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Associations of breakfast cereal consumption with all-cause and cause-specific mortality: a large-scale prospective analysis

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Abstract

Background Previous studies have explored the relationship between breakfast cereal consumption and mortality risk, but these studies reported inconsistent findings and did not distinguish between consumers of different breakfast cereal types. This prospective cohort study aims to elucidate the dose-response relationship between specific breakfast cereal types and mortality risk.

Methods A total of 186,168 participants aged 40 to 69 years from UK Biobank that completed at least one online 24-hour dietary recall questionnaire and reported information on breakfast cereal consumption were included. Self-reported types and amounts of dietary breakfast cereal intake, and mortality from CVD (cardiovascular disease), cancer, and all causes were estimated. Cox regression analyses were employed to illustrate the correlation between the daily intake of different breakfast cereal types and mortality risk.

Results During a median follow-up of 13.4 years, 9402 deaths were recorded (including 5073 cancer deaths and 1687 CVD deaths). The intake of muesli was significantly correlated with reduced all-cause mortality, with the HRs (hazard ratios) (95% CIs) being 0.89 (0.83–0.95) (> 0-0.5 bowls/d) and 0.85 (0.79–0.92) (> 0.5-1 bowls/d), respectively. Bran cereal consumption also exhibited inverse correlations with all-cause mortality, showing an HR of 0.88 (95% CI: 0.81–0.95) (> 0-0.5 bowls/d) and 0.88 (95% CI: 0.80–0.98) (> 0.5-1 bowls/d). Moderate intake of porridge (> 0.5-1 bowls/day) was correlated with a reduced risk of all-cause mortality, with an HR (95% CI) of 0.89 (0.84–0.96). Furthermore, moderate consumption of muesli and bran cereal correlated with reduced mortality risks related to CVD and cancer, while plain cereal intake was correlated with increased CVD-specific mortality risk, and sweetened cereal consumption was correlated with elevated cancer-specific mortality risk. Additionally, participants who reported adding dried fruit to their breakfast cereals exhibited significantly lower risks of all-cause mortality and cause-specific mortality, and those who added milk to their breakfast cereals had a reduced risk of all-cause mortality.

Conclusions The findings support the moderate intake of several breakfast cereal types, including porridge, bran cereal, and muesli, as part of a healthy diet, while oat crunch and sweetened cereal consumption should be reduced to lower premature mortality risk.

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Keywords Breakfast cereal, Healthy diet, Mortality, Prospective study, UK Biobank

Introduction

Breakfast cereal is a widely consumed food product that has gained popularity over the years [1, 2]. Breakfast cereals are grain-based food made from oats, corn, wheat, or rice, and can be minimally processed, such as by drying and rolling the grain, or more substantially processed, such as by boiling and then flaking or puffing [2]. The potential roles of breakfast cereals in a balanced diet have been investigated for many years [1]. Breakfast cereals are often fortified with various vitamins and minerals, making them a potential source of essential nutrients [1, 2, 3]. Studies have shown that breakfast cereal consumers have higher nutrient intakes and a better nutritional profile than non-consumers [4, 5]. Multiple lines of evidence have demonstrated that the consumption of whole grains in cereal can effectively decrease the risks of human diseases, such as type 2 diabetes, CVD, and metabolic diseases [6, 7, 8]. For instance, lower weight gain was observed in those who consumed at least 1 serving of breakfast cereal per day compared to those who rarely consumed cereals [9]. A previous investigation based on three prospective cohort studies has indicated that the highest intake levels of whole-grain cold breakfast cereal effectively reduced the risk of type 2 diabetes [7]. However, concerns have been raised regarding the health implications of cereal consumption, particularly due to its potential association with excessive sugar intake and refined cereal consumption [8, 10]. Recent studies have reported that cereals may be a source of sugar intake, and excessive sugar consumption is closely related to various adverse health effects, including obesity and dental caries [11, 12, 13]. Furthermore, multiple studies have indicated that refined cereal consumption is associated with multiple adverse health outcomes. A prospective cohort study across 21 countries has reported that compared with low consumption (< 50 g/day) of refined cereals, high consumption (> 350 g/day) was closely related to the increased risk of the composite outcome, all-cause mortality, and non-cardiovascular mortality with the HRs (95%CI) being 1.28 (1.15–1.42), 1.27 (1.11 to 1.46), and 1.33 (1.16 to 1.52), respectively, while no-significant associations were observed between whole grains consumption and mortality risks after full adjustment [8, 10]. These controversial findings may be attributed to the phenomenon that the types of cereals are not well classified among different studies. Hence, it is worth further exploring the long-term effects of different cereal types consumption on health outcomes.

Several previous studies have reported that higher breakfast cereal consumption is related to a lower risk of mortality. For instance, a previous meta-analysis has demonstrated that breakfast cereals intake was correlated with a lower all-cause mortality risk [14]. However, the correlations of breakfast cereal consumption with all-cause and cause-specific mortality risks have not been comprehensively examined and established, and the available evidence is limited. Besides, current studies have mostly focused on the correlations of whole-grain cereal and refined cereal consumption with mortality risks [7, 15, 16, 17]. Notably, there are many different kinds of breakfast cereals, such as bran cereal, muesli, and oat crunch, and sugar, milk, and dried fruit added into breakfast cereals may also change the nutritional value of breakfast cereals [18]. There is limited evidence to distinguish the effects of different types of breakfast cereals on mortality risk [6]. Hence, more comprehensive research is needed to provide information on correlations across relatively detailed breakfast cereal types. Moreover, the appropriate amount of breakfast cereals that should be consumed to reduce premature mortality risks has not been well investigated. Nowadays, different dietary recommendations have provided unclear and inconsistent quantities of cereal consumption for health promotion, and most dietary recommendations are vague and qualitative. Therefore, the dose-dependent analysis of the associations between breakfast cereal consumption and mortality can provide more detailed and consistent dietary guidelines regarding the optimal quantity of breakfast cereals to reduce the risk of premature mortality.

In the present study, our objective was to evaluate the dose-dependent associations between the consumption of specific breakfast cereal types (porridge, muesli, oat crunch, plain cereal, bran cereal, whole-wheat cereal, and sweetened cereal) and mortality risks. We aimed to provide comprehensive, up-to-date, and detailed evidence on the health effects of breakfast cereal consumption in preventing mortality. Furthermore, we explored the potential impact of the addition of milk, sugar, artificial sweeteners, and milk in breakfast cereals on mortality risks (Fig. 1).

Methods

Study participants

Our study was conducted based on UK Biobank, a large-scale prospective cohort study with 502,543 participants aged 37 to 73 years (2006–2010). Participants completed a touch-screen questionnaire, a nurse-led interview, and physical measurements, and provided their sociodemographic and lifestyle information and biological samples. In our present analysis, a total of 210,947 participants who had completed at least one online 24-hour dietary

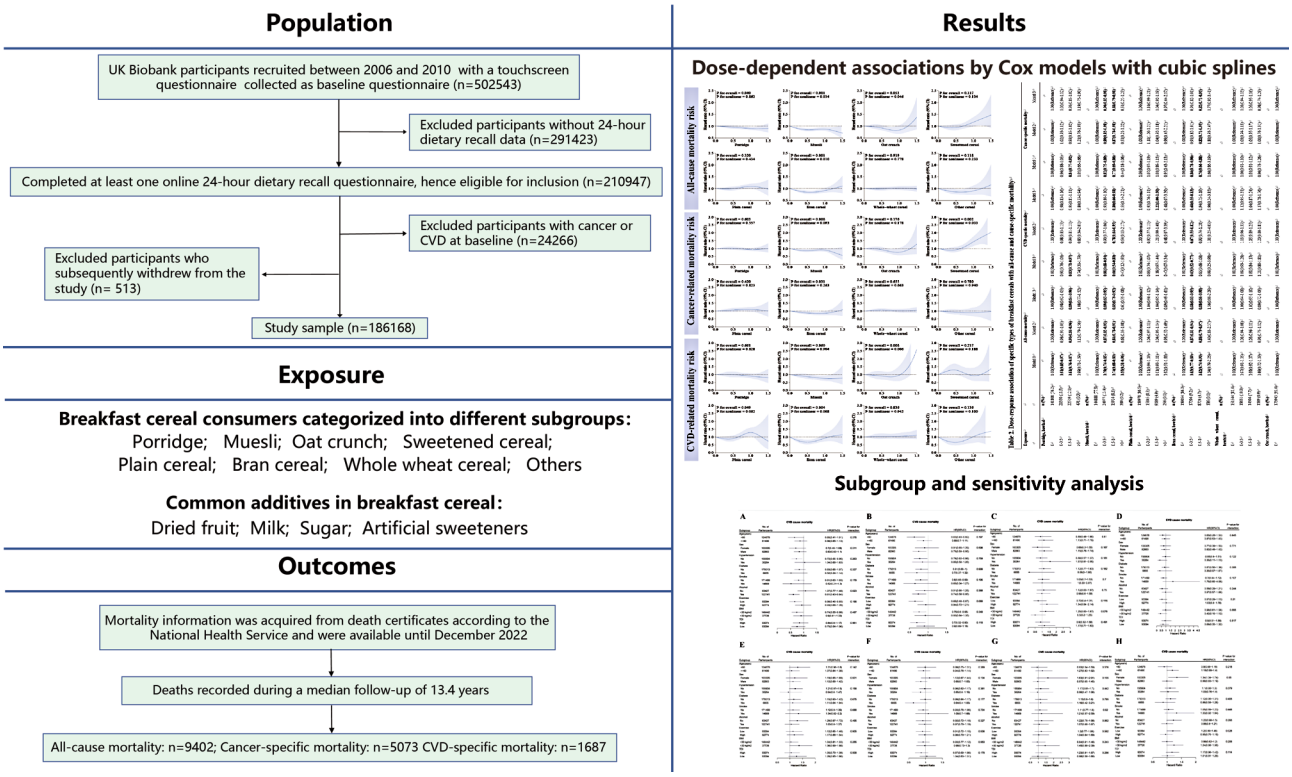

Fig. 1 Workflow of the associations between breakfast cereal consumption and mortality risk

recall questionnaire and reported information on breakfast cereal consumption were included. After excluding participants with cancer or cardiovascular disease (CVD) at baseline (24,266) and those who subsequently withdrew from the study (513), a total of 186,168 participants were included for further investigation (Fig. 1).

Exposures assessment

Daily consumption of breakfast cereal was collected by utilizing a 24-hour dietary recall questionnaire called the OxfordWebQ. Participants were invited to complete a total of five questionnaires between 2009 and 2012. The first questionnaire round was added towards the end of the recruitment phase. After the close of recruitment, four additional questionnaire rounds were conducted online, with invitations emailed to participants at 3- to 4-month intervals. In each 24-hour dietary recall questionnaire, participants were asked to answer "Did you eat any breakfast cereal yesterday? This could be at any time of the day. Please include hot cereals, but not cereal bars". Participants who reported breakfast cereal consumption on at least one recall were identified as breakfast cereal consumers, while the others were categorized as non-consumers. Besides, information on specific breakfast cereal types and the quantity of each, including porridge, muesli, oat crunch, plain cereal, bran cereal, whole-wheat cereal, sweetened cereal, and other breakfast cereals, was obtained from the 24-hour dietary recall questionnaire (UK Biobank Category ID: 100102). For example, participants were asked, "How many bowls of porridge, hot oat cereal (e.g. Ready Brek)?" The mean number of bowls consumed across multiple recalls was then calculated as the exposure variable for each specific breakfast cereal. Additionally, participants were asked to answer whether they added milk, sugar, artificial sweeteners, and dried fruits to breakfast cereals in the 24-hour recall questionnaire (Data-Field 100880, 100910, 100900, and 100890).

Outcomes assessment

Mortality information was obtained from death certificates by data linkage with national datasets from the National Health Service (NHS) Information Centre (England and Wales) and the NHS Central Register Scotland (Scotland). Death data were available until December 2022. We censored participants in the mortality analysis at this censoring date or the date of death, whichever occurred first. Specific-cause mortality was identified according to the International Classification of Diseases, 10th Revision: CVD (codes I00 to I99) and cancer (codes C00 to D48).

Covariates assessment

To minimize the influence of potential confounding factors, we selected demographic and contextual covariates.

These covariates, including demographic variables (age, sex, ethnicity, Townsend deprivation index (TDI), education), body mass index (BMI), smoking status, alcohol consumption, physical activity, dietary intake of various nutrients and foods (red meat, vegetables, fruit, starchy food, bread, milk, coffee, tea, total intake of energy, fat, and sugar), the supplements of vitamin and minerals, medical history (hypertension, diabetes, high cholesterol, long-standing illness, the use of cholesterol drug, hypertension drug, and insulin drug, family history of CVD and cancer). Ethnicity was categorized as white and others. TDI was employed to evaluate the area-based socioeconomic status (deprivation) by assessing unemployment, overcrowded households, and non-car and non-home ownership. BMI was calculated by the formula of weight/height^2 during the initial Assessment Centre visit. Milk, coffee, and tea consumption refer to any type of milk, coffee, and tea. Consumers are indicated by 1, and non-consumers by 0. Total intake of energy, fat, and sugar was estimated from participants' answers to the dietary questionnaire [19]. Vitamin supplements include vitamins A, B, C, D, and E, folic acid or folate, or multivitamins or minerals. Minerals supplements include selenium, iron, zinc, calcium, glucosamine, and fish oil. Physical activity was identified in metabolic equivalent of task minutes per week (MET-min/wk), which effectively measured the overall physical activity levels [20]. Self-reported medical history was employed to evaluate health status. Multivariate imputation by chained equations was employed to fill in missing covariate data.

Statistical analysis

The baseline characteristics of the participants were summarized as percentages for categorical variables and as means and standard deviations (SDs) for continuous variables. Analysis of variance (ANOVA) was used to compare continuous variables across breakfast cereal intake categories, while chi-squared tests were used for categorical variables. Cox proportional hazard models were employed to assess the prospective correlations between overall breakfast cereal consumption, specific types of breakfast cereal consumption, and mortality risks. The entry time was specified as the recruitment time of each participant, and the exit time was defined as the time the event occurred or when the participant was censored. The proportional hazards assumption was accessed using Schoenfeld residuals, and no evidence of serious violation was found. To visualize the dose-dependent relationship between specific types of breakfast cereal intake and mortality risks, the nonparametrically cubic spline regression with knots at the 33rd and 67th percentiles was utilized. The consumptions of different types of breakfast cereal were further divided into three or four categories. Porridge, muesli, plain, bran, and whole wheat cereal were divided into the following four categories: 0 bowl/d, > 0-0.5 bowl/day, > 0.5-1 bowl/day, and > 1 bowl/day, while oat crunch, sweetened cereal, and other cereal were divided into three categories: 0 bowl/day, > 0-0.5 bowls/day and > 0.5 bowls/day due to few participants consuming more than 1 bowls of these types of cereal. For each specific type of breakfast cereal, Cox models were used to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for mortalities comparing across categories of cereal intake with the 0 bowl/day as the reference group. Cox models were also employed to evaluate the potential impact of the addition of sugar, artificial sweeteners, milk, and dried fruit in breakfast cereals on mortality risk. Analyses were conducted using three models that adjusted for different sets of covariates: Model 1 adjusted for demographic variables; Model 2 also adjusted for body mass index (BMI) (kg/m^2), smoking status (never, sometimes, often), alcohol consumption (g/day), physical activity (MET min/week), dietary intake of various nutrients and substances; Model 3 also adjusted for medical history. In evaluating the impact of specific types of cereals on mortality, adjustments were also made for the intake of other cereal types to ensure a mutual correction among various cereals.

In addition, to investigate whether the correlations between the intake of different types of breakfast cereals and mortality risk differed by subgroups, we conducted stratified analysis by sex, age category (< 60 and > _60 years), BMI (< 30 kg/m2 and > 30 kg/m2), and TDI (Low (below median) and High (above median)), Physical activity (Low (below median) and High (above median)), alcohol consumption (Yes: >0 g/day and No: = 0 g/day), smoking status (Yes: sometimes/often and No: never), hypertension (Yes and No), and diabetes (Yes and No). To evaluate the robustness of our findings, several sensitivity analyses were conducted. We re-ran the models after removing participants with missing covariates, participants who died during the first 2 years of follow-up, those who reported consuming other starchy food (including pasta, rice, sushi, couscous, and other starchy food apart from breakfast cereal), participants who reported no intake of bread, and further adjusted for additional environmental covariates.

Results

Baseline characteristics

Table 1 presents the baseline characteristics of the participants. The mean age of participants was 55.6 years. The proportion of males and females was 44.5% and 55.5%, respectively. The mean TDI was − 1.58 and the mean BMI was 26.9 kg/m^2. Among 186,168 participants, 48,789 were non-breakfast cereal consumers, and 137,379 were breakfast cereal consumers. Breakfast cereal consumers were more likely to have higher income and higher

Table 1 Demographic and lifestyle characteristics of participants across different categories of breakfast cereal consumption in the UK biobank study

Characteristic	Total	Non-consumers	Consumers	*P*-value
Participants, n (%)	186,168	48,789	137,379	
Mean age (SD), y	55.58 (7.95)	54.31 (8.00)	56.04 (7.88)	< 0.001
Male sex, n (%)	82,863 (44.5)	22,251 (45.6)	60,612 (44.1)	< 0.001
Mean TDI (SD)	-1.58 (2.87)	-1.11 (3.06)	-1.74 (2.78)	< 0.001
White ethnicity, n (%)	168,914 (90.8)	42,522 (87.2)	126,392 (92.0)	< 0.001
College or university degree education, n (%)	80,352 (43.2)	20,291 (41.6)	60,061 (43.7)	< 0.001
Mean physical activity time, MET min/week (mean (SD))	2,498.87 (2,468.23)	2,470.60 (2,567.94)	2,508.86 (2,431.96)	0.007
BMI (SD)	26.88 (4.61)	27.47 (4.93)	26.67 (4.47)	< 0.001
Hypertension, n (%)	30,264 (16.9)	8803 (18.7)	21,461 (16.2)	< 0.001
Diabetes, n (%)	6855 (3.7)	1888 (3.9)	4967 (3.6)	0.010
High cholesterol, n (%)	20,948 (11.3)	5683 (11.6)	15,265 (11.1)	0.001
Family history of CVD, n (%)	103,047 (56.3)	25,981 (54.3)	77,066 (57.0)	< 0.001
Family history of cancer, n (%)	63,992 (34.9)	16,441 (34.4)	47,551 (35.1)	0.002
Long-standing illness, n (%)	49,155 (26.9)	13,396 (28.0)	35,759 (26.5)	< 0.001
Cholesterol-lowering drug use, n (%)	22,635 (12.2)	6019 (12.4)	16,616 (12.1)	0.130
Blood pressure drug use, n (%)	29,302 (15.8)	8139 (16.8)	21,163 (15.5)	< 0.001
Insulin drug use, n (%)	1374 (0.7)	342 (0.7)	1032 (0.8)	0.291
Smoking status, n (%)				< 0.001
Never	106,957 (57.6)	24,761 (50.9)	82,196 (60.0)	
Sometimes	64,054 (34.5)	17,352 (35.7)	46,702 (34.1)	
Often	14,669 (7.9)	6518 (13.4)	8151 (5.9)	
Alcohol, g/d (mean (SD))	16.25 (21.23)	20.77 (26.01)	14.65 (19.00)	< 0.001
Total energy intake, KJ/d (mean (SD))	8,853.61 (2,728.31)	8,545.72 (2,985.86)	8,962.96 (2,622.11)	< 0.001
Total fat intake, g/d (mean (SD))	73.34 (0.83)	73.35 (0.83)	73.34 (0.83)	0.520
Total sugar, g/d (mean (SD))	121.07 (52.30)	106.71 (54.86)	126.17 (50.39)	< 0.001
Vegetables, servings/d (mean (SD))	4.90 (3.28)	4.94 (3.61)	4.88 (3.16)	0.001
Fruit, servings/d (mean (SD))	3.09 (2.55)	2.61 (2.52)	3.26 (2.54)	< 0.001
Processed meat, servings/d (mean (SD))	1.82 (1.07)	1.91 (1.10)	1.78 (1.05)	< 0.001
Poultry, servings/d (mean (SD))	2.27 (0.91)	2.30 (0.92)	2.26 (0.91)	< 0.001
Red meat, servings/d (mean (SD))	3.60 (1.76)	3.68 (1.82)	3.57 (1.74)	< 0.001
Coffee consumption, n (%)	142,604 (76.6)	36,096 (74.0)	106,508 (77.5)	< 0.001
Tea consumption, n (%)	155,482 (83.5)	37,548 (77.0)	117,934 (85.8)	< 0.001
Milk consumption, n (%)	178,040 (95.7)	42,800 (87.9)	135,240 (98.5)	< 0.001
Vitamin supplements, n (%)	28,147 (15.1)	6993 (14.3)	21,154 (15.4)	< 0.001
Minerals supplements, n (%)	43,062 (23.1)	10,708 (21.9)	32,354 (23.6)	< 0.001

TDI = Townsend deprivation index; BMI = body mass index; CVD = cardiovascular disease; MET = metabolic equivalent of task

education levels with lower BMI, and higher energy intake. Non-breakfast cereal consumers were more likely to have hypertension, diabetes, and high cholesterol and had higher intakes of sugar, processed meat, and red meat.

Breakfast cereal consumption and mortality risks

During a median follow-up of 13.4 years, 9402 deaths were recorded (including 5073 cancer deaths and 1687 CVD deaths). The breakfast cereal consumption was correlated with lower all-cause and CVD-related mortality risks in our multivariable-adjusted models (Table S1). In Model 1, relative to non-consumers, breakfast cereal consumers exhibited reduced all-cause, cancer-specific, and CVD-specific mortality risks, with HRs (95% CI) of 0.82 (0.78–0.85), 0.85 (0.80–0.90) and 0.77 (0.70–0.86), respectively. After full adjustment (Model 3), the consumption of breakfast cereal was significantly correlated with reduced all-cause mortality [HR (95% CI): 0.91 (0.87–0.96)], and decreased CVD-specific mortality risk [HR (95% CI): 0.89 (0.79-1.00)]. The HR (95% CI) of cancer-specific mortality was 0.94 (0.88–1.01), though not statistically significant.

Furthermore, we illustrated the dose-response associations of specific breakfast cereal types consumption with all-cause, CVD-, and cancer-specific mortality risks by Cox models with cubic splines. Figure 2 exhibited the statistically significant U-shaped associations between bran cereal intake and all-cause mortality risk. There were similar correlations between sweetened cereal intake and

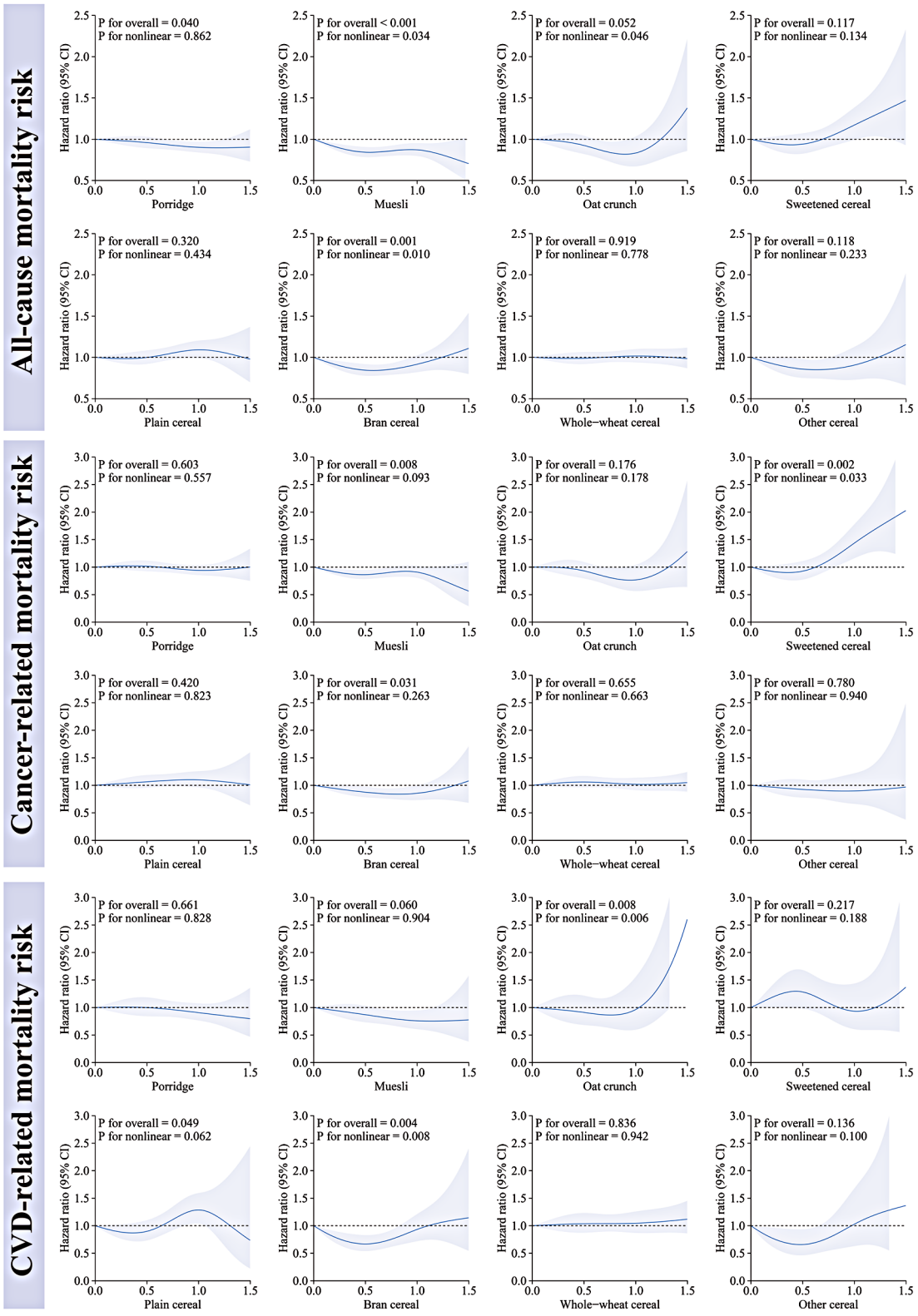

Fig. 2 Dose-response associations of different types of breakfast cereal consumption with all-cause, cancer, and CVD mortality

cancer-specific mortality risk. The analogous associations of the intake of bran cereal and oat crunch with CVD-related mortality risk were also detected (Fig. 2). Next, breakfast cereal consumers were categorized into different groups by different intake amounts. Concerning all-cause mortality, compared with non-consumers, the HRs (95%CI) for porridge consumers who consumed > 0 to 0.5, > 0.5 to 1, and > 1 bowls/day were 0.98 (0.92–1.05), 0.89 (0.84–0.96), and 1.08 (0.77–1.52), respectively. For muesli consumers, the HRs (95% CIs) were 0.89 (0.83–0.95), 0.85 (0.79–0.92), and 0.61(0.35–1.08), respectively. The HRs (95% CIs) of bran cereal consumers who consumed (> 0 to 0.5, > 0.5 to 1, > 1 bowls/d) were 0.88 (0.81–0.95), 0.88 (0.80–0.98), and 1.36 (0.80–2.29), respectively. The 95% CIs for plain cereal (a type of breakfast food made without added sugars, artificial colors, or preservatives), whole-wheat cereal, oat crunch, and sweetened cereal included 1 across all consumption levels, suggesting no significant correlations with all-cause mortality risks (Table 2). These findings indicated that the moderate consumption of porridge, muesli, and bran cereal was significantly correlated with lower all-cause mortality risk.

Concerning CVD-specific mortality, our results showed that the consumption of muesli (> 0.5 to 1 bowls/d), bran cereal (> 0 to 0.5 bowls/d), and other cereal types (> 0 to 0.5 bowls/d) was significantly correlated with reduced CVD-specific mortality risk, with the HRs (95% CIs) being 0.80 (0.66–0.98), 0.68 (0.55–0.83), and 0.65 (0.47–0.89), respectively. Conversely, the intake of plain cereal (> 0.5-1 bowls/d) might increase CVD-specific mortality risk [HRs (95%CI): 1.22 (1.00-1.50)] (Table 2). For cancer-specific mortality, our findings indicated that the moderate intake of muesli (> 0 to 0.5 > 0.5 to 1 bowls/d) significantly reduced the cancer-related mortality risk, with respective HRs of 0.90 (0.82–0.99) and 0.88 (0.79–0.98). The consumption of bran cereal (0.5 to 1 bowls/d) was also correlated with a decreased cancer-specific mortality risk [HRs (95%CI): 0.82 (0.71–0.95)]. In contrast, the intake of sweetened cereal (> 0.5 bowls/d) was significantly correlated with an increased cancer-specific mortality risk [HRs (95%CI): 1.41 (1.16–1.72)] (Table 2).

Additionally, we investigated the associations among breakfast cereal consumers who reported adding milk, sugar, artificial sweeteners, and dried fruit. Our findings revealed an inverse association between breakfast cereal consumption and all-cause, cancer-specific, and CVD-specific mortality risk among those who reported adding dried fruit to breakfast cereals, compared with non-consumers with the respective HRs (95% CI) of 0.86 (0.82, 0.91), 0.89 (0.83, 0.96), and 0.82 (0.72, 0.94), respectively. Consumers of breakfast cereals without adding sugar exhibited significantly lower all-cause, CVD-specific, and cancer-specific mortality risks, with the HRs (95% CI) being 0.89 (0.85–0.94), 0.86 (0.76–0.97), and 0.91 (0.85–0.98), respectively. Breakfast cereals consumers who did not add artificial sweeteners also exhibited significantly lower all-cause, CVD-specific, and cancer-specific mortality risks, with the HRs (95% CI) being 0.91 (0.87–0.96), 0.88(0.79–0.99), and 0.94 (0.88-1.00), respectively. Conversely, no significant associations were observed between consumers who reported adding sugar or artificial sweeteners into breakfast cereals and mortality risks, indicating that adding sugar or artificial sweeteners might impair the protective effects of breakfast cereal intake on health. The associations of breakfast cereal intake with lower all-cause mortality risk were not significantly influenced by added milk into breakfast cereals (Table 3).

Subgroup and sensitivity analysis

We further conducted several stratified analyses to assess the associations of breakfast cereal intake with all-cause and cause-specific mortality. Significant inverse associations between muesli intake and all-cause mortality risk were detected in participants aged over 60 years, females, non-smokers, individuals without diabetes, and those with BMI < 30 kg/m^2. We found stronger inverse associations between oat crunch intake and total mortality in the participants younger than 60 years and those without hypertension (P for interaction = 0.021 and 0.018 respectively). Oat crunch consumers who reported low exercise intensity also exhibited a decreased risk of total mortality. Consumers of sweetened breakfast cereals who reported consuming alcohol showed a higher risk of all-cause mortality (P for interaction = 0.039). Additionally, the HRs for all-cause mortality were higher in sweetened breakfast cereal consumers aged over 60 years than in sweetened breakfast cereal consumers aged below 60 years (P for interaction = 0.099) (Fig. 3). The stratified analyses for cause-specific mortality were presented in Figure S1-S2.

To confirm the robustness of the results, we conducted several sensitivity analyses (Table S2-S6). Excluding participants with missing covariates did not significantly alter the results. Similarly, when adjusting for additional environmental covariates, including exposure to PM2.5, PM2.5-10, PM10, inverse distance nearest major road, average sound level, and greenspace, the results remained stable. Moreover, we observed that the results changed slightly after excluding participants who died during the first 2 years of follow-up, those who reported consuming other starchy food, and participants who reported no intake of bread.

Discussion

In the present prospective study of the UK Biobank, we first and comprehensively evaluated the dose-dependent associations between the intake of different types of

Table 2 Dose-response association of specific types of breakfast cereals with all-cause and cause-specific mortality

	Exposure			All-cause mortality			CVD-specific mortality			Cancer-specific mortality		
		Person years	n (%)	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Porridge, bowls/d	0	1,898,306	141,808 (76.2)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	286,770	21,350 (11.5)	**0.91(0.85–0.97)**	0.98(0.91–1.05)	0.98(0.92–1.05)	0.90(0.76–1.06)	0.98(0.83–1.15)	0.98(0.83–1.16)	0.96(0.88–1.05)	1.02(0.93–1.12)	1.02(0.94–1.12)
	> 0.5-1	301,836	22,519 (12.1)	**0.81(0.76–0.87)**	**0.90(0.84–0.96)**	**0.89(0.84–0.96)**	**0.83(0.71–0.97)**	0.94(0.81–1.11)	0.95(0.81–1.11)	**0.84(0.77–0.92)**	0.93(0.85–1.02)	0.93(0.85–1.02)
	> 1	6500	491 (0.3)	0.99(0.71–1.39)	1.12(0.79–1.56)	1.08(0.77–1.52)	0.74(0.31–1.79)	0.83(0.34–2.01)	0.80(0.33–1.94)	1.05(0.66–1.66)	1.21(0.76–1.93)	1.19(0.75–1.90)
Muesli, bowls/d	0	1,937,705	144,888 (77.8)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	336,375	24,977 (13.4)	**0.79(0.74–0.85)**	**0.87(0.82–0.93)**	**0.89(0.83–0.95)**	**0.80(0.68–0.94)**	0.90(0.77–1.06)	0.93(0.80–1.10)	**0.82(0.75–0.89)**	**0.89(0.82–0.98)**	**0.90(0.82–0.98)**
	> 0.5-1	214,085	15,914 (8.5)	**0.74(0.68–0.80)**	**0.84(0.78–0.91)**	**0.85(0.79–0.92)**	**0.66(0.54–0.80)**	**0.78(0.64–0.95)**	**0.80(0.66–0.98)**	**0.77(0.69–0.86)**	**0.87(0.78–0.98)**	**0.88(0.79–0.98)**
	> 1	5246	389 (0.2)	**0.55(0.31–0.96)**	0.61(0.35–1.08)	0.61(0.35–1.08)	0.47(0.12–1.90)	0.54(0.13–2.17)	0.55(0.14–2.21)	0.44(0.18–1.06)	0.51(0.21–1.22)	0.51(0.21–1.23)
Plain cereal, bowls/d	0	2,156,410	160,978 (86.5)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	212,470	15,845 (8.5)	1.01(0.94–1.09)	1.04(0.97–1.13)	1.04(0.96–1.12)	0.89(0.74–1.07)	0.92(0.77–1.11)	0.92(0.76–1.11)	1.07(0.97–1.19)	1.10(1.00-1.21)	1.10(0.99–1.21)
	> 0.5-1	121,083	9089 (4.9)	1.01(0.93–1.11)	1.04(0.95–1.14)	1.04(0.95–1.14)	1.18(0.97–1.44)	1.21(0.99–1.48)	**1.22(1.00-1.50)**	1.01(0.89–1.15)	1.04(0.92–1.18)	1.04(0.92–1.19)
	> 1	3449	256 (0.1)	0.92(0.51–1.66)	0.93(0.52–1.69)	0.89(0.49–1.61)	0.47(0.07–3.34)	0.48(0.07–3.39)	0.48(0.07–3.39)	0.95(0.43–2.13)	0.99(0.45–2.21)	0.97(0.44–2.17)
Bran cereal, bowls/d	0	2,142,312	160,054 (86.0)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	231,751	17,204 (9.2)	**0.83(0.77–0.89)**	**0.87(0.81–0.94)**	**0.88(0.81–0.95)**	**0.63(0.52–0.77)**	**0.67(0.55–0.82)**	**0.68(0.55–0.83)**	**0.86(0.78–0.96)**	0.91(0.82–1.01)	0.91(0.82–1.01)
	> 0.5-1	116,866	8724 (4.7)	**0.82(0.74–0.90)**	**0.88(0.79–0.97)**	**0.88(0.80–0.98)**	0.85(0.68–1.08)	0.93(0.74–1.18)	0.94(0.75–1.19)	**0.76(0.66–0.88)**	**0.82(0.71–0.95)**	**0.82(0.71–0.95)**
	> 1	2482	186 (0.1)	1.34(0.79–2.26)	1.40(0.83–2.37)	1.36(0.80–2.29)	0.99(0.25–3.98)	1.01(0.25–4.03)	0.96(0.24–3.85)	1.66(0.86–3.19)	1.80(0.93–3.47)	1.77(0.92–3.41)
Whole wheat cereal, bowls/d	0	2,030,521	151,544 (81.4)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	249,814	18,631 (10.0)	0.97(0.91–1.05)	1.01(0.94–1.08)	1.00(0.94–1.08)	1.09(0.93–1.28)	1.13(0.96–1.33)	1.12(0.95–1.31)	1.00(0.91–1.10)	1.03(0.94–1.13)	1.03(0.94–1.13)
	> 0.5-1	190,546	14,304 (7.7)	0.99(0.92–1.07)	1.03(0.96–1.11)	1.02(0.95–1.10)	1.00(0.84–1.19)	1.05(0.89–1.25)	1.04(0.87–1.24)	1.01(0.91–1.12)	1.05(0.95–1.17)	1.05(0.95–1.16)
	> 1	22,531	1689 (0.9)	0.89(0.72–1.09)	0.91(0.75–1.12)	0.89(0.72–1.09)	1.20(0.80–1.81)	1.20(0.80–1.81)	1.17(0.78–1.76)	0.96(0.73–1.26)	1.00(0.76–1.31)	0.98(0.74–1.29)

Table 2 (continued)

	Exposure			All-cause mortality			CVD-specific mortality			Cancer-specific mortality		
		Person years	n (%)	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Oat crunch, bowls/d	0	2,328,852	173,943 (93.4)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	129,052	9586 (5.1)	**0.89(0.80–0.98)**	0.94(0.85–1.04)	0.95(0.86–1.06)	0.83(0.65–1.07)	0.90(0.70–1.15)	0.93(0.72–1.19)	0.90(0.78–1.03)	0.94(0.82–1.08)	0.95(0.83–1.08)
	> 0.5	35,508	2639 (1.4)	**0.78(0.64–0.95)**	**0.82(0.67-1.00)**	0.84(0.69–1.02)	0.86(0.56–1.33)	0.92(0.59–1.42)	0.97(0.63–1.50)	0.77(0.59–1.01)	0.81(0.62–1.07)	0.82(0.63–1.08)
Sweetened cereal, bowls/d	0	2,367,388	176,749 (94.9)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	90,448	6736 (3.6)	0.93(0.83–1.04)	0.92(0.82–1.03)	0.93(0.83–1.04)	1.25(0.99–1.59)	1.24(0.97–1.57)	1.26(0.99–1.60)	0.87(0.74–1.02)	0.86(0.73–1.01)	0.86(0.73–1.01)
	> 0.5	35,576	2683 (1.4)	**1.21(1.03–1.41)**	1.16(0.99–1.35)	1.15(0.98–1.34)	0.97(0.65–1.45)	0.94(0.63–1.40)	0.93(0.62–1.39)	**1.46(1.20–1.77)**	**1.42(1.16–1.72)**	**1.41(1.16–1.72)**
Other cereal, bowls/d	0	2,373,095	177,232 (95.2)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)	1.00(Reference)
	> 0-0.5	93,133	6914 (3.7)	**0.84(0.75–0.95)**	**0.88(0.79–0.99)**	**0.87(0.78–0.98)**	**0.62(0.46–0.86)**	**0.65(0.48–0.90)**	**0.65(0.47–0.89)**	0.90(0.78–1.04)	0.94(0.81–1.09)	0.94(0.81–1.09)
	> 0.5	27,183	2022 (1.1)	0.86(0.70–1.04)	0.90(0.74–1.10)	0.88(0.72–1.07)	0.94(0.60–1.46)	1.00(0.64–1.55)	0.97(0.62–1.51)	0.83(0.63–1.09)	0.89(0.68–1.16)	0.88(0.67–1.15)

Model 1: adjusted for sex, age, Townsend deprivation index (TDI), ethnicity, and education. Model 2: Model 1 also adjusted for smoking status, alcohol consumption, physical activity, BMI, total intake of energy, fat and sugar, red meat, vegetable, fruit, starchy food, bread, milk, coffee, tea, vitamins and minerals. Model 3: Model 2 also adjusted for hypertension, diabetes, high cholesterol, the use of cholesterol drugs, hypertension drugs, insulin drugs, and long stand illnesses

Table 3 Associations of breakfast cereals with risk of all causes and cause-specific mortality stratified by added sugar, artificial sweetener, milk, and dried fruit

Outcome	None-consumer	Breakfast cereal consumer	
		Add	Not add
All-cause mortality			
Sugar	1(reference)	0.96(0.91–1.02)	**0.89(0.85–0.94)**
Artificial sweetener	1(reference)	0.92(0.83–1.02)	**0.91(0.87–0.96)**
Milk	1(reference)	**0.91(0.87–0.96)**	**0.89(0.82–0.97)**
Dried fruit	1(reference)	**0.86(0.82–0.91)**	0.95(0.90-1.00)
CVD cause mortality			
Sugar	1(reference)	0.98(0.85–1.13)	**0.86(0.76–0.97)**
Artificial sweetener	1(reference)	0.96(0.75–1.21)	**0.88(0.79–0.99)**
Milk	1(reference)	0.90(0.80–1.01)	0.83(0.68-1.00)
Dried fruit	1(reference)	**0.82(0.72–0.94)**	0.95(0.84–1.07)
Cancer cause mortality			
Sugar	1(reference)	1.02(0.94–1.11)	**0.91(0.85–0.98)**
Artificial sweetener	1(reference)	1.00(0.86–1.15)	**0.94(0.88-1.00)**
Milk	1(reference)	0.94(0.88–1.01)	0.94(0.84–1.05)
Dried fruit	1(reference)	**0.89(0.83–0.96)**	0.99(0.92–1.06)

Model adjusted for sex, age, Townsend deprivation index (TDI), ethnicity, education, smoking status, alcohol consumption, physical activity, BMI, total intake of energy, fat and sugar, red meat, vegetable, fruit, starchy food, bread, milk, coffee, tea, vitamin and minerals, hypertension, diabetes, high cholesterol, cholesterol drug, hypertension drug, insulin drug and long stand illness

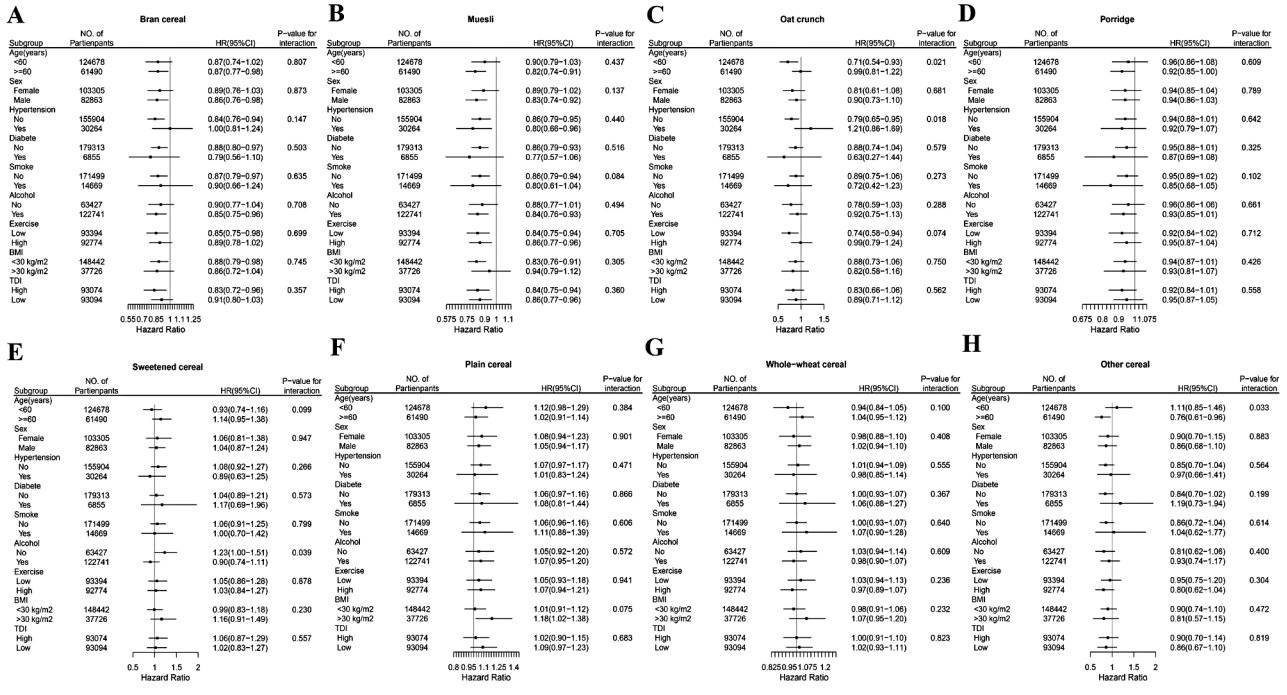

Fig. 3 The stratified analyses of associations between (**A**) bran cereal, (**B**) muesli, (**C**) oat crunch, (**D**) porridge, (**E**) sweetened cereal, (**F**) plain cereal, (**G**) whole-wheat cereal, and (**H**) others consumption with all-cause mortality

breakfast cereal and mortality risks. Our findings indicated that moderate bran cereal consumption was correlated with a U-shaped low risk for all-cause CVD-specific, and cancer-specific mortality risks. The moderate consumption of muesli was also significantly correlated with reduced all-cause, CVD-specific, and cancer-specific mortality risks, and there were also inverse associations between porridge consumption and all-cause mortality risk. The intake of sweetened cereal was strongly correlated with increased cancer-specific mortality risks. Consumers who reported adding dried fruit to breakfast cereals had a significantly reduced all-cause, CVD- and cancer-specific mortality risk. There was also an inverse association between consumers who reported added milk

into breakfast cereals and all-cause mortality risk. Breakfast cereal consumers without adding sugar or artificial sweeteners had a lower mortality risk, and such association was impaired in consumers adding sugar or artificial sweeteners in breakfast cereals. These findings suggest that moderate consumption of bran cereal, muesli, and porridge can be an indicator of a normal and healthy lifestyle for preventing premature mortality. On the contrary, sweetened breakfast cereals should be discouraged and not be promoted as a choice for breakfast cereal consumption. Besides, adding milk and dried fruits, rather than sugar and artificial sweeteners into breakfast cereals, may be recommended to reduce mortality risk.

Several previous studies have investigated the associations between breakfast cereal consumption and mortality risk. For instance, a previous meta-analysis of prospective studies has reported that the consumption of whole-grain bread, whole-grain breakfast cereals, total breakfast cereals pasta, and total bread was significantly correlated with all-cause mortality risk [21]. A cohort study of 86,190 US males has found that whole-grain breakfast cereal consumption was inversely associated with all-cause and CVD-related mortality risk, while no significant associations were detected between the consumption of total and refined breakfast cereals [22]. A systematic meta-analysis has demonstrated that the consumption of breakfast cereals was associated with a lower total mortality risk (relative risk (RR): 0.88, 95% CI: 0.83–0.92) [14]. There were also significant associations between whole-grain breakfast cereals consumption and reduced total mortality, CHD-specific, stroke-specific, and cancer-specific mortality risks among 7,839 participants in the Scandinavian HELGA cohort [23]. These findings indicated the associations between breakfast cereals intake and mortality risks are still inconsistent and controversial. Notably, breakfast cereals consist of multiple types, such as bran cereal, whole-wheat cereal, and sweetened cereal, however, limited evidence has distinguished different breakfast cereal types and investigated their associations with health outcomes. Hence, illustrating the associations of specific breakfast cereal type consumption with mortality risks in prospective cohort studies is of great importance. In the present analysis, breakfast consumers were classified into the consumers of bran cereal, plain cereal, whole-wheat cereal, muesli, oat crunch, sweetened cereal, and other cereal types. Our findings indicated that the moderate intake of muesli and bran cereal was significantly associated with reduced total and cause-specific mortality risks, and U-shaped associations of bran cereal consumption with mortality risk were detected. Bran cereals and muesli are critical grains in the Western diet. A Mendelian randomization study has reported that the intake of muesli was associated with a lower risk of migraine [24]. It has been reported that the consumption of muesli correlates with a low risk of multiple CVD types, including coronary heart disease, myocardial infarction, heart failure, ischemic stroke, large artery stroke, and small-vessel stroke [25]. A systematic review and meta-analysis investigation has demonstrated that cereal bran consumption was inversely associated with multiple CVD risk factors, such as blood pressure, total cholesterol, and low-density lipoprotein cholesterol, thus suggesting that bran cereal consumption may provide benefits in terms of CVD risk [26]. These findings indicate the benefits of muesli and bran cereal intake on cardiovascular health, but no available data has focused on their effects on preventing premature mortality. Our findings indicated that potential beneficial effects are seen mostly with moderate bran cereal intake whereas such effects were significantly impaired with high intake, which produces the observed U-shaped association with mortality. Despite health warnings, the consumption of sugar remains high in many regions, and the growing consumption of sugar or sweeteners has become a severe public health problem. Multiple studies have investigated the effects of sweetened food and beverages and sugar intake from diet on human health and diseases. For instance, a Mendelian randomization analysis has reported that the intake of artificial sweeteners from coffee, tea, and cereal was positively associated with type 2 diabetes mellitus [27]. However, the associations between sweetened cereals and mortality risks have not been illustrated yet. Our study showed that the intake of sweetened cereals was connected with a higher risk of cancer-related mortality, suggesting that public health efforts should be exerted to prioritize the reduction of sweetened cereals consumption.

Several mechanisms may explain the benefits of these specific breakfast cereal types in reducing mortality risks. The high fibre content in breakfast cereals can help reduce the postprandial glucose and insulin responses, thus reducing the risk of multiple metabolic diseases, such as obesity and type 2 diabetes, which are acknowledged risk factors for malignancies, CVD, and premature mortality [28, 29]. In addition, diet fibre can reduce the level of low-density lipoprotein cholesterol, which is an important risk factor for CVD [30]. Consuming fibre, especially soluble fibre, may lower cholesterol levels by inhibiting bile acid reabsorption and bacterial fermentation in the colon. This fermentation leads to the production of short-chain fatty acids that inhibit cholesterol synthesis in the liver [31, 32]. For cancer-related mortality, dietary fibre can decrease cancer risk by removing damaged cells from the digestive tract mechanically, increasing stool bulk, diluting carcinogens, reducing transit time, influencing gut microbiota, and binding with estrogens in the colon to enhance their fecal excretion, lowering estrogen levels [33]. Furthermore, various

bioactive compounds and nutrients in breakfast cereals may also enhance immunity and anti-inflammation capability and are beneficial for human-positive nutrition [34, 35].

Moreover, we also addressed the addition of milk, sugar, artificial sweeteners, and dried fruits in breakfast cereals. Compared with non-consumers, the consumers of breakfast cereals without adding sugar and artificial sweeteners had significantly lower all-cause and CVD-specific mortality risks. No inverse associations between breakfast cereals intake and all-cause and cause-specific mortality risk were detected among those we reported added sugar or artificial sweeteners. These findings suggest that sugar and sweeteners added to breakfast cereals may impair the health benefits of breakfast cereal consumption. Furthermore, breakfast cereals consumers who added dried fruit had a significantly lower mortality risk from all causes, cancer, and CVD. Dried fruits are nutrient-rich and a good source of bioactive substances/phytochemicals [36, 37]. Epidemiological evidence suggests that dried fruit intake is correlated with a reduced risk of CVD, type 2 diabetes, various cancers, and other chronic diseases [37, 38]. For instance, a significant decrease (65%, $P = 0.009$) in pancreatic cancer-specific mortality risk was observed in participants reporting the intake of ≥ 3 servings of dried fruit per week, compared to low-consumers or non-consumers in the California AHS [39]. In addition, consumers who reported adding milk to breakfast cereals also had a significantly lower all-cause mortality risk. These findings indicated that breakfast cereals with dried fruit and milk can be consumed. On the other hand, the sugar or sweeteners added to breakfast cereals may have harmful effects and should be consumed cautiously.

Strength and limitations

The present study demonstrates several notable strengths, including its prospective design, a large sample size, and comprehensive information on breakfast cereal. The detailed data collection process enabled the inclusion of various types of breakfast cereal that are often overlooked in other studies, such as porridge, muesli, bran cereal, and whole-wheat cereal. In addition, the common addition of sugar, artificial sweeteners, milk, and dried fruits to breakfast cereal, was also taken into consideration.

However, it is important to acknowledge the potential limitations of our study. First, due to the observational nature of the research, the presence of residual confounding cannot be completely ruled out. Second, it is worth noting that the UK Biobank sample may not be entirely representative of the general population, as the existence of a "healthy volunteer" bias has been observed. Nevertheless, representative population sampling is not an absolute requirement for valid exposure-disease relationship assessments. Self-reported exposures assessed by the 24-hour diet recall questionnaires were subject to inevitable measurement error and recall bias, although the questionnaire has been validated. Participants might have misunderstood the volume of breakfast cereals they consumed, leading to inaccuracies in reporting. Additionally, baseline measurements of exposure may not capture changes in breakfast cereal consumption over time. The 24-hour dietary recall approach inherently limits our ability to capture variations in dietary habits over time, as it does not account for day-to-day fluctuations or longer-term dietary patterns. In contrast, a more comprehensive method, such as a 7-day dietary recall or a food frequency questionnaire, would provide a broader perspective on participants' usual dietary intake and help to mitigate these limitations. Participants may change the breakfast cereal types they consume. It is important to note that dietary habits and food composition can change over time, and accurate measurement of dietary intake presents challenges in epidemiological studies. Measurement errors in dietary assessments can compromise the identification of associations between dietary factors and disease occurrence. While efforts are being made to refine dietary assessment methods and reduce measurement errors (e.g., collecting multiple 24-hour recall surveys), it is unlikely to completely eliminate measurement errors from dietary assessment.

Conclusions

In conclusion, our results provide further evidence for the beneficial effects of the moderate consumption of muesli, bran cereal, and porridge on reducing mortality risks, and the intake of sweetened cereal was correlated with a higher risk of mortality. Adding dried fruits and milk to breakfast cereals may be recommended as a healthy diet. These findings, if confirmed by future studies, support dietary recommendations to increase the intake of specific breakfast cereal types for better health outcomes.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-025-01109-5.

Supplementary Material 1
Supplementary Material 2
Supplementary Material 3
Supplementary Material 4
Supplementary Material 5
Supplementary Material 6
Supplementary Material 7
Supplementary Material 8

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Author contributions
ZJ L, and M Z contributed to the study design. M Z and ZJ S analyzed data. YL W, ZJ L, and M Z wrote the first draft of the manuscript and edited the manuscript. H Z and T L contributed to the review and revision of the manuscript. All authors read and approved the final manuscript. ZJ L, and M Zcontributed equally to this work.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The UK Biobank received full ethical approval from the NHS National Research Ethics Service (16/NW/0274). All participants gave written informed consent before recruitment.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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