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Modelling the public health benefits of fibre fortification in the Chinese population through food reformulation

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ABSTRACT

Objectives Various studies have highlighted how consuming adequate dietary fibre (DF) foods could confer multiple potential health benefits to humans, though data suggested that the average intake of the population is below the recommendations. The aim of this study, which involved probabilistic, mathematical and statistical modelling, was to understand, for the first time, how fibre fortification in a broad array of food categories could impact the diet and health status of Chinese consumers.

Design A simulation-based approach was used to examine the potential impact of fibre fortification. The China Health and Nutrition Survey dataset was used to evaluate intakes of DF together with a dietary intake mathematical model. Commercially manufactured foods and beverages eligible for fibre fortification were identified and a total of 296 food and beverages were selected for fibre fortification calculation. Foods and beverages eligible for fibre fortification and the concentration of fibre used at intervention were identified based on Chinese legislations and regulations of nutrition label claims. Populations who meet the dietary reference values of fibre fortification have their health outcomes such as weight, cardiovascular disease (CVD) and type 2 diabetes risk quantified prefibre and postfibre reformulation as per published studies.

Results The simulated fibre fortification intervention model has shown that the mean DF intake increased by 13.28%, from 12.8 g/day of baseline to 14.5 g/day, leading to an increase of 48% (from 6.85% to 10.13%) and 54% (from 14.22% to 21.84%) of the adult and children population, respectively, achieving the recommended fibre guidelines. Additionally, 234 diabetes cases per day (85 340 cases per year) as well as 73 065 deaths secondary to CVD could also potentially be averted or delayed with the increase of DF intake via fibre fortification.

Conclusions This study provides a practical application implicating the potential public health benefits that could be achieved with food product reformulation.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is the first modelling study exploring the public health effects of fibre fortification in China.
⇒ Data from the China Health and Nutrition Survey, the most recent up-to-date published dataset that surveyed 15 135 individuals aged 1–101 years in nine provinces of China, was analysed to express the effects of the food reformulation in terms of a real-world impact.
⇒ Chinese regulations related to nutrition labelling claims were implemented in the simulation.
⇒ The algorithms used in this study were mostly based on adult populations, hence the public health benefits of the intervention could only be applied to adult subjects.
⇒ As the explored health outcomes were mutually exclusive, the study could not consider the influence of time.

INTRODUCTION

A plethora of studies have highlighted how consuming high dietary fibre (DF) foods could confer multiple potential health benefits to humans.[1] A series of systematic reviews and meta-analyses commissioned by the WHO to establish evidence base guidance for DF recommendations found that compared with a low-fibre diet (15–19 g/day), a high-fibre diet (25–29 g) reduces the risk of coronary heart disease (17%–31%), type 2 diabetes (10%–22%), colorectal cancer (11%–22%), body weight, cholesterol and blood pressure.[2]

Considering these potential health benefits of high DF intake, most countries, as well as the WHO, have provided recommendations of daily fibre intake in the range of 25–35 g for adults and less for children and older adults, depending on age.[3] However, the average daily fibre intakes of most countries are well below these recommended amounts. The daily total DF intake of Chinese residents was reported as only 9.7 g, while the recommendation of daily fibre intake of the Chinese Nutrition Society for adults is set at 25–30 g/day.[4 5]

To address dietary needs, nutritional fortification has been suggested in China as a primary measure of nutritional intervention, which plays a role in improving the nutritional status of the population.[6] Around the world, food reformulation, the process of altering foods and beverages to change their nutritional composition between two time points, has been proposed as one potential way for fibre fortification.[7 8] Moreover, fortifying foods with DF helps to increase fibre intakes while maintaining calories at recommended levels.[9 10] Modelling studies in both the UK and the USA have shown how reformulating foods by fortifying fibre results in clear health benefits.[10 11] To our knowledge, a study of this kind is still missing in China.

Commercial benefits could also derive from food reformulation, making it appealing to food industries for the possibility of making claims, marketing to a new audience of consumers, increasing sales and prices by rejuvenating, extending a product line or adding premium ingredients.[10] There are different reasons for reformulating foods, and it is carried out with the aim of improving the nutritional profile of foods while having a positive impact on the health of the consumers.

To better address, and study in-depth, one of the different options that can be implemented to achieve a significant increase in fibre intake in China, we conducted a statistical modelling study to understand how fibre fortification in a broader array of food categories can impact the diet and health status of consumers. A dietary exposure model built by Creme Global was used.[12] The food categories for fibre fortification were identified as referring to a previous UK study.[10] Using these selected food categories, nutritional composition changes were implemented and related nutritional intake outcomes were also assessed. Comparisons were made against the baseline diet (representing the market pre-reformulation) and the results were measured for their impact on health outcomes. For the latter part, algorithmic methods of measuring potential health impacts from dietary changes were sourced from literature.

The objective of this study, which involved probabilistic, mathematical and statistical modelling, was to understand how fibre fortification in a broad array of food categories could impact the diet and health status of Chinese consumers.

METHODS

No human participants were recruited as this is a modelling study, where a simulation-based approach was used to examine the potential impact of fibre fortification, so that ethical approval and consent to participate are not applicable to the current investigation.

Data sources

The data for the calculation were from the China Health and Nutrition Survey (CHNS) conducted between the Carolina Population Center at the University of North Carolina at Chapel Hill and the National Institute of Nutrition and Health of the Chinese Center for Disease Control and Prevention. The CHNS 2011 is the most recent up-to-date dataset published for public use, which was conducted over a 3-day period using a multistage, random cluster process to draw a sample of 15 135 individuals aged 1–101 years in nine provinces of China.[13] This sample is representative of the Chinese population in terms of geographical location, economic development, public resources and health indicators. A subset of this cohort representing ‘consumer only’ of the relevant food group was created in each assessment scenario. All summary statistics and the results generated from the Creme Food Data Science Model[12] were statistically weighted for age and gender. Weightings allowed the survey to be more representative of the total population in China for the year that the survey was carried out. If it was discovered that an age group in the subjects table was oversampled compared with the proportion of the overall population for the same age group, the weighting would be below 1. If the subjects were undersampled, the weighting would be above 1.

Food diaries, nutritional composition and recategorisation

Three-day food diaries are available for each subject in the CHNS dataset, which lists foods and beverages by name and quantity consumed. The nutritional information for each food and beverage was obtained from the complementary China Food Composition Tables.[14] ‘Dietary Fibre-Total’ contained in the CHNS dataset was selected to be used to model the fibre fortification in this study. This definition included all fibre types, both intrinsic and added fibres.[14]

Commercially prepared foods and beverages eligible for fibre fortification were identified, and some exclusions were applied. In particular, we included bakery products including but not limited to bread, rolls, breakfast cereals, cakes and biscuits; convenience fast food products; flavoured dairy and non-dairy products such as milk, milk powders, yoghurts and ice cream; sauces and dressings which would be considered low in fibre including fermented sauces, pastes and curds; legume products; while excluding 100% fruit and vegetable juices, nectars, juice drinks and soft drinks; foods which would be considered a traditional commodity such as milk, grains or cheese; coffee, tea and infusions; sugar confectionery; canned soups and powdered soups and sauces to be reconstituted; and composite dishes (foods containing several ingredients). This selection was made so that the results could be comparable with a previous similar modelling study,[10] presence (or absence) on the local market of fibre-fortified products belonging to the different categories, ease and applicability of reformulation at the simulated fortified levels, according also to local regulations and legislations, as described below.

Accordingly, food groups available in the CHNS 2011 were regrouped into the following food groups: beverages, bakery, dairy, soups, sauces, dressings and convenience. As these are relatively commonly consumed and broad categories, we confirmed that there were no small numbers of observations for any groups included in the reformulation modelling, as such could produce unstable estimates with very large CIs. Where an original food group in the CHNS was deemed to not match with any of the project food groups, the original food group in the CHNS was listed as 'Other'. Within the original food group in the CHNS called 'MISCELLANEOUS' foods/beverages were individually assessed based on their food names and placed in project food groups or 'Other'.

Baseline intakes

Creme Global's dietary intake model,[12] 'Expert Model Food Data Science', was applied for the baseline assessment with CHNS Dietary Survey data including subject information, food diary information and nutritional information of the foods (the nutrient values per 100 g of food/beverage of total DF and energy in kcal) as model inputs. Nutrient intake was calculated as follows:

(Weight of food/beverage (g) consumed)*(Nutrient content in that food or beverage (g/100 g))

The total nutrient intakes were summed up with all consumptions during these 3 days per person, per nutrient. These values were divided by 3 to get an average daily nutrient intake over the 3-day survey period per person.

Intervention intakes

Commercially manufactured foods and beverages eligible for fibre fortification were identified and some exclusions were applied, as referring to our previous UK study and in total 296 food and beverages were recognised for fibre fortification. As per the terminology of 'fibre', we refer to carbohydrates with three or more monomeric units which are not hydrolysed by the endogenous enzymes in the small intestine of humans, as multiple such definitions of fibres include both naturally occurring in the food as consumed and isolated fibres added to foods.[15,16]

The Chinese regulation of nutrition label claims[17] was referred to for the fibre concentration used for intervention: foods or beverages labelled as a 'source of fibre' need to contain ≥3 g/100 g (solid) or 1.5 g/100 mL (liquid), while foods or beverages labelled as 'high fibre' are required to contain ≥6 g/100 g (solid) or 3 g/100 mL (liquid), respectively. The altered fibre concentration was calculated in different ways depending on the existing fibre concentration of the food, as well as whether it was a food or beverage, as follows:

- Foods containing <3 g fibre/100 g: increased fibre content to 3 g/100 g.
- Foods containing ≥3 g fibre/100 g: additional 3 g fibre was added. This decision was informed by the nutrition claims regulation,[17] which designates foods labelled 'high fibre' as those containing ≥6 g/100 g. As a conservative approach, we chose to add 3 g fibre.
- Beverages containing <1.5 g fibre/100 mL: increased fibre content to 1.5 g/100 mL.
- Foods/beverages containing 0 g fibre/100 g or 100 mL: kept at 0.

Creation of distributions

Market shares (MSs) were used to assign probabilities to foods with altered fibre content being consumed. Two MSs were assumed: a 'conservative' 50% scenario and a 'best-case' 100% scenario. These scenarios represent the probability of a food item being eaten 50% or 100% of the time for each individual eating event, respectively. This was done via the creation of a distribution, with the altered fibre concentrations being assigned a MS of 50% or 100%, respectively. In the 50% scenario, three iterations of each assessment were conducted so that each eating event was simulated three different times. Iterations increase the sampling times of each subject during an assessment, resulting in a more accurate representation of the population distribution. It helps reduce the variability in probabilistic assessments between rerun, which helps to improve the reproducibility of results. Three iterations were chosen after running multiple assessments and noticing that this number yielded to the stabilisation (ie, when the mean and P95 approached the numerical value of each other as an increase in iteration is carried out) of the mean and P95. In addition to the total population and food consumers (people who consume at least one food or beverage from a given food category), stratification of the population was done by residential location and age for closer examination of population subsets.

Dietary reference values

Dietary reference values (DRVs) of total DF intake for adults, namely ≥ 25 g/day, were obtained from Dietary Reference Intakes for Chinese 2013 published by the Chinese Nutrition Society.[5] For children, a daily requirement of age plus 5 g of DF per day was used, referring to previous literature.[18]

The number and percentage of subjects within the population that meet DRVs were quantified at both baseline and intervention. Adults and children meeting the DRV for fibre were quantified, and the population was broken down into age-based subpopulations, urban versus rural subpopulations as well as total population.

Health outcomes

A postanalysis step was conducted using health outcome-based algorithms to express the effects of the food reformulation in terms of a real-world impact. Algorithms were applied to the baseline and intervention intake results for fibre fortification. The time frame used in this project was not a fixed period and therefore did not consider the influence of time on some health outcomes.

Cardiovascular health (cardiovascular disease (CVD))

The CVD risk value was estimated through a multistep process. First, a CVD risk value was calculated using the algorithm sourced from the D'Agostino study[19] which naturally logarithmically transformed covariates such as age, total cholesterol, high-density lipoprotein cholesterol, systolic blood pressure, antihypertensive medication use, current smoking and diabetes status to improve discrimination and calibration of the model and to minimise the influence of extreme observations. Where subjects' blood pressure value or diabetic status was not recorded, it was assumed the subject was not in these medical situations. Then, a polynomial regression was fitted using data from the *Reynolds* study,[4] from which a CVD reduction value was calculated for each subject. The reduction was applied to subjects who achieved an increase in fibre consumption at intervention from baseline and consumed more than 15 g of fibre and less than 35 g of fibre at intervention, based on previous studies[2,10] but also taking into account that 30–35 g/day are among the highest DF recommendations around the world[3] that have also been shown to provide a series of health benefits,[2] compared with low-fibre diets.

CVD mortality

The impacts on CVD mortality were quantified using the 'Preventable Risk Integrated Model' (PRIME), an openly available modelling tool.[20,21] The only difference between baseline and counterfactual distribution data was the fibre intake. A Monte Carlo simulation of 10 000 iterations was used to generate 95% credible intervals for the estimate of deaths delayed or averted under the counterfactual scenario. This model was used to estimate the potential number of deaths from CVD that could be averted or delayed by increasing daily fibre intake of Chinese residents.

Type 2 diabetes

The QDiabetes algorithm[22] was used as the first part of a two-step process to estimate the impacts of fibre fortification on type 2 diabetes risk. A simple linear regression was fitted using data from the Reynolds study.[4] A type 2 diabetes risk reduction score was calculated and applied to subjects who achieved an increase in fibre consumption at intervention and consumed more than 15 g of fibre and less than 35 g of fibre at intervention, based on previous studies[2,10] but also taking into account that 30–35 g/day are among the highest DF recommendations around the world[3] that have also been shown to provide a series of health benefits,[2] compared with low-fibre diets. The QDiabetes algorithm had specific parameters, as such, a subset of the survey population was selected to fit within these parameters to calculate the resulting p values. In particular, age was required to be greater than 24 years and less than 85 years, and only subjects with defined ethnicity, smoking status, height and body weight were chosen. Where subjects' blood pressure medication value was not recorded, it was assumed the subjects were not on blood pressure medication as it was presumed subjects on blood pressure medication would be at lower risk of type 2 diabetes.

Patient and public involvement

No patients were involved.

RESULTS

Both 50% MS and 100% MS intervention scenarios were assessed with this modelling study. To ensure the readability of the manuscript, we report here only results obtained with the 'conservative' 50% scenario, while all the results related to the 'best-case' 100% MS intervention results could be found in subsequent online supplemental materials.

Fibre baseline intakes

Based on the preintervention nutrient intake assessment, the mean fibre intake in the Chinese population was 12.8±0.1 g/day from all foods (table 1). The mean fibre intake from diets ranged from 9.14±0.15 g/day in children and adolescents (1–17 years) to 13.38±0.1 g/day in adults (18+) (table 1). In the total population, only 6.85% of subjects aged 18+ achieved the DRV of ≥25 g fibre intake per day. After dividing the total population into rural and urban residents, 7% of subjects aged 18+ in the

Table 1 Baseline and 50% MS intervention dietary fibre intakes (g/day) and percentages of change (numbers; mean values±SEMs; percentages)*

			Baseline (g/day)		50% MS intervention (g/day)		% Change in fibre intake	
	Age (years)	n	Mean	P95	Mean	P95	Mean	P95
Urban	1–17	823	9.44±0.22	21.8±0.83	11.74±0.25	25.85±0.19	24.36%±3.93	18.58%
	18+	5422	13.47±0.17	26.71±0.41	15.43±0.19	29.8±0.08	14.55%±2.02	11.57%
	Total	6280	12.92±0.14	26.19±0.35	14.93±0.17	29.36±0.08	15.56%±1.82	12.10%
Rural	1–17	1343	8.95±0.22	21.08±1.06	10.29±0.21	23.84±0.13	14.97%±3.67	13.09%
	18+	7475	13.31±0.11	27.49±0.33	14.91±0.12	30.82±0.07	12.02%±1.29	12.11%
	Total	8855	12.64±0.09	26.87±0.35	14.21±0.11	29.89±0.07	12.42%±1.18	11.24%
Both	1–17	2166	9.14±0.15	21.36±0.67	10.81±0.17	24.8±0.11	18.16%±2.69	16.10%
	18+	12 897	13.38±0.1	27.18±0.32	15.13±0.11	30.33±0.05	13.08%±1.18	11.59%
	Total	15 135	12.8±0.1	26.6±0.3	14.5±0.09	29.72±0.05	13.28%±1.13	11.73%

*n=sample size, P5 = 5th percentile, P95 = 95th percentile; CHNS sampling weights have been applied to all estimated results.
CHNS, China Health and Nutrition Survey; MS, market share.

Table 2 Population meeting fibre DRV at baseline and 50% MS intervention*

Population	Total dietary fibre of DRV	Subpopulation	Age group	Baseline (%)	50% MS intervention (%)	% Change
Total	≥xg/day (x=age +5)	Children	2–17	14.22	21.84	+53.59
	≥25 g/day	Adults	18+	6.85	10.13	+47.88
Urban	≥xg/day (x=age +5)	Children	2–17	15.92	27.95	+75.57
	≥25 g/day	Adults	18+	6.64	9.97	+50.16
Rural	≥xg/day (x=age +5)	Children	2–17	13.18	18.62	+41.27
	≥25 g/day	Adults	18+	7.00	10.27	+46.71

*CHNS sampling weights have been applied to all estimated results.
CHNS, China Health and Nutrition Survey; DRV, dietary reference value; MS, market share.

rural population achieved the DRV, whereas only 6.64% of subjects aged 18+ in the urban population achieved the DRV (table 2).

Fibre fortification intervention intake assessment

As a result of the fibre fortification intervention, the mean fibre intake in the population rose to 14.5±0.09 g/day postintervention, signifying a 1.7 g fibre/day (13.28%) increase from the baseline diet (table 1). The overall mean fibre increase achieved by urban and rural residents was 2.01 g/day (15.56%) and 1.57 g/day (12.42%), respectively (table 1). Adults (18+) achieved a 13.08% increase from their baseline diet, with a mean intake of 15.13±0.11 g/day postintervention. Children aged 1–17 years achieved a 1.66 g/day increase from the baseline, with a mean intake of 10.81±0.17 g/day postintervention and signifying an 18.16% increase (table 1). The greatest increase in fibre intake from a single food category was observed in dairy and dairy alternatives across all ages, demonstrating a 181.13% increase from a contribution of 0.53±0.02 g/day to 1.49±0.02 g/day to the total fibre intake at intervention. Adults in the total population achieving the DRV of fibre rose from 6.85% at baseline to 10.13%, signifying a 47.88% increase. Children aged 2–17 years in the total population achieving their relative DRV of fibre rose from 14.22% at baseline to 21.84%, signifying a 53.59% increase (table 2).

Fibre consumption and cardiovascular risk

A reduction in CVD risk was observed postfibre fortification intervention. At baseline, the mean risk in the Chinese population was observed to be 22.85% likelihood of CVD within the next 10 years, with a reduction to 22.23%. The range dropped from 15.68% to 26.73% at baseline to 12.2% to 26.68% postintervention ($p \leq 0.05$). Postintervention, the mean and median CVD risk reduced by 2.74% and 1.39% from baseline, respectively ($p \leq 0.05$). The reduction in both the mean and median suggests an overall decrease in the population's risk of CVD. The greatest reductions in CVD risk were observed at the lower percentiles, mainly P5–P50, compared with baseline. Figure 1 shows how 50% of people with a CVD risk value of approximately 22.93% experienced the greatest benefit from fibre fortification in the diet postfibre fortification intervention. After the intervention, there is a significant shift towards lower-risk values, with a greater number of subjects having a reduced risk of CVD in the next 10 years. The observed shift results in a bimodal distribution of CVD risk, with approximately 20% of the population having a baseline risk of 23% chance of CVD in the next 10 years reducing to approximately 19.5%. Reynolds reports a non-linear relationship between fibre intake and CVD risk, and this non-linearity is reflected in the bimodal risk distribution seen after the intervention.[4]

Fibre consumption and CVD mortality

The results of our modelling suggest that a fibre fortification intervention could also help avert or delay a mean of 73 065 deaths due to CVD (2.1% of total deaths due to CVD) in male and female adolescents and adults (15+), compared with the baseline (Wilcoxon signed-rank test, $p \leq 0.05$). In particular, a mean of 38 961 (1.95%) deaths by coronary heart disease, and 34 035 (1.6%) by stroke could have been averted or delayed, compared with baseline.

Fibre consumption and type 2 diabetes

A slight reduction in type 2 diabetes risk was observed in the fibre fortification scenario when compared against

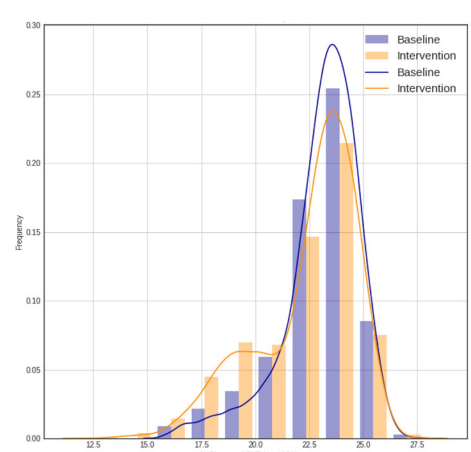

Figure 1 CVD risk (10-year percentage chance of CVD) distribution plot. CVD, cardiovascular disk.

baseline. A mean of 10.44% chance of type 2 diabetes within the next 10 years at baseline was reduced to 10.29% chance postintervention. This represents a change of 1.41% at intervention (Wilcoxon signed-rank test, p≤0.05).

DISCUSSION

DF has been gaining more attention as the evidence accumulated in the last decades on their beneficial effects on chronic diseases.[3] Residents of most countries do not meet the recommended daily DF intake amounts, which is 25–35 g/day.[5] Our study confirmed that, in China, the average daily DF intake was only 12.8±0.1 g/day, comparable to previous reports,[1] while the recommendation is 25–30 g/day. Moreover, recent studies found that the trends in food consumption patterns of Chinese significantly changed during the past decades as the consumption of cereals and legumes decreased, potentially leading to an even lower daily fibre intake.[23 24] Food reformulation has therefore been proposed as a potential useful tool to provide a way for fibre fortification to increase daily fibre consumption of consumers. However, a scarcity of research, including modelling studies, has failed to provide more information on the potential public health impacts of higher fibre intake as a result of food reformulation in China.

In this study, the first modelling study exploring the public health effects of fibre fortification in China, we have shown how including fibre in a variety of food products, could help in addressing such fibre gap in a straightforward solution, by significantly increasing fibre intake in the Chinese population.

In addition, a fibre fortification scenario as the one modelled in this study could provide additional public health benefits such as reducing CVD risk-related deaths. This is of particular importance as CVD is the leading cause of both death and premature death in China, being the cause of 40% of deaths in the Chinese population.[25]

Moreover, such intervention could also help reduce type 2 diabetes risk. As the International Diabetes Federation indicated, over the past 10 years people with diabetes in China has increased from 90 million to 140 million (56% increase).[26] The weighted prevalence of total diabetes and pre-diabetes diagnosed were 12.8% and 35.2%, respectively, in the Chinese adult population.[26] As approximately 4.5 standardised diabetes incidence per 100 person-per year occurred in 2011,[26] equating to 6052500 new cases per annum or 16582 new cases per day, our simulation suggests that fibre fortification could lead to a reduction of 234 cases per day or 85340 cases per annum of diagnosed type 2 diabetes.

The primary strength of the study was the relatively large sample size, modelling calculations of various scenarios and subgroup analysis that were carried out. However, as a modelling study, we acknowledge some limitations. For instance, as the algorithms used in this study were mostly based on adult populations, the public health benefits of the intervention could only be applied to subjects within these age ranges, and the health outcomes explored were mutually exclusive, without considering the influence of time. In addition, as we applied a theoretical approach, we could not explore the actual feasibility and implementation of the derived fibre fortification reformulations and any postadverse effects following the interventions. However, as different fibres show different tolerance levels in both adults and children,[27 28] a potential strategy to address this issue could be opting for a combination of different fibres for fibre fortification. Our simulated distributions of different market shares are also reliant on the assumption that the target population would accept the reformulated products, regardless of the potential differences in sensory and/or price compared with the non-reformulated versions, although we tried to minimise this by introducing both a 'conservative' and 'best-case' scenarios.

Conclusion

As the first modelling study exploring the effects of fibre fortification in China, this study provides a good overview of the potential public health benefits of reformulating food products. Overall, the results of our modelling study highlighted both the potential nutrition (ie, increased adherence to recommended fibre intakes in the population) and public health benefits (ie, reduction of type 2 diabetes and CVD risk) that reformulating food products using a fibre fortification scenario could achieve in different settings and food categories. This could provide support and encouragement for food and beverage producers in China to consider fibre fortification through food reformulation.

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

Patient consent for publication Not applicable.

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