the older groups had a higher burden of diet-related IHD (**Tables S40-S42**). In 2023, the age group between 25-29 years had the lowest rate of IHD deaths (3.40 [95% UI, 0.30 to 5.08] per 100,000 population), while the age group over 95 years had the highest death rates (1895.84 [439.18 to 3259.98]). Diet-related IHD death rates were higher in age groups over 65 years (65-69 years, 160.12 [95% UI, 30.54 to 243.69] per 100,000 population; 70-74 years, 212.77 [36.84 to 328.9]; 75-79 years, 305.31 [66.14 to 482.06]; 80-84 years, 513.54 [116.74 to 822.82]; 85-89 years, 866.66 [192.58 to 1397.65]; 90-94 years, 1379.36 [315.50 to 2261.52]) compared to age groups under 45 years (25-29 years, 3.404 [0.30 to 5.08]; 30-34 years, 6.74 [0.61 to 10.12]; 35-39 years, 11.18 [1.31 to 15.77]; 40-44 years, 20.86 [1.84 to 28.85]).

Impact of individual components of diet on deaths and DALYs

Globally, most of the diet-related age-standardized death rates were attributable to 4 diet factors: low in nuts and seed (9.95 [95% UI, 2.85 to 16.87] deaths per 100,000 population), low in whole grains (9.22 [4.73 to 13.54]), low in fruits (7.32 [1.55 to 13.35]), and high in sodium (7.14 [0.85 to 17.86]). For DALY rate, diets low in nuts and seeds (252.31 [95% UI, 74.66 to 428.33] DALYs per 100,000 population), low in whole grain (230.92 [124.94 to 341.88]), and

low in fruits (198.58 [46.01 to 351.18]) were the leading causes.

The burden of each component responsible for diet-related IHD varied across 21 regions (**Figure 3**). Compared to the global average burden, certain regions exhibited specifically higher or lower burdens for each individual component, despite similar rankings. Regions such as central Asia, eastern Europe, north Africa and Middle East, south Asia, and Oceania displayed overall higher age-standardized rates of deaths and DALYs for each component compared to other regions. Conversely, western Europe, Australasia and high-income Asia Pacific showed lower overall burdens.

Specific dietary components showed significant regional variations. For instance, although a diet low in seafood omega-3 fatty acids ranked as a high-risk factor in most regions, high-income Asia Pacific had the lowest IHD death burden related to this component compared to other ingredients (0.11 [95% UI, 0.01 to 0.39]). While a diet low in vegetables was responsible for only a small portion of IHD death burden in most regions, ranking 10 out of 13 globally, it had a higher proportion in certain regions, ranking 1 out of 13 (9.18 [95% UI, 4.12 to 15.39] deaths per 100,000 population) in central sub-Saharan Africa and 3 out of 13 (18.82 [8.31 to 30.25]) in Oceania. The detailed distribution of each individual component and its impact are illustrated in **Figure 4** and **Tables S23-S35**. Additional analyses on the exposure levels of individual dietary factors and their contribution to IHD burden are presented in **Figures S2** and **S3**.

Percent change of individual components

Figure 4 illustrates the impact of individual dietary components on deaths and DALYs. The percent change (PC) in the burden of diet-related IHD burden from 1990 to 2023 varied

significantly across 21 GBD regions. While the global PC showed a 43.61% decrease in diet-related IHD deaths, and most regions experienced a decline, certain areas did not exhibit significant changes during this period. These regions include southeast Asia (-22.21% PC), western sub-Saharan Africa (-15.95% PC), south Asia (-12.65% PC), Oceania (10.22% PC), eastern sub-Saharan Africa (12.41% PC), and central sub-Saharan Africa (13.16% PC). The most substantial decreases in diet-related IHD deaths from 1990 to 2023 were observed in Australasia (-77.32% PC), western Europe (-69.79% PC), and high-income north America (-64.34% PC). Diet-related IHD DALYs followed similar patterns.

The impact of individual dietary components on these changes varied significantly (**Tables S23-S35**). For diet-related IHD deaths, among the 13 components analyzed, diets high in sugar-sweetened beverages (-18.81% PC) and sodium (-33.35% PC) showed lowest reductions, while diets high in trans fatty acids (-58.94% PC) and processed meat (-61.85% PC) exhibited the greatest reductions. In regions with less significant decreases between 1990 and 2023, PC for IHD deaths attributable to sugar-sweetened beverages were commonly high (East Asia, 359.53% PC; Western Sub-Saharan Africa, 314.17% PC; Southeast Asia, 178.48% PC; South Asia, 94.50% PC; Eastern Sub-Saharan Africa, 63.15% PC; Southern Sub-Saharan Africa, 11.35% PC). The IHD death burden related to diets high in processed meat also increased significantly in these regions (East Asia, 83.43% PC; Southeast Asia, 48.02% PC). Various regions showed substantial decreasing trends in IHD death burden related to diets high in trans fatty acids between 1990 and 2023 (High-income North America, -100.00% PC; Western Europe, -94.64% PC; Southern Sub-Saharan Africa, -87.96% PC; Central Europe, -87.58% PC; Eastern Europe, -51.83% PC; Western Europe, -94.64% PC). Similar patterns were observed for diet-related IHD DALYs.

Burden of IHD attributable to dietary risks across SDI levels

Figure 5 shows the burden of IHD attributable to individual dietary components across different SDI levels. In 2023, the highest age-standardized rates of all diet-related deaths and DALYs were observed in low-middle SDI countries (61.95 [95% UI, 7.80 to 96,32] deaths per 100,000 population and 1503.15 [181.55 to 2252.02] DALYs per 100,100 population). The lowest rates were found in high SDI countries (36.15 [95% UI, 9.42 to 54.15] deaths per 100,000 population and 812.19 [228.60 to 1163.99] DALYs per 100,100 population). However, the differences were not statistically significant. Countries with higher SDI experienced significant reductions in age-standardized rates of diet-related deaths and DALYs between 1990 and 2023 (High SDI, -57.40% PC of death rate and -55.50% PC of DALY rate; High-middle SDI, -37.54% PC of death rate and -38.73% PC of DALY rate). By contrast, low and low-middle SDI countries did not show significant reductions in the IHD burden.

Higher age-standardized rates of IHD death attributable to diets deficient in certain components were observed in countries with lower SDI. For instance, diet low in seafood omega-3 fatty acids (low SDI, 9.95 deaths per 100,000 population; low-middle SDI, 12.34; high-middle SDI, 5.60; high SDI, 3.67), diet low in fiber (low SDI, 6.99; low-middle SDI, 5.67; high-middle SDI, 2.78; high SDI, 2.45), diet low in fruits (low SDI, 13.06; low-middle SDI, 13.30; high-middle SDI, 7.54; high SDI, 4.58), and diet low in vegetables (low SDI, 6.91; low-middle SDI, 5.24; high-middle SDI, 2.27; high SDI, 1.82). However, countries with higher SDI had higher IHD death related to diet excessive in certain component such as high in red meat (low SDI, 0.15; low-middle SDI, 0.48; high-middle SDI, 1.91; high SDI, 2.80) and high in sugar-sweetened beverages (low SDI, 0.21; low-middle SDI, 0.46; high-middle SDI, 0.73; high SDI, 0.95).

DISCUSSION

Key findings

This comprehensive study evaluates the global, regional, and national burden of IHD attributable to dietary risks across 204 countries, providing an extensive overview of how suboptimal diet patterns impact population-level IHD based on GBD 2023 estimates. While the absolute number of diet-related IHD cases has increased, age-standardized rates have decreased, suggesting population growth and health improvements. Subgroup analysis revealed significant variations in diet-related IHD burden across demographic groups. Males showed higher diet-related IHD burden across all age groups without statistical significance. Individuals over 65 years had significantly higher death rates than those under 45. Most regions showed a decline in IHD burden from suboptimal diet over time, except southeast Asia, sub-Saharan Africa, Oceania, and South Asia. Globally, diets low in nuts and seeds, whole grains, fruits, and high in sodium were the major contributors for diet-related IHD burden. From 1990 to 2023, IHD burden related to high consumption of sugar-sweetened beverages and sodium showed minimal improvements, while that of trans fatty acids and processed meat decreased substantially. The highest burden of diet-related IHD was observed in low-middle SDI countries, which had prominent burden due to inadequate intake of protective dietary components. In contrast, higher SDI countries exhibited a notable trend of IHD burden resulting from excessive consumption of potentially harmful dietary factors. These findings highlight significant disparities in the pattern of diet-related IHD burden across regions and demographics, emphasizing the need for comprehensive and targeted interventions by regional diet patterns.

Comparison with previous studies

Previous observational studies have suggested various associations between dietary components and cardiovascular disease outcomes. Al-Shaar et al. reported that red meat consumption increases coronary heart disease risk by approximately 10-15% per daily serving increment.⁶ Similarly, Aune et al. identified that whole grain consumption decreases cardiovascular disease risk by 19%.⁸ Additional research found that fruit and vegetable intake was associated with a 4% reduction in cardiovascular mortality,¹⁷ whereas sugar-sweetened beverages corresponded to a 9% increase in cardiovascular disease incidence.⁷ Furthermore, one recent study developed a dietary scoring system based on beneficial components versus potentially harmful ones, revealing that higher scores associated with a 19% decrease in coronary heart disease risk.¹⁸ Several prior studies have investigated the relationship between dietary risks and IHD using GBD 2019 modeling approaches.¹⁹⁻²² While these studies identified important associations between each ingredient and heart disease risk, our study advances current knowledge in three critical ways. First, by setting the dietary TMREL where IHD risk is minimized, this study provided actionable targets beyond simply indicating directional relationships. Second, we quantified the IHD burden attributable to suboptimal intake of 13 dietary components, providing priority dietary components for intervention. Third, our study systematically quantified the global burden of IHD attributable to suboptimal diet using the standardized GBD methodology. This approach ensures direct comparability of estimates across regions and populations, addressing a key limitation of prior single-country or region-specific analyses. By leveraging the updated GBD 2023 modeling framework, our study offers a precise assessment of dietary risks for IHD. The insights derived from this refined methodology may provide guidance for region-specific dietary guidelines and intervention strategies.

Possible explanation

From 1990 to 2023, the diet-related age-standardized death and DALY rates for IHD have decreased. However, dietary risk remains a primary risk factor responsible for IHD. IHD accounts for the highest burden of premature mortality among non-communicable diseases.¹¹ In response to this persistent challenge, various interventions have been implemented to reduce its prevalence.²³ Dietary factors have been considered an optimal target for public health intervention due to their modifiable nature.²⁴ Additionally, a range of policy interventions such as mass media campaigns, food labeling regulations, economic measures like subsidies and taxation, and school food procurement policies have been enacted to address this issue.²⁵ Despite ongoing efforts and a declining trend, IHD continued to pose a major public health burden, with an estimated 4.1 million deaths attributable to dietary risk factors in 2023.

The burden of diet-related IHD showed pronounced disparities across different SDI levels, with lower SDI countries experiencing less decrease compared to higher SDI countries. This disparity could be attributed to several factors. First, the disparities in dietary quality are often associated with income, ethnicity, and education.⁵ Previous studies reported that low-income families, often from minority populations with limited education access, were more susceptible to suboptimal and unbalanced diets.^{26,27} Economic barriers in lower SDI countries contribute to nutrition insecurity, as healthy and fresh foods are generally more expensive than energy-dense, nutrient-poor alternatives.²⁸ Structural barriers, such as the limited availability of healthy food options in certain regions, further exacerbate the problem by making it easier for residents to choose processed or fast food.²⁹ Lack of nutritional education can lead to diets high in sodium, processed foods, and added sugars, making individuals more vulnerable to unhealthy food marketing.³⁰ Global issues, including food supply chain disruptions, economic crises, civil conflicts, and climate change, have disproportionally influenced on the availability

and affordability of nutrient-rich foods, particularly in low SDI countries.^{31,32}

Lower SDI countries experienced higher IHD burden related to insufficient consumption of nutritious diets. However, higher SDI countries face health challenges from excessive intake of sweetened foods associated with increased cardiovascular risks. Food and nutrition insecurity in low SDI countries may explain their higher burden of diets deficient in healthy components such as vegetables, fruits, fibers, nuts and seeds. This is consistent with previous research on dietary patterns in low-income countries of South Asia and Sub-Saharan Africa.³³ While these regions show low consumption of harmful components like sugar-sweetened beverages and processed meat, insufficient intake of beneficial foods such as seafood, vegetables, and fruits seems to negate these benefits, contributing to an overall increase in IHD burden. By contrast, high SDI countries exhibit a different dietary pattern as they consume excessive amounts of both nutritious and less healthy components.³³ This dietary pattern partially explains the differences in diet-related IHD across countries with varying SDI levels.

A concerning trend is emerging in low SDI countries as they undergo urbanization and industrialization. Their diets are shifting to resemble those of higher SDI countries, adopting more Westernized diet patterns.³⁴ This transition is characterized by increased consumption of processed foods, particularly processed meats and sugar-sweetened beverages.³⁵ Our findings show that the burden of deaths and DALYs from these foods in low SDI countries is growing, though the absolute burden remains lower than in high SDI countries. While consumption of sugar-sweetened beverages is declining in many high SDI countries, it is increasing in low-SDI countries, likely due to greater availability as economies develop.^{36,37} Higher consumption of sugar-sweetened beverages shows a dose-dependent relationship with cardiovascular diseases, primarily through increased body weight and metabolic syndrome risk.²⁹ The shift towards

Westernized diets in developing countries has led to increased consumption of red meat, particularly processed meat. Studies have shown that processed meat is associated with a higher risk of overall mortality compared to unprocessed meat.³⁸ The affordability and convenience of processed meat have contributed to its increased consumption in developing countries.³⁹ Although these components currently constitute a small proportion of the overall dietary burden in lower SDI countries, they present a growing health concern.

Our findings indicate that individuals aged 75 and older experienced the highest burden of IHD attributable to dietary risk. This finding likely reflected a cumulative effects of lifelong dietary habits and age-related physiological changes that may interact synergistically to increase cardiovascular risk.⁴⁰ Moreover, older individuals with mobility limitations and inadequate social support are particularly at risk for both social isolation and malnutrition, as they may face challenges in accessing and preparing foods.⁵ Additionally, there were no statistically significant sex differences in the burden of diet-related IHD, as the UI for males and females overlapped. Although previous studies attempted to explain the observed disparity of diet-related mortality between sexes through differences in dietary patterns and sociodemographic characteristics,⁴¹ the limited number of studies directly examining sex-specific effects of dietary factors on cardiovascular outcomes suggests these findings warrant cautious interpretation and highlights the need for additional research.

Clinical and policy implications

Dietary risks, being modifiable and strongly linked to noncommunicable diseases, require comprehensive policy approaches. Our findings show that diets low in nuts and seeds, whole grains, fruits, and high in sodium remain the primary risk factors responsible for diet-related IHD. This contrasts with previous global actions that focused mainly on reducing sodium, sugar,

and fat consumption.^{42,43} Our findings corroborate previous study, which has shown that simultaneously decreasing total meat consumption and increasing the intake of healthy foods can more effectively lower mortality risk.³⁸ This implies that while reduction of unhealthy dietary components remains important, enhancing the intake of protective nutritional elements is of comparable significance.

Although food labeling and nutritional education initiatives have been widely implemented, population-based strategies may offer greater effectiveness than approaches that rely solely on individual choices.^{44,45} Historically, global actions have prioritized food availability; however, our findings underscore the critical importance of nutrition security. Notably, even in high-income countries, there remains a substantial burden of IHD linked to diets low in whole grains, seafood, and legumes, highlighting persistent challenges in achieving nutrition security. As such, a comprehensive improvement in food systems is warranted, including sustainable farming, fair trade policies, and efficient distribution systems, to enhance the supply and accessibility of nutritious foods.⁴⁶

Additionally, focusing on overall dietary pattern, exemplified by the Mediterranean diet, has gained significant attention in cardiovascular disease prevention. This diet, rich in whole grains, fruits, vegetables, nuts, legumes, and unsaturated fats,⁴⁷ has shown its effectiveness comparable to established cardiovascular interventions such as aspirin, statins, and physical activity.⁴⁷ Recent research has shown that the Mediterranean diet surpasses low-fat diets in preventing major cardiovascular events,⁴⁸ emphasizing that balanced, diverse dietary patterns are more crucial than simply manipulating individual components.

Strengths and limitations

This study offers an comprehensive analysis of diet-related IHD burden across global regions, utilizing the GBD 2023 data. However, our study has several limitations. First, the reliance on

GBD dataset estimates introduces potential inherent biases. Given the difficulties in directly measuring dietary factor exposure across all 204 countries, the GBD study utilized data from countries with available information to estimate missing data for others through its modeling processes. Second, quantification of dietary risk factors' impact on health outcomes relies heavily on meta-analyses of prospective observational studies. These studies have inherent limitations in their ability to establish causality. Despite efforts to control for known confounders like age, sex, smoking status, and physical activity levels, the intricate relationships between dietary patterns and various lifestyle factors can have bias due to residual confounding factors.³ Third, the focus of many cohort studies on harmful dietary factors may lead to an overestimation of their impact, as real-world consumption often includes offsetting healthy components. The complexity of dietary patterns, combining various healthy and unhealthy factors, complicates the accurate estimation of overall dietary risk impact on IHD. Fourth, while we provided a comprehensive analysis of IHD burden attributable to suboptimal diet across 204 countries, subnational disparities may exist based on residential location (urban versus rural), socioeconomic status, and educational attainment.⁴⁹ Previous research has indicated that suboptimal dietary patterns are more prevalent among urban residents, individuals with lower educational attainment, and those of lower socioeconomic status.⁴⁵ Although this study examines diet-related IHD burden stratified by country-level SDI, these potential within-country variations should be considered when interpreting the results. Future studies investigating these subnational disparities would provide valuable insights for more targeted public health interventions. Fifth, although previous studies have suggested that genetic factors may influence the relationship between healthy diets and cardiovascular disease,⁵⁰ genetic data was not incorporated in modeling, as they are not included in the current GBD framework.

Conclusion

While the number of diet-related IHD case has increased, age-standardized rates have declined, indicating population growth and health improvements. The older populations had a higher IHD burden attributable to suboptimal diet compared to younger populations. Among individual dietary factors, insufficient intake of nuts and seeds, whole grains, fruits, and high in sodium contributed substantially to the IHD burden. Lower SDI countries faced higher burdens related to inadequate consumption of healthy dietary components, while higher SDI countries had relatively higher burdens related to excessive intake of harmful dietary factors. By disentangling dietary causes, we identified the portion of the IHD burden that is directly modifiable and preventable through food interventions.

Data availability

The findings from this study were produced using data available in public online repositories or in the published literature, data that are publicly available on request from the data provider, and data that are not publicly available due to restrictions by the data provider and which were used under license for the current study. Details on data sources can be found on the GHDx website, including information about the data provider and links to where the data can be accessed or requested (where available). To download the data used in these analyses, please visit the Global Health Data Exchange GBD 2023 website at <https://ghdx.healthdata.org/gbd-2023>.

Conflicts of interest

Our study is official IHME collaborator-lead paper and, in principle, we will submit an COI list of authors when carrying out a revision status (1214 authors).

Ethics and Inclusion statement

The GBD framework ensures that estimates are derived from diverse data sources, including population-based registries and national health surveys, covering 204 countries and territories. The research team included collaborators from various regions who contributed expertise in epidemiology, disease modeling, and health policy. All authors agreed upon roles and responsibilities at the outset of the study. This study is a systematic analysis for the GBD study, which the University of Washington Institutional Review Board has approved under IRB ID 9060.

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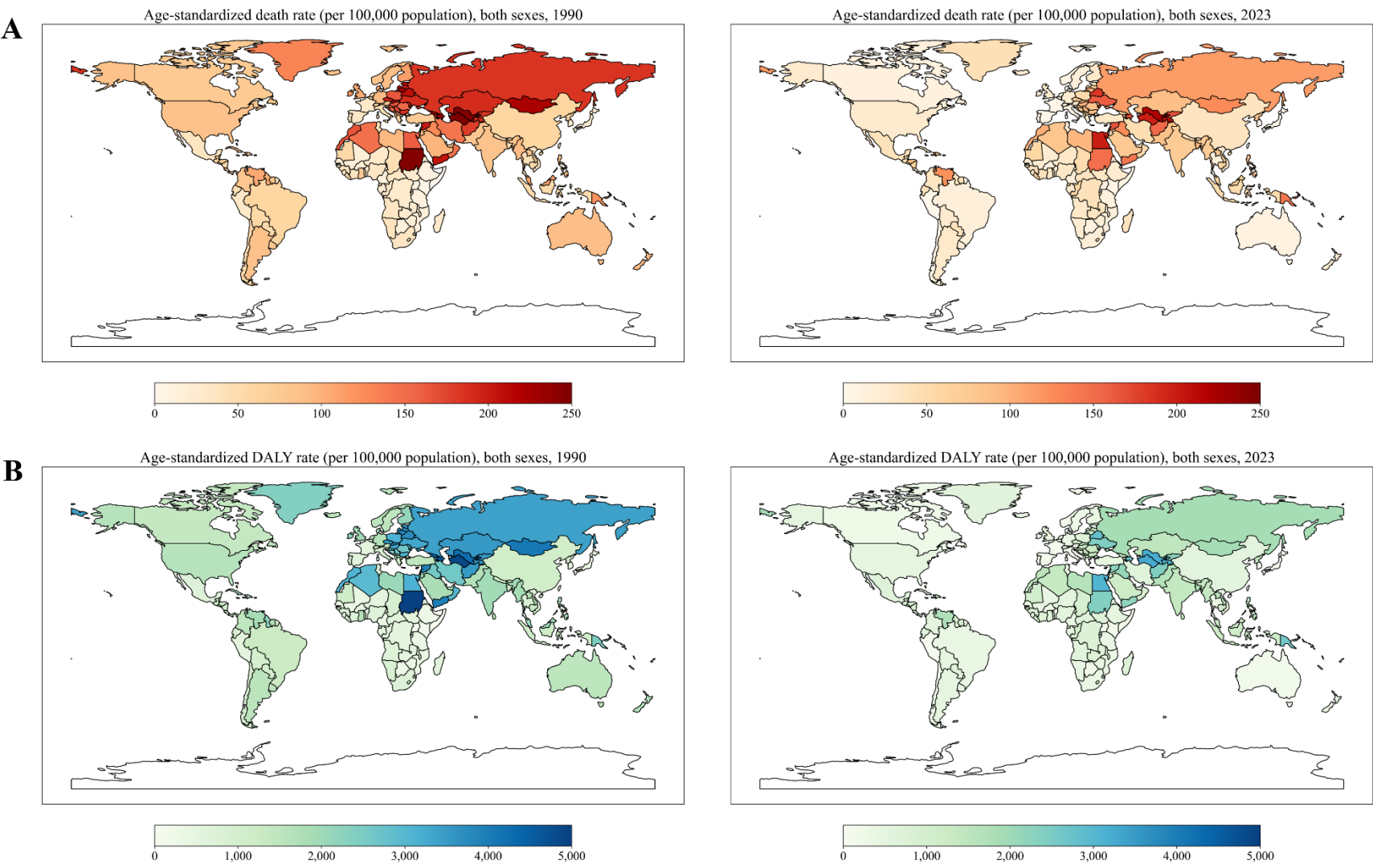
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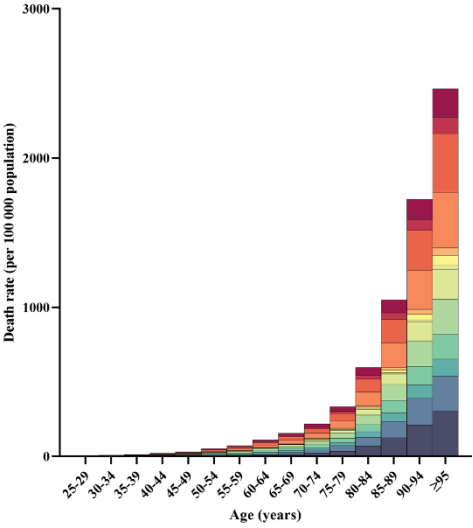
671 **Figure 1. Age-standardized death and DALY rates of ischemic heart diseases attributed to dietary risks per 100 000 population in 1990**
672 **and 2023 for both sexes. (A) Death rate in 1990, (B) death rate in 2023, (C) DALY rate in 1990, and (D) DALY rate in 2023.**



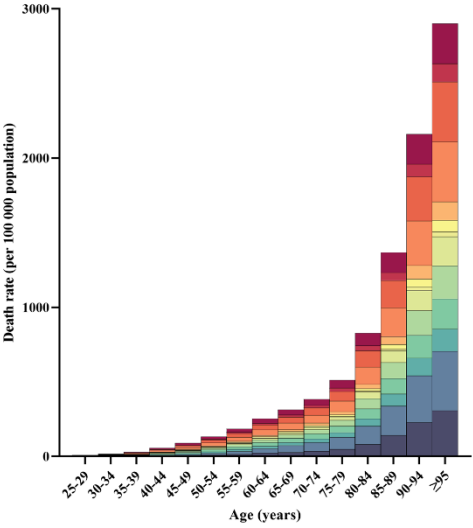
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Figure 2. Death and DALY rates of ischemic heart diseases attributed to each dietary risk per 100 000 population in 2023. (A) death rate in females, (B) death rate in males, (C) DALY rate in females, and (D) DALY rate in males.

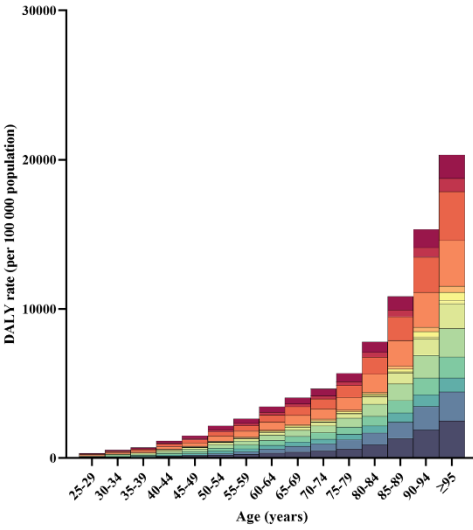
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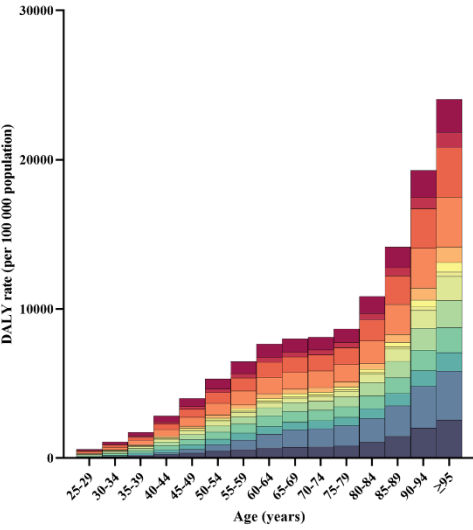
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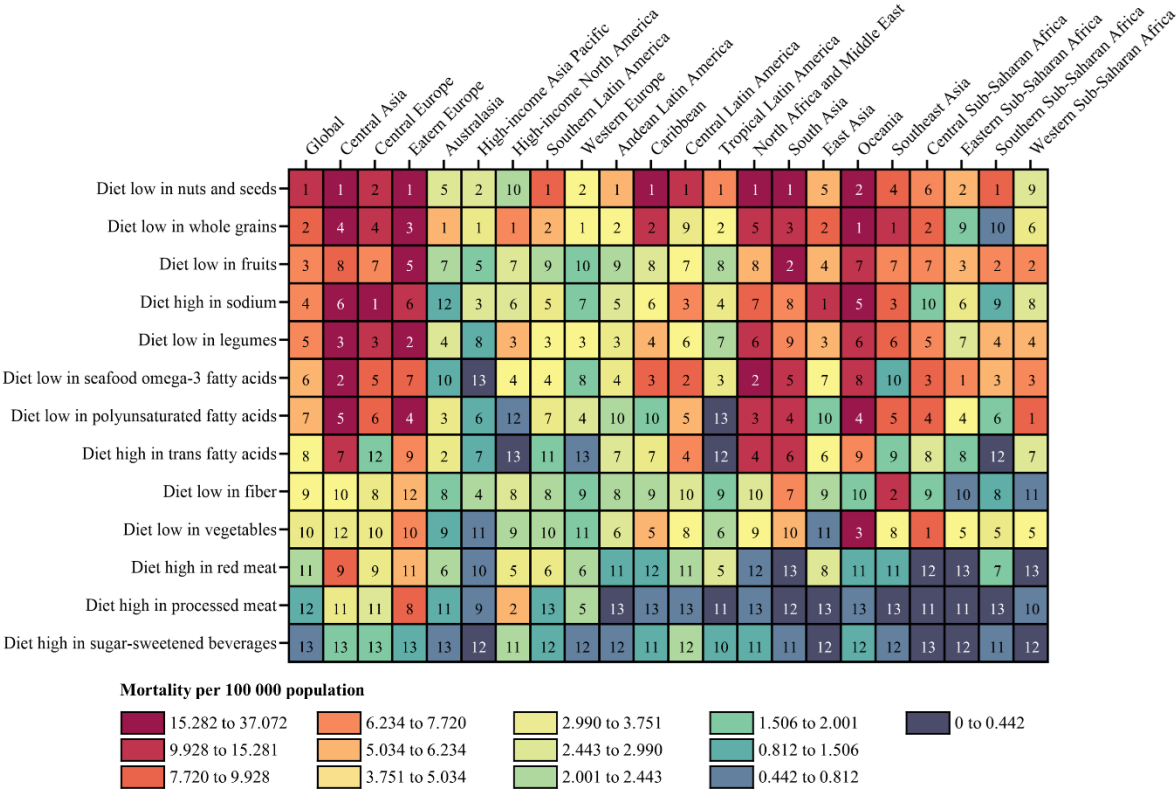
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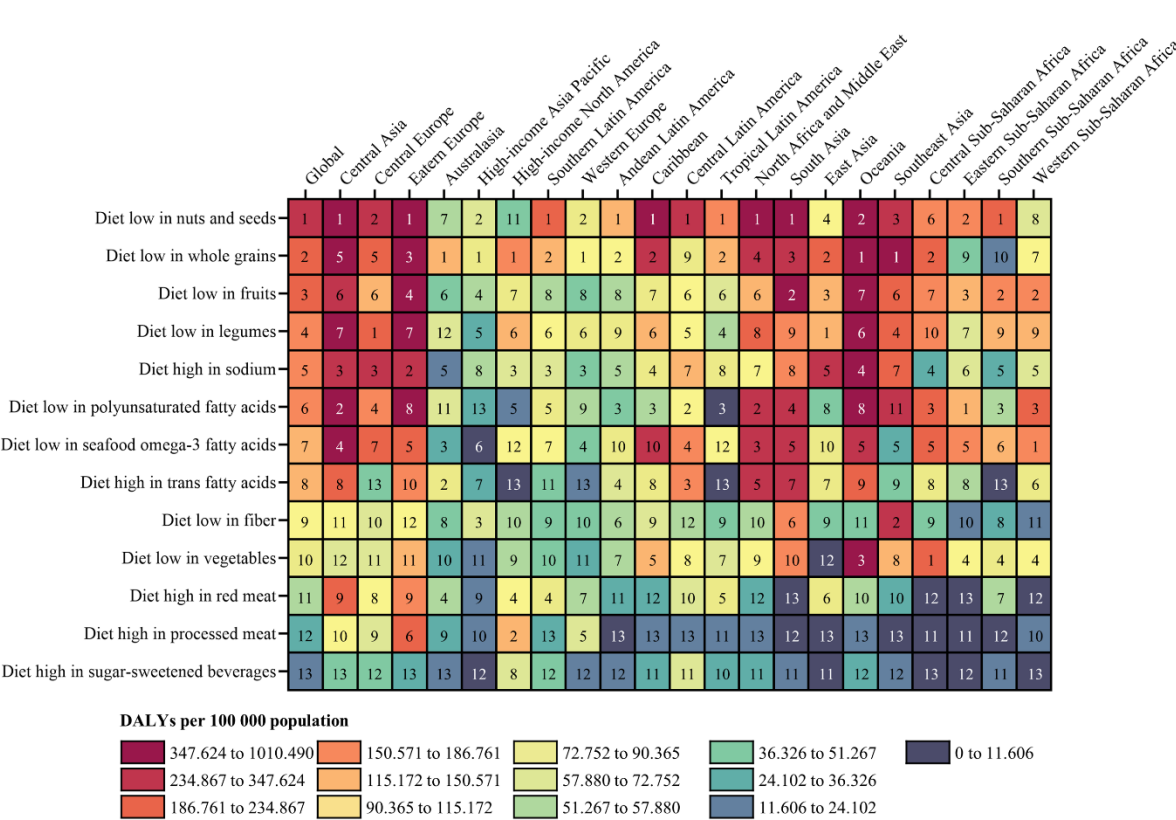
- Diet low in fruits
- Diet low in vegetables
- Diet low in whole grains
- Diet low in nuts and seeds
- Diet high in red meat
- Diet high in processed meat
- Diet high in sugar-sweetened beverages
- Diet low in fiber
- Diet low in seafood omega-3 fatty acids
- Diet low in polyunsaturated fatty acids
- Diet high in trans fatty acids
- Diet high in sodium
- Diet low in legumes

679 **Figure 3. Ischemic heart diseases attributed to each dietary risk ranked by age-**
680 **standardized death (A) and DALY (B) rates, globally and by super-region, for both sexes**
681 **in 2023.**

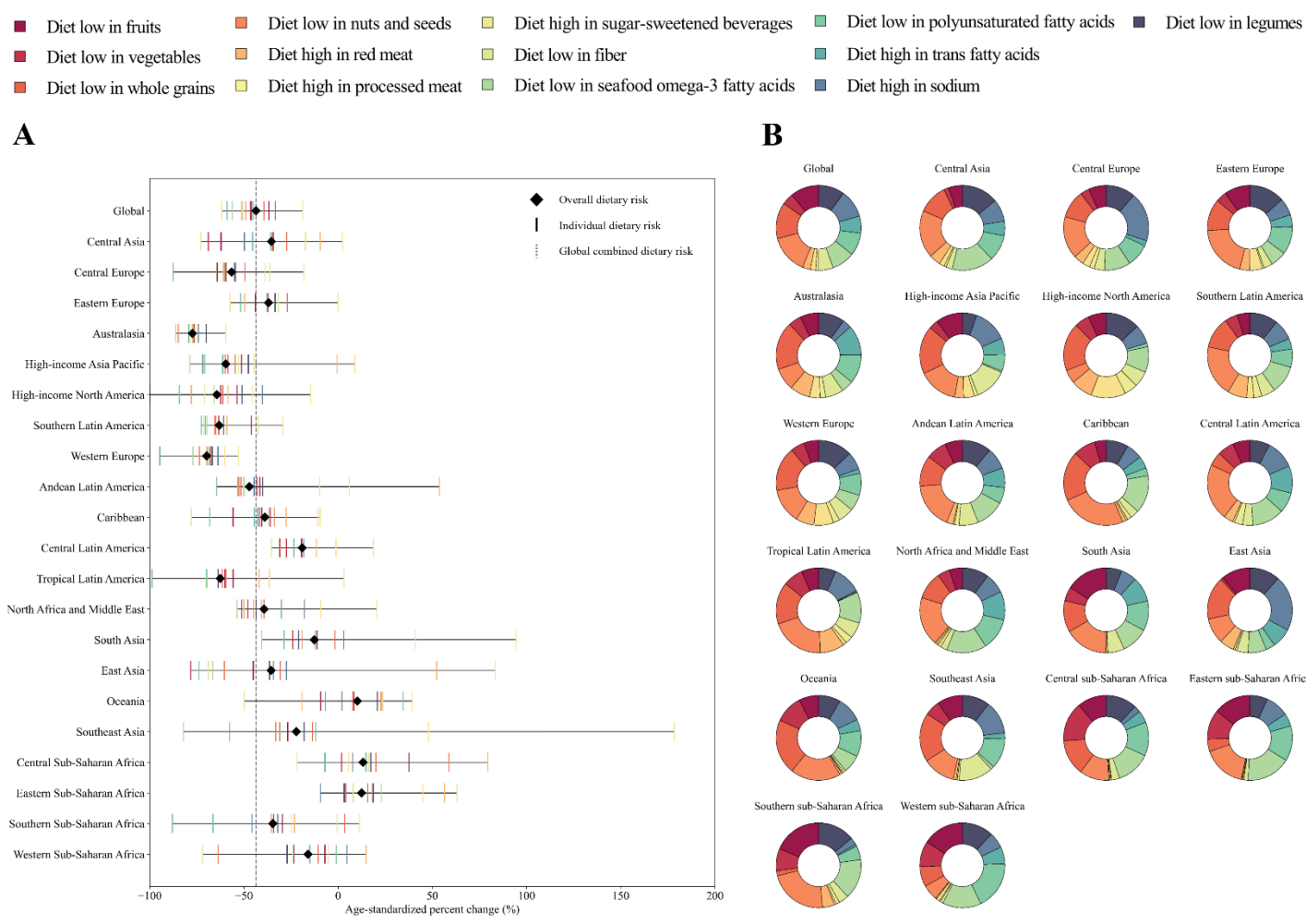
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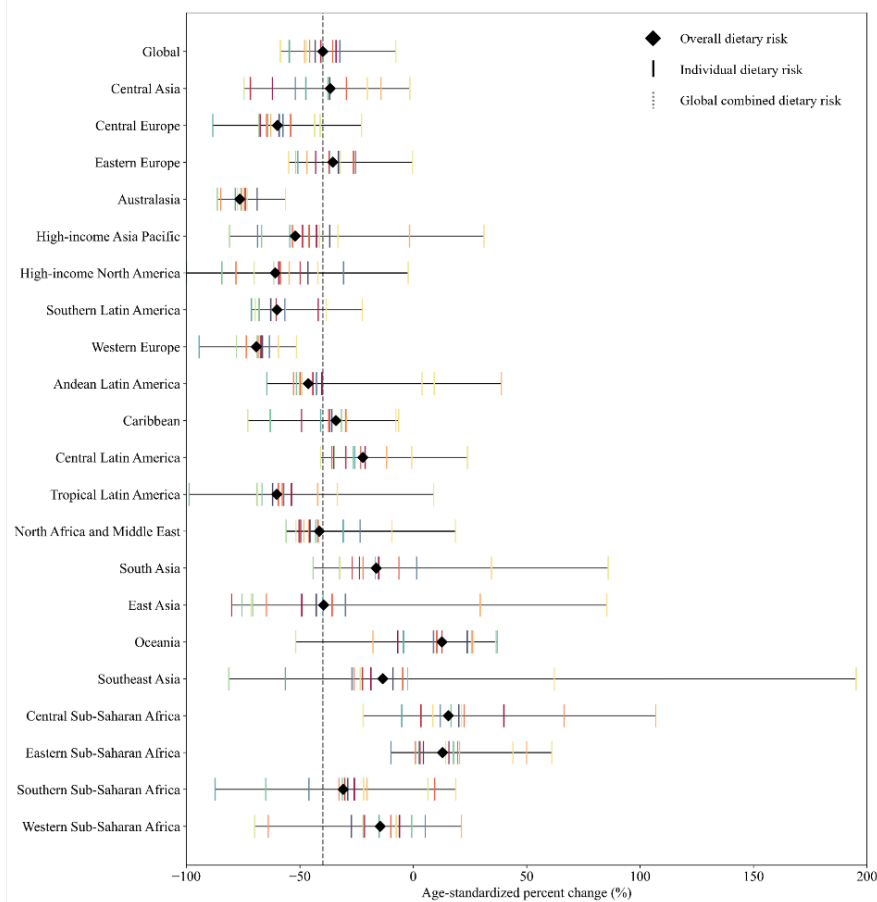
B



682 **Figure 4. Percent change of age-standardized rate of ischemic heart diseases attributed to each dietary risk between 1990-2023 and age-**
683 **standardized proportions of ischemic heart diseases attributed to individual dietary risks at global and regional levels in 2023. (A) Age-**
684 **standardized death percent change, (B) age-standardized death proportions, (C) age-standardized DALYs percent change, and (D) age-**
685 **standardized DALYs proportions**



C



D



688 **Figure 5. Age-standardized death (A) and DALY (B) rate (per 100,000 population) of ischemic heart diseases attributed to each dietary**
 689 **risk for both sexes, by socio-demographic index, 2023.**

