Opportunities for diet quality improvement: the potential role of staple grain foods

Mariane de Mello Fontanelli ¹ (marianefontanelli@gmail.com, <https://orcid.org/0000-0002-3480-6948>)

Angela Martinez Arroyo ^{1,2} (angela.martinez@uv.cl, <https://orcid.org/0000-0001-6380-5701>)

Cristiane Hermes Sales ¹ (cristianehermes@yahoo.com.br, <https://orcid.org/0000-0001-8474-2439>)

Chris J Seal ³ (chris.seal@newcastle.ac.uk, <https://orcid.org/0000-0001-6313-6691>)

Regina Mara Fisberg ¹ (rfisberg@usp.br, <https://orcid.org/0000-0002-4490-9035>)

¹ Department of Nutrition, School of Public Health, University of São Paulo, Avenida Dr. Arnaldo, 715, Cerqueira Cesar, São Paulo, SP, Brazil

² School Nutrition and Dietetics, Faculty of Pharmacy, University of Valparaíso, Valparaíso, Chile

³ Human Nutrition Research Centre, Public Health Sciences Institute, Newcastle upon Tyne, NE2 4HH, United Kingdom

Corresponding author: Regina Mara Fisberg

Avenida Dr. Arnaldo, 715, Cerqueira Cesar. 01246-904. São Paulo, SP, Brazil

Phone number: +55 11 3061 7869, Fax number: +55 11 3061 7130

E-mail: rfisberg@usp.br

Shortened version of the title: The potential role of staple grain foods

This is an Accepted Manuscript for Public Health Nutrition as part of the Cambridge Coronavirus Collection. This peer-reviewed article has been accepted for publication but not yet copyedited or typeset, and so may be subject to change during the production process.

The article is considered published and may be cited using its DOI

10.1017/S1368980021001531

Public Health Nutrition is published by Cambridge University Press on behalf of The Nutrition Society

Acknowledgements: We would like to thank all fieldworkers and all participants of the Health Survey of São Paulo. We also acknowledge the work on dietary data performed by the Evaluation of Food Consumption Research Group (*Grupo de Avaliação do Consumo Alimentar*) at University of São Paulo.

Financial Support: The 2015 Health Survey of São Paulo was supported by the São Paulo Municipal Health Department (grant number 2013-0.235.936-0), São Paulo Research Foundation (grant numbers 2012/22113-9, 2017/05125-7), and National Council for Scientific and Technological Development (grant numbers 472873/2012–1, 402674/2016–2, 301597/2017–0). This work was supported by São Paulo Research Foundation (grant number 2016/18742-1).

Conflict of Interest: None.

Authorship: MMF, AMA, CHS, and RMF conceptualized the study. MMF performed data management and statistical analysis. AMA, CHS, RMF supervised the analyses. MMF wrote the original draft. AMA, CHS, CJS, and RMF critically reviewed the manuscript for important intellectual content. All authors approved the version to be published.

Ethics approval: This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the School of Public Health, University of São Paulo, Brazil Institutional Review Board (certificate of presentation for ethical appreciation # 32344014.3.0000.5421, 36607614.5.0000.5421, and # 65484517.5.0000.5421). Written informed consent/assent was obtained from all participants.

Abstract

Objective: Given the high disease burden associated with the low intake of whole grains, modelling studies that estimate the impact of dietary strategies to increase more healthful grain foods consumption are essential to inform evidence-based and culturally-specific policies. This study investigated the potential nutritional impact of replacing staple grain foods with more healthful options.

Design: Based on the 2015 Health Survey of São Paulo, a cross-sectional, population-based study, we modelled the substitution of white rice and white bread with brown rice and whole-wheat bread. Outcomes included changes in more healthful grain foods, energy, and nutrient intakes.

Setting: Urban area of São Paulo, Brazil.

Participants: Participants aged over 12 years who completed a semi-structured questionnaire and one 24-h recall (n=1741).

Results: The substitution of all white rice and white bread with brown rice and whole-wheat bread, respectively, would result in more than 5% increases in zinc (+9.1%), calcium (+9.3%), vitamin E (+18.8%), dietary fibre (+27.0%), and magnesium (+52.9%) intake, while more than a 5% decrease would be seen for total carbohydrate (-6.1%), folate (-6.6%), available carbohydrate (-8.5%), iron (-8.6%), vitamin B6 (-12.5%), vitamin B2 (-17.4%), and vitamin B1 (-20.7%). A substantial increase in the amount of more healthful grain foods consumed would be seen (10g/d to 220g/d), or from 4% to 69% of total grain intake.

Conclusions: Replacing white rice and white bread with their whole-grain versions has the potential to improve diet quality, suggesting they are prime targets for policy actions aiming at increasing intake of more healthful grain foods.

Keywords: Whole grains; Dietary fibre; Nutrients; Strategies; Modelling

Introduction

More than fifty years have passed since epidemiological observations suggested that processing grains with the removal of varying proportions of the bran and germ, including dietary fibre, may play a part in development of cardiometabolic diseases ^(1,2). Despite the well-established health benefits, little has been achieved concerning the global intake of whole-grain foods since then, which remains substantially lower than recommended levels ⁽³⁻⁵⁾. In 2017, low intake of whole grains was among the leading dietary risk factors identified for death and disability-adjusted life-years (DALYs) worldwide, accounting for 3 million deaths and 82 million DALYs ⁽⁵⁾. At the same time, grain foods are still the major carbohydrate-providing foods in the global diet, also contributing to protein, fibre, and micronutrient intake (according to the degree of processing) in many populations ^(6,7). This central role in the human diet makes them a convenient target for nutrition policies focused on improving dietary quality and reducing disease burden ⁽⁸⁾. In Brazil, for example, there is mandatory fortification of maize and wheat flour with iron and folic acid, but there is no information regarding fortification of grain products with other nutrients on a population basis ⁴⁵.

Owing to challenges of intervention studies, such as sufficient sample size, duration, participant adherence, and economic feasibility, dietary modelling studies are becoming more frequent as they enable comparisons between hypothetical scenarios and can provide evidence which can then be tested in targeted interventions and converted into policies ⁽⁹⁾. In this context, modelling studies that estimate the impact of dietary strategies to increase consumption of more healthful grain foods are essential to inform evidence-based policy actions. Prior investigations focusing on changing from refined to whole-grain consumption reported improvements in dietary nutrient density and quality, and even a reduction in diet cost ⁽¹⁰⁻¹³⁾. However, these studies were developed in high-income countries, and generalizability of findings to low and middle-income countries is limited due to differences in dietary intake of carbohydrate-rich foods, upon which the modelling strategy is based ⁽¹⁴⁾. Additionally, varying strategies can be used to achieve the goal of the modelling process, which are usually culturally-specific.

To our knowledge, approaches to increase the intake of more healthful grain foods in Brazil have not been previously tested. This information may provide a useful overview for subsequent interventions, given the importance of grains in the Brazilian diet and the high disease burden associated with low whole-grain intake in the country ⁽⁵⁾. The present study aimed to estimate the potential nutritional impact of replacing staple grain foods with more healthful grain food options in the population of São Paulo, Brazil under current eating patterns. We hypothesized that the substitution of white rice and white bread, which are among the five most consumed foods in the

country⁽¹⁵⁾, by equivalent more healthful options (brown rice and whole-wheat bread) would result in improvement in diet nutritional content.

Methods and materials

Data source

Data came from the 2015 Health Survey of São Paulo (*Inquérito de Saúde de São Paulo*), the third edition of a complex, multistage probability, cross sectional survey designed to represent São Paulo urban residents⁽¹⁸⁾. The municipality is one of the world's most populous cities (more than 12.3 million people lived in São Paulo in 2020), located in south-eastern Brazil. The survey included 4059 participants aged over 12 years (865 aged 12 to 19 years, 2169 aged 20 to 59 years, and 1025 aged over 60 years) that completed a semi-structured questionnaire regarding demographic and socioeconomic data, as well as lifestyle information⁽¹⁸⁾. A subsample of 1741 participants (553 aged 12 to 19 years, 643 aged 20 to 59 years, and 545 aged 60 years or more) completed a 24-h dietary recall, on which the substitution models in this study were based. Further information regarding the study design is described by Fisberg *et al.*⁽¹⁹⁾.

Dietary intake data were collected during the household interview using the Multiple Pass Method⁽²⁰⁾. Self-reported foods and beverages consumed were converted into nutritional values using the Nutrition Data System for Research software 2014 version (Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN). Nutrient content of food items included in the survey were compared with those available in Brazilian national food composition tables^(21,22). Nutritional values in the database were corrected if the concordance rate was not between 80% and 120% with corresponding foods consumed by the São Paulo population⁽¹⁹⁾.

Sociodemographic variables

Demographic and socioeconomic data were assessed using a standardized questionnaire collected during face-to-face interviews. Participants were categorized in the following age groups: 12 to 19 years, 20 to 59 years and over 60 years, according to the definitions of the World Health Organization (WHO) and the Brazilian Statute for Children and Adolescents^(23,24). Education level was categorized as below high school graduate, high school graduate/equivalent, and college or some college. Individual education was considered for adults, and householder education was used for adolescents. *Per capita* family income was calculated as the sum of the income of all family members and divided by the number of family members, and was considered as less than one minimum wage, two to three minimum wages, more than three minimum wages, and “do not know”. The monthly minimum wage was 788.00 Brazilian Reals (BRL) in 2015, equivalent to 253.00 United States Dollars (USD) (currency exchange based on the Brazilian Central Bank on

July 1st 2015). Self-reported ethnicity classification was based on Brazilian law for admission into public universities (number 12711) as “white or yellow”, and “black, brown or indigenous” ⁽²⁵⁾. This is an affirmative law that determines the number of public university vacancies that should be fulfilled by self-declared black, brown or indigenous populations ⁽²⁶⁾.

Substitutions models

The main feature of this study was the systematic replacement of white rice and white bread reported as consumed in the 24-h dietary recall with brown rice and whole-wheat bread, respectively. Food items were selected based on the top ten contributors to energy intake from grain foods estimated in a previous investigation performed with the same population ⁽²⁷⁾. White rice and white bread (French bread and commercial white bread) accounted for 57.0% of energy intake from grain foods not containing 1g of fibre per 10g of carbohydrate (not meeting the carbohydrate to fibre $\leq 10:1$ -ratio), which was used as a criterion to identify more healthful grain foods ⁽²⁷⁾. Three approaches were then used to replace each food item by its nearest more healthful grain food equivalent: model 1) white rice was replaced with brown rice; model 2) white bread was replaced with whole-wheat bread; model 3) white rice was replaced with brown rice, and white bread was replaced with whole-wheat bread, i.e. model 1 plus model 2 (**Supplementary Table 1**). The amount (in grams) of the original food item was replaced by the same amount of the alternative product. Nutritional values of food items included in the substitution models are shown in **Supplementary Table 2**.

The consequences of the substitution models on nutrient and energy intakes were estimated considering whether 25%, 50%, 75% or 100% of the population had their consumption changed. Assuming that complete replacement models are not achievable from a public health perspective, partial substitution models better represent the probable impact of corresponding interventions. Participants were assigned into subsamples (25%, 50% and 75%) by creating a uniformly-distributed random variate over the interval (0,1). The proportion of sociodemographic characteristics and rice or bread consumption was similar comparing subsamples to the total sample (**Supplementary Table 3**). For participants consuming white rice or white bread more than one time per day, we also estimated the potential nutritional impact of replacing white rice and white bread in one eating occasion, with the purpose to explore if a one-time replacement is enough to provide significant changes in the population’s diet. Substitution models were also performed for sex and age subgroups to investigate possible differences among replacement models.

Statistical analyses

The association between the prevalence of consumers of grain foods included in the modelling process and demographic and socioeconomic characteristics was assessed using chi-square tests. White rice consumers, white bread consumers, and those consuming either white rice or white bread represent the part of the population that had their consumption changed in the replacement models 1, 2, and 3, respectively.

Study primary outcomes included change in observed intake of more healthful grain foods (foods meeting the carbohydrate to fibre $\leq 10:1$ -ratio, g/d) and the contribution of more healthful grain foods to total grains (%). We considered as secondary outcomes the percent change of the following nutrients: energy (kcal/d), carbohydrate (g/d), available carbohydrate [carbohydrate – dietary fibre] (g/d), dietary fibre (g/d), total sugar (g/d), added sugars (g/d), protein (g/d), total fat (g/d), saturated fatty acids (g/d), polyunsaturated fatty acids (g/d), monounsaturated fatty acids (g/d), vitamin B1 (mg/d), vitamin B2 (mg/d), vitamin B3 (mg/d), vitamin B6 (mg/serving), folate (DFE μ g/d), vitamin E (mg/d), sodium (mg/d), calcium (mg/d), potassium (mg/d), iron (mg/d), selenium (μ g/d), magnesium (mg/d), and zinc (mg/d). All study participants were included in the modelling process, but only participants reporting white rice or white bread intake had their consumption changed.

Changes in intakes of more healthful grain foods, energy and nutrients were tested for significance using t-tests. Given the large number of participants consuming the refined versions of bread and rice, and as a result affected by the substitution models, even small differences between observed and modelled intakes would be statistically significant. For that reason, statistically significant changes were only interpreted if relative change in intake was 5% or more comparing pre and post-modelled intake (considered “moderate” changes), and statistically significant changes in intake greater than 10% (or less than -10%), were described as “strong”. These cut-off points were used in a previous study, which adopted a 10% value based on the definition of the United States Food and Drug Administration (USDA) of a “good source” of nutrients^(12,28). As this value varies according to the nutrient in question in the Brazilian legislation, we opted to use the USDA cut-off point⁽²⁹⁾.

Stata version 14.0 (StataCorp) was used to perform the modelling process, and statistical significance was established at two-sided $p < 0.05$. We used the survey module of Stata to account for the complex survey sampling design of the study, and as a result, findings from this study are considered representative of the São Paulo population aged 12 years or more.

Results

The majority of the population consumed white rice (80.8%), white bread (62.8%), and ate either white rice or white bread (91.6%) on the assessment day, but brown rice, whole-wheat bread or

either brown rice or whole-wheat bread consumption was limited, 3.3%, 4.6% and 7.5%, respectively (**Table 1**). Higher prevalence of white rice consumers was observed among males, those with education level below high school graduate, with family income *per capita* between one and three minimum wages, and those who self-reported black, brown, or indigenous ethnicity. For brown rice, higher prevalence of consumption was observed among females. Higher prevalence of white bread consumption was observed among males, and those with education level below high school graduate. For whole-wheat bread, higher prevalence of consumption was observed among participants aged 60 years or more, females, those with education level of college or some college, with family income *per capita* more than three minimum wages, and who self-reported white or yellow ethnicity. Considering participants who consumed either white rice or white bread, higher prevalence of consumption was observed among males, those with education level below high school graduate, and family income *per capita* lower than one minimum wage, and those who self-reported black, brown or indigenous ethnicity. On the other hand, higher prevalence of either brown rice or whole-wheat bread consumption was observed among participants aged 60 years or more, females, those with college and some college education, with family income *per capita* more than three minimum wages, and those who self-reported white or yellow ethnicity.

The pre-modelled and post-modelled population daily consumption of more healthful grain foods, energy and nutrient intakes are reported in **Tables 2, 3 and 4** and **Figures 1 and 2**. All white rice consumed by São Paulo population was replaced with brown rice in model 1 at 100% change. This resulted in moderate percent changes among available carbohydrate (-5.4%, 95% CI: -5.8 to -5.1), and strong percent changes were found for vitamin B1 (-10.9%, 95% CI: -11.5 to -10.2), dietary fibre (18.0%, 95% CI: 16.9 to 19.1), and magnesium (45.0%, 95% CI: 41.8 to 48.1) (**Figure 1**). After the replacement of all the white bread consumed for whole-wheat bread (model 2 at 100% change), moderate percent changes were observed for zinc (5.6%, 95% CI: 5.2 to 6.1), folate (-7.8, 95% CI: -8.3 to -7.3), magnesium (8.0%, 95% CI: 7.4 to 8.5), iron (-8.1%, 95% CI: -8.6 to -7.7), dietary fibre (9.0%, 95% CI: 8.3 to 9.6), calcium (9.4%, IC 95%: 8.5 to 10.3), and vitamin B1 (-9.9%, 95% CI: -10.6 to -9.1), while strong changes were found for vitamin B6 (-12.5%, 95% CI: -13.4 to -11.6), vitamin E (14.5%, 95% CI: 13.4 to 15.7), and vitamin B2 (-17.3%, 95% CI: -18.5 to -16.1) (**Figure 1**). The substitution of all white rice and white bread for brown rice and whole wheat bread, respectively (model 3 at 100% change) resulted in moderate percent changes for total carbohydrate (-6.1%, 95% CI: -6.4 to -5.8), folate (-6.6%, 95% CI: -7.1 to -6.1), available carbohydrate (-8.5%, 95% CI: -8.9 to -8.1), iron (-8.6%, 95% CI: -9.1 to -8.1), zinc (9.1%, 95% CI: 8.6 to 9.6), and calcium (9.3%, 95% CI: 8.4 to 10.2), while strong changes were observed for vitamin B6 (-12.5%, 95% CI: -13.4 to -11.6), vitamin B2 (-17.4%, 95% CI: -18.6 to -16.2), vitamin

E (18.8%, 95% CI: 17.5 to 20.1), vitamin B1 (-20.7%, 95% CI: -21.8 to -19.7), dietary fibre (27.0%, 95% CI: 25.6 to 28.3), and magnesium (52.9%, 95% CI: 49.6 to 56.3) (**Figures 1**).

In general, all replacement models resulted in an absolute increase of dietary fibre (from 1.2 g/d in model 2 to 4.0 g/d in model 3), in magnesium intake (from 16.9 g/d in model 2 to 114.6 in model 3), and a decrease in vitamin B1 (from -0.3 mg/d in model 3 to -0.2 mg/d in models 1 and 2).

Differences between models were observed for carbohydrate (-14.2 g/d in model 3), available carbohydrate (-11.8 g/d in model 1 and -18.3 g/d in model 3), vitamin B2 (-0.3 mg/d in models 2 and 3), vitamin B6 (-0.2 mg/d in models 2 and 3), folate (-27.1 µg/d in model 2 and -23.9 µg/d in model 3), vitamin E (+0.9 mg/d in model 2 and +1.1 mg/d in model 3), iron (-0.9 mg/d in models 2 and 3), and zinc (+0.8mg/d in model 3) (**Tables 2, 3 and 4**).

The majority of the modelling effects were seen if 100% of the population had their consumption of white rice or white bread replaced with brown rice and whole-wheat bread. However, statistically significant changes were also observed at 25%, 50% and 75% substitution levels. At the 25% level, magnesium (models 1 and 3), and vitamin B6 (model 2) would change. At the 50% level, changes would be seen for dietary fibre (models 1 and 3), vitamin B1 (models 1, 2 and 3), vitamin B2 (model 3), vitamin B6 (model 2), vitamin E (models 2 and 3), and magnesium (models 1, 2 and 3). At the 75% level, changes in available carbohydrate (model 3), dietary fibre (models 1, 2 and 3), vitamin B1 (models 1, 2 and 3), vitamin B2 (models 2 and 3), vitamin B6 (models 2 and 3), folate (model 2), vitamin E (models 2 and 3), iron (models 2 and 3), magnesium (models 1, 2 and 3), and zinc (model 3) would be observed.

Observed mean intake of more healthful grain foods before the models were applied was 10.1 g/d and these foods were consumed by 15.8% (95% CI: 13.5-18.3) of the population. Post-modelled absolute changes in more healthful grain foods consumption ranged from 48.8 g/d in model 2 to 220.2 g/d in model 3, both at the 100% substitution level (**Tables 3 and 4**). At this level of intake, the majority of the population would be consuming at least one more healthful grain food, from 71.6% of the population (95% CI: 69.0-74.0) in model 2 to 94.5% of the population (95% CI: 92.9-95.7) in model 3. Pre-modelled intake of more healthful grain food as a percentage of total grains intake was 4.0% (95% CI: 3.3-4.8), and increased to 52.5% (95% CI: 50.5-54.5), 20.9% (95% CI: 19.6-22.2) and 69.4% (95% CI: 67.3-71.5) in models 1, 2 and 3, respectively (**Figure 2**). Results from proportional substitutions indicate more healthful grain foods would increase significantly at 25, 50, and 75% levels of population adherence ($p < 0.001$ for each level of substitution for each model, **Tables 2, 3 and 4**).

Given that part of the population of São Paulo consumed either white rice or white bread more than one time a day (by 33.8% of the population (95% CI: 31.0-36.7) for white rice and by 16.0% of the

population (95% CI: 14.1-18.0) for white bread), substitution models were also performed to estimate the replacement of these food items in one eating occasion and similar results were found, but the effects were smaller as expected (**Supplementary Table 4**). Changes in intake of nutrients by substitution models performed among age and sex subgroups were comparable to models performed considering the overall population, with the greatest impact among subgroups with lower prevalence of brown rice and whole-wheat bread consumption, such as adolescents and males (**Supplementary Tables 5, 6, 7, 8, 9, and Supplementary Figures 1 and 2**).

Discussion

We estimated the potential nutritional impact of approaches to increase more healthful grain foods intake among São Paulo residents under current eating patterns. Substitution models were based on two staple grain foods, rice and bread, which together resulted in substantial changes on population dietary intake. Observed mean intake of more healthful grain foods before the substitutions was 10.1 g/d, which represented 4.0% of total grain intake. This would potentially increase to 220.2 g/d, representing 69.4% of total grain intake if the entire population currently consuming white rice and white bread changed all of their consumption to brown rice and whole wheat bread. Overall, estimated intakes of zinc, calcium, vitamin E, dietary fibre, and magnesium increased by more than 5% after applying the models. In contrast intakes of total carbohydrate, available carbohydrate, folate, iron, and vitamins B6, B2, and B1 decreased by more than 5% post-modelling. The results provide evidence for future interventions and policy efforts to improve the intake of more healthful grain foods.

Findings from this study suggest that shifting consumption from usually-eaten grain foods to more healthful equivalent options may represent a valuable strategy to increase the intake of nutrients with high prevalence of inadequacy among the Brazilian population (more than 70%), such as dietary fibre, magnesium, calcium, and vitamin E³⁰⁻³⁵. It is interesting to note that the different modelling strategies led to different effects on the population nutritional intake. The substitution of white rice with brown rice resulted in greater changes in dietary fibre and magnesium intake than occurred when substituting white bread with whole-wheat bread, while the replacement of white bread with whole-wheat bread produced greater changes in vitamin E and calcium dietary intake. As a result of the varied nutritional content and bioactive compounds in the food items, different physiological effects may be expected^(36,37). Antidiabetic properties, decreased inflammation, and the modulation of lipid metabolism and oxidative stress have been documented in *in vitro* studies and clinical trials investigating health benefits of consuming brown rice⁽³⁸⁾. A recent systematic review and meta-analysis of randomized controlled trials found that, compared with white rice, brown rice led to an improvement in triacylglycerol levels (-1.6 mg/dL) in interventions ranging

from 150 to 400g of cooked rice⁽³⁹⁾. One serving of brown rice per day was also associated with reductions in type 2 diabetes risk (Hazard ratio [HR] 0.72) in three large prospective studies from the United States of America (USA); however the association was no longer significant after adjusting for BMI⁽⁴⁰⁾. For whole-wheat bread, there are also consistent beneficial effects reported. The intake of 90 g (~ 3 servings) of whole-grain bread was associated with risk reductions of coronary heart disease (Relative Risk [RR] 0.83), cardiovascular disease (RR 0.87), total cancer (RR 0.91), and all-cause mortality (RR 0.85)⁽⁴¹⁾. Dark bread consumption was also associated with type 2 diabetes risk reduction and significant effects were seen for just one serving of this food (HR 0.93 (95% CI: 0.91 to 0.95)⁽⁴⁰⁾. Findings from an earlier study performed with the same population suggested that each 1% increase in energy intake from more healthful grain foods (including brown rice and whole-wheat bread) was associated with lower concentrations of blood triacylglycerol (-10.7%), reduced triacylglycerol/high-density lipoprotein cholesterol ratio (-14.9%), fasting insulin (-13.6%), and homeostasis model assessment for insulin resistance (-14.0%)⁽²⁷⁾. Considering model 3 at the 100% level, pre and post-modeled percentages of energy from more healthful grain foods in the present investigation were 1.5% and 23.1%, respectively (data not shown), which could represent a substantial predicted improvement in cardiometabolic health.

As found in previous dietary modelling studies, substitution models revealed potentially unwanted dietary effects^(12,42). In the present study intake of iron, folate and vitamins B1, B2 and B6 would decrease if all the white rice and white bread consumed were substituted for brown rice and whole-wheat bread, respectively. In this sense, the results presented here support the balance between consumption of whole and refined grains in the diet in order to get the best nutritional composition possible from grain foods⁽⁴³⁾. However, even if 50% of the population changed their white rice and white bread consumption, a decrease would be seen for vitamins B1 and B2, and it may be necessary to encourage the consumption of other sources of these nutrients, especially vitamin B1, which has a considerable prevalence of inadequacy among Brazilians (between 30 and 50% of the population depending on age group)^(30,31). Additionally, quality standards for whole-grain food production are required to ensure minimal losses during the milling process⁽⁴⁴⁾. Possible losses of B vitamins may have contributed to the lower intake levels observed in post-modelled data. The majority of these nutrients is located in the bran and germ of the grain, which are removed during the refining process, and then recombined or reconstituted to produce whole-grain flours; incomplete recombination may result in lower-than-expected concentrations in whole-grain flours^(7,45).

The mandatory fortification of wheat flour with iron and folic acid in Brazil may be one explanation for the lower intake of these micronutrients in the post-modelled estimations, since whole-wheat

flour is not enriched due to technological issues^(46,47). Consistent with this, breads (including all types of refined breads) were among the main contributors to iron and folate intake in the post-fortification period in Brazil⁽⁴⁸⁻⁵⁰⁾. Therefore, a combination of refined and whole grain foods may be the best way to mitigate the unwanted effects observed, or alternative methods for fortification of grains should be promoted for example during food processing⁽⁵¹⁾ or by biofortification⁽⁵²⁾. From another perspective, the Brazilian diet comprises other sources of iron and folate, such as beans, meat and vegetables, and dietary strategies aimed at improving the nutritional quality of grain foods consumed by the population must be aligned with actions to improve overall diet quality^(15, 53). In addition, dietary surveillance is essential to monitor dietary intake, evaluate interventions and shed light on future development of public health strategies.

Several approaches were used in previous modelling investigations focusing on grains or grain-based products. An improvement in diet quality was observed after substituting white bread, rolls, biscuits, and spaghetti for equivalent whole wheat foods, and after replacing white rice with brown rice in diets of adults living in the USA⁽¹¹⁾. Solid foods consumed at breakfast were replaced with ready-to-eat cereals in data collected in the National Nutrition Examination Survey (NHANES) and this resulted in higher intakes of whole grains (84.6%), fibre (14.3%), vitamin D (14.0%), iron (54.5%), and folic acid (104.6%), and led to a decline in intake of solid fats (-10.9%). On the other hand, an unwanted increase in added sugars intake (5.0%) was observed⁽¹²⁾. By replacing refined grain ingredients with whole-grain ingredients in foods usually consumed by children in the USA, Keast *et al.* observed an increase of approximately 50 g/d of whole grains, and pre and post-modelled whole-grain intake were 6% and 28% of total grains intake, respectively⁽¹⁰⁾. Recently, bread, pasta and ready-to-eat cereals were replaced with whole grain equivalent options in the United Kingdom National Diet and Nutrition Survey which significantly increased the intake of whole grains (from 23.9 g/d to 74.4 g/d) and fibre (from 18.3 g/d to 21.7 g/d)⁽¹³⁾. Our findings corroborate with the previous literature, indicating that replacing refined grain foods with their whole-grain versions has the potential to improve diet quality. However, the impact on dietary intake at the population level will depend largely on intervention adherence.

Apart from the significant nutritional impact seen when modelling at 100% change, partial substitution models, in which replacement was performed in 25%, 50%, and 75% of the population, may provide a better representation of effects of such interventions on population dietary intake, given that individuals will respond differently to any dietary intervention⁽⁵³⁾. Substitutions made on a proportional basis indicate that important changes in nutrient intakes would be observed even if part of the population adheres to the proposed intervention. For example, increase in magnesium intake would be observed if only 25% of the population replaced their consumption of white bread

and white rice with brown rice and whole-wheat bread, while mean dietary fibre intake increases from 50% adherence level. Grain-based foods are the predominant food group in the Brazilian diet, and account for approximately 40% of total energy intake⁽¹⁷⁾. Together, white rice and white bread accounted for more than half (57%) of the energy intake provided from grain foods⁽²⁷⁾. Because of this central role in the Brazilian diet, it suggests that nutrition policy actions focused on these food items may provide wide-ranging effects on the population dietary intake. In particular they may better target subgroups of the population with low intakes of more healthful grain foods, such as younger individuals, men, those with lower education and family income levels, and those reporting black, brown and indigenous ethnicity⁽¹⁷⁾. Development and evaluation of effective strategies to change such a deep-rooted eating habit deserves further investigation.

Multiple factors influence population food choices, and evidence suggests that policy measures emphasizing personal responsibility are not sufficient to increase whole-grain intake, especially among countries, like Brazil, where-grain foods are traditionally consumed as refined grains^(53,54). Successful public health interventions aimed at increasing whole-grain intake comprised numerous stakeholder partnerships, specification of target intakes in dietary guidelines, labelling standards, food reformulation to increase the whole-grain ingredient content, educational materials, social media campaigns, and events to familiarize communities with the taste of whole grain and preparation methods for whole-grain foods^(55,56). In Brazil, initiatives to address the problem are beginning to emerge. For example, a formal definition of what constitutes a whole-grain food is under debate, and a new regulatory instrument for these products will be available soon in the country⁽⁵⁷⁾. This is a crucial step to help consumers chose healthy whole-grain options and support policy actions aimed at increasing population intake of more healthful grain foods.

Our analysis did not include information on the costs of brown rice and whole-wheat bread compared with the refined alternatives, but the proposed substitutions would probably increase dietary cost^(58,59). Considering that price strongly influence food choice, fiscal incentives for more healthful grain foods may be required in order to promote dietary change, especially among low-income subgroups⁽⁵³⁾. Another strategy to improve whole-grain intake is the inclusion of whole-grain foods in the basic food basket, and in already existing programmes, such as the National School Meal Program (*Programa Nacional de Alimentação Escolar*) and the Worker's Food Program (*Programa de Alimantação do Trabalhador*). Increased whole-grain consumption may result in health improvement resulting in reduced health system burden and concomitant healthcare cost savings, for that reason, strategies to tackle the problem should be urgently implemented^(60,61).

Strengths of this study include the quality of the data used as input for the dietary modelling. This was derived from a representative sample of residents in a large metropolis of a middle-income

country, where the low intake of whole grains was the leading dietary risk for death and DALYs in 2017 ⁽⁵⁾. In addition, our previous study demonstrated that whole-grain intake is still far from recommended levels in this population ^(16,17), and this intake was associated with diet inequalities in São Paulo strongly suggesting that policy actions are required in this population ⁽¹⁶⁾. The strategies used to model an increase the intake of more healthful grain foods took into account the particular composition of the Brazilian diet and considered the impact of varying levels of population adherence. Finally, the analysis covered a wide spectrum of the nutrient content of the diet.

Potential limitations should be acknowledged. First, dietary intake data was based on self-reported 24-h recalls, which include random and systematic errors, and are susceptible to misreporting of dietary intake ⁽⁶²⁾. Refined grain foods may be more underreported, and as a result, post-modelled intakes could be underestimated ⁽⁶³⁾. However, 24-h recalls were collected by trained interviewers using standardized methods to enable complete recalls, such as the Multiple Pass Method and a standardized procedure to detail food items consumed ⁽¹⁹⁾. Second, models were based on a single 24-h dietary recall. Therefore, we were not able to compare nutrient adequacy between observed and modelled nutrient intakes. In addition, the classification of participants according to their consumption of rice and bread, in particular brown rice and whole-wheat bread, does not distinguish between true non-consumers and occasional non-consumers of the study foods in question ⁽⁶²⁾. Importantly, even with a single dietary recall, the study included a good representation of weekend day food consumption (~31%) ⁽¹⁹⁾. Third, our analyses were based on standard versions of food items consumed by the Brazilian population and did not consider fortified foods, except for those fortified with iron and folic acid, which fortification is mandatory. Fourth, the cost implication of the modelling outcomes was not considered in the modelling process and may have an impact on the translation of the models into real life.

Conclusions

Overall, the substitution of staple grain foods with more healthful options would lead to favourable changes in diet content of São Paulo residents. A significant increase in more healthful grain foods intake would be seen if the entire population consuming white rice and white bread changed their consumption to brown rice and whole wheat bread, respectively. However, substitution resulted in unwanted effects for B vitamins, and results support the balance between consumption of whole and refined grains in the diet. Our findings suggest that rice and bread are prime targets for policy actions aiming at increasing more healthful grain food intake in a Brazilian context.

References

1. Cummings JH, Engineer A (2018) Denis Burkitt and the origins of the dietary fibre hypothesis. *Nutr Res Rev* **31**, 1-15. doi: 10.1017/S0954422417000117.
2. Reynolds AN, Akerman AP, Mann J (2020) Dietary fibre and whole grains in diabetes management: Systematic review and meta-analyses. *PLoS Med* **17**, e1003053. doi: 10.1371/journal.pmed.1003053.
3. Mann KD, Pearce MS, Seal CJ. Providing evidence to support the development of whole grain dietary recommendations in the United Kingdom. *Proc Nutr Soc* 2017;**76**(3), 369-377. doi: 10.1017/S0029665116000793.
4. Micha R, Shulkin ML, Peñalvo JL *et al.* (2017) Etiologic effects and optimal intakes of foods and nutrients for risk of cardiovascular diseases and diabetes: Systematic reviews and meta-analyses from the Nutrition and Chronic Diseases Expert Group (NutriCoDE). *PLoS One* **12**, e0175149. doi: 10.1371/journal.pone.0175149.
5. GBD 2017 Diet Collaborators (2019) Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* **393**, 1958-72. doi: 10.1016/S0140-6736(19)30041-8.
6. FAO - Food and Agriculture Organization (2019) FAO Cereal Supply and Demand Brief 2019. <http://www.fao.org/worldfoodsituation/csdb/en/>. (accessed November 2019)
7. Seal CJ, Nugent AP, Tee ES *et al.* (2016) Whole-grain dietary recommendations: the need for a unified global approach. *Br J Nutr* **115**, 2031-8. doi: 10.1017/S0007114516001161
8. Mattei J, Malik V, Wedick NM *et al.* (2015) Reducing the global burden of type 2 diabetes by improving the quality of staple foods: The Global Nutrition and Epidemiologic Transition Initiative. *Global Health* **11**. doi: 10.1186/s12992-015-0109-9
9. Grieger JA, Johnson BJ, Wycherley TP *et al.* (2017) Evaluation of Simulation Models that Estimate the Effect of Dietary Strategies on Nutritional Intake: A Systematic Review. *J Nutr* **147**, 908-31. doi: 10.3945/jn.116.245027
10. Keast DR, Rosen RA, Arndt EA *et al.* (2011) Dietary modeling shows that substitution of whole-grain for refined-grain ingredients of foods commonly consumed by US children and teens can increase intake of whole grains. *J Am Diet Assoc* **111**, 1322-8. doi: 10.1016/j.jada.2011.06.008
11. Thomson JL, Tussing Humphreys LM, Onufrak SJ *et al.* (2011) A simulation study of the potential effects of healthy food and beverage substitutions on diet quality and total energy intake in Lower Mississippi Delta adults. *J Nutr* **141**, 2191-7. doi: 10.3945/jn.111.144659

12. Rehm CD, Drewnowski A (2017) Replacing American Breakfast Foods with Ready-To-Eat (RTE) Cereals Increases Consumption of Key Food Groups and Nutrients among US Children and Adults: Results of an NHANES Modeling Study. *Nutrients* **9**,1010. doi: 10.3390/nu9091010
13. Mann K, Yu D, Hopkins S *et al.* (2018) Investigating the impact of replacing refined grain foods with whole-grain foods on fibre intake in the UK. *Proc Nutr Soc* **77**, E134. doi:10.1017/S0029665118001404
14. Dehghan M, Mente A, Zhang X *et al.* (2017) Associations of fats and carbohydrate intake with cardiovascular disease and mortality in 18 countries from five continents (PURE): a prospective cohort study. *Lancet* **390**, 2050-62. doi: 10.1016/S0140-6736(17)32252-3
15. Souza AM, Pereira RA, Yokoo EM *et al.* (2013) Most consumed foods in Brazil: National Dietary Survey 2008-2009. *Rev Saude Publica* **47**, 190-9. doi: 10.1590/S0034-89102013000700005
16. Mello AV, Sarti FM, Pereira JL *et al.* (2018) Determinants of inequalities in the quality of Brazilian diet: trends in 12-year population-based study (2003-2015). *Int J Equity Health* **17**, 72. doi: 10.1186/s12939-018-0784-2
17. Fontanelli MM, Sales CH, Castro MA *et al.* (2020) Healthful grain foods consumption by São Paulo residents: a 12-year analysis and future trends. *Public Health Nutr.* Published online: 1 July 2020. doi:10.1017/S1368980020001342
18. Alves M, Escuder MML, Goldbaum M *et al.* (2018) Sampling plan in health surveys, city of Sao Paulo, Brazil, 2015. *Rev Saude Publica* **52**, 81. doi: 10.11606/s1518-8787.2018052000471
19. Fisberg RM, Sales CH, Fontanelli MM *et al.* (2018) 2015 Health Survey of Sao Paulo with Focus in Nutrition: Rationale, Design, and Procedures. *Nutrients* **10**,169. doi:10.3390/nu10020169
20. Moshfegh AJ, Rhodes DG, Baer DJ *et al.* (2008) The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. *Am J Clin Nutr* **88**, 324-32. doi:10.1093/ajcn/88.2.324
21. NEPA - Center for Food Study and Research. UNICAMP - State University of Campinas (2011) Brazilian food composition table. Campinas, Brazil: NEPA. [In Portuguese]
22. USP - São Paulo University. FORC - Food Research Center (2017) Brazilian food composition table (TBCA). <https://www.fcf.usp.br/tbca/> (Accessed September 2019) [In Portuguese]
23. Brazil. Law # 8.069, 13 July 1990. Provides for the Child and Adolescent Statute and makes other arrangements. Brasília, Federal District: Union Official Journal 1990. [In Portuguese]
24. WHO – World Health Organization Maternal, newborn, child and adolescent health (2019) Achieving universal health coverage for the world's 1.2 billion adolescents. Geneva: World

- Health Organization. https://www.who.int/maternal_child_adolescent/adolescence/universal-health-coverage/en/ (Accessed October 2019)
25. Brazil. Law # 12.711, 29 Aug 2012. Provides for the entry into federal universities and institutions and makes other arrangements. Brasília, Federal District: Union Official Journal; Aug 30th 1 2012. [In Portuguese]
  26. Santos H, Souza MG, Sasaki K (2013) Social by products from Brazilian higher education quota system. *Rev Bras Estud Pedagog* **94**, 542-563. doi: 10.1590/S2176-66812013000200010. [In Portuguese]
  27. Fontanelli MM, Micha R, Sales CH *et al.* (2020) Application of the $\leq 10:1$ carbohydrate to fiber ratio to identify healthy grain foods and its association with cardiometabolic risk factors. *Eur J Nutr* **59**, 3269–3279. doi:10.1007/s00394-019-02165-4
  28. U.S. Food and Drug Administration (2013) Guidance for Industry: A Food Labeling Guide. <http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm064916.htm>. (Accessed August 2019)
  29. Brazil, Ministry of Health, National Health Surveillance Agency (2012) Resolution # 54, 12 Nov 2012. Provides for the Technical Regulation on Complementary Nutritional Information. Brasília, Federal District: Union Official Journal. [In Portuguese]
  30. Araujo MC, Bezerra IN, Barbosa FS *et al.* (2013) Macronutrient consumption and inadequate micronutrient intake in adults. *Rev Saude Publica* **47**, 177s-89s. doi:10.1590/S0034-89102013000700004
  31. Fisberg RM, Marchioni DM, Castro MA *et al.* (2013) Inadequate nutrient intake among the Brazilian elderly: National Dietary Survey 2008-2009. *Rev Saude Publica* **47**, 222s-30s. doi: 10.1590/S0034-89102013000700008.
  32. Santos PV, Sales CH, Vieira DA *et al.* (2016) Family income per capita, age, and smoking status are predictors of low fiber intake in residents of Sao Paulo, Brazil. *Nutr Res* **36**, 478-87. doi: 10.1016/j.nutres.2015.12.011
  33. Silva GMD, Durante ÉB, Assumpção D *et al.* (2019) High prevalence of inadequate dietary fiber consumption and associated factors in older adults: a population-based study. *Rev Bras Epidemiol* 2019;22:e190044. doi:10.1590/1980-5497201900
  34. Sales CH, Fontanelli MM, Vieira DA *et al.* (2017) Inadequate dietary intake of minerals: prevalence and association with socio-demographic and lifestyle factors. *Br J Nutr* **117**, 267-77. doi: 10.1017/S0007114516004633
  35. Souza AM, Barufaldi LA, Abreu GA *et al.* (2019) ERICA: intake of macro and micronutrients of Brazilian adolescents. *Rev Saude Publica* **50**, 5s. doi: 10.1590/S01518-8787.2016050006698

36. Bach Knudsen KE, Nørskov NP, Bolvig AK *et al.* (2017) Dietary fibers and associated phytochemicals in cereals. *Mol Nutr Food Res* **61**. doi: 10.1002/mnfr.201600518.
37. P NPV, Joye IJ (2020) Dietary Fibre from Whole Grains and Their Benefits on Metabolic Health. *Nutrients* **12**, E3045. doi: 10.3390/nu12103045
38. Mir SA, Shah MA, Bosco SJD *et al.* (2020) A review on nutritional properties, shelf life, health aspects, and consumption of brown rice in comparison with white rice. *Cereal Chem* **97**, 895-0903. doi:10.1002/cche.10322
39. Marshall S, Petocz P, Duve E *et al.* (2020) The Effect of Replacing Refined Grains with Whole Grains on Cardiovascular Risk Factors: A Systematic Review and Meta-Analysis of Randomized Controlled Trials with GRADE Clinical Recommendation. *J Acad Nutr Diet* **120**, 1859-1883.e31. doi: 10.1016/j.jand.2020.06.021
40. Hu Y, Ding M, Sampson L *et al.* (2020) Intake of whole grain foods and risk of type 2 diabetes: results from three prospective cohort studies. *BMJ* **370**, m2206. doi: 10.1136/bmj.m2206
41. Aune D, Keum N, Giovannucci E *et al.* (2016) Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: systematic review and dose-response meta-analysis of prospective studies. *BMJ* **353**, i2716. doi: 10.1136/bmj.i2716.
42. Nordstrom J, Thunstrom L (2009) The impact of tax reforms designed to encourage healthier grain consumption. *J Health Econ* **28**, 622-34. doi: 10.1016/j.jhealeco.2009.02.005
43. Jones JM, García CG, Braun HJ (2020) Perspective: Whole and Refined Grains and Health-Evidence Supporting "Make Half Your Grains Whole". *Adv Nutr* **3**, 492-506. doi: 10.1093/advances/nmz114.
44. Ross AB, van der Kamp JW, King R *et al.* (2017) Perspective: A Definition for Whole-Grain Food Products-Recommendations from the Healthgrain Forum. *Adv Nutr* **8**, 525-31. doi:10.3945/an.116.014001
45. Jones JM, Adams J, Harriman C *et al.* (2015) Nutritional Impacts of Different Whole Grain Milling Techniques: A Review of Milling Practices and Existing Data. *AACC International* **60**, 130-9. doi: 10.1094/CFW-60-3-0130
46. Brazil, Ministry of Health, National Health Surveillance Agency (2018) Enrichment of wheat and corn flours with iron and folic acid. Brasília, Federal District: National Health Surveillance Agency.
<http://portal.anvisa.gov.br/documents/33916/2810640/Enriquecimento+de+farinhas+de+trigo+e+de+milho/b58edc35-4cb3-4b6f-8701-11ec25d00f1f> . (Accessed April 2019) [In Portuguese]
47. Brazil. Resolution #150, 13 April 2017. Provides for the enrichment of wheat and corn flours with iron and folic acid. Brasília, Federal District: Union Official Journal, 2017; 37. [In Portuguese]

48. Palchetti CZ, Steluti J, Verly E Jr *et al.* (2019) Prevalence of inadequate intake of folate after mandatory fortification: results from the first National Dietary Survey in Brazil. *Eur J Nutr* **59**, 2793-803. doi: 10.1007/s00394-019-02127-w.
49. Steluti J, Selhub J, Paul L *et al.* (2017) An overview of folate status in a population-based study from São Paulo, Brazil and the potential impact of 10 years of national folic acid fortification policy. *Eur J Clin Nutr* **71**, 1173-8. doi: 10.1038/ejcn.2017.60.
50. Vieira DAS, Steluti J, Verly Jr E *et al.* (2017) Brazilians' experiences with iron fortification: evidence of effectiveness for reducing inadequate iron intakes with fortified flour policy. *Public Health Nutr* **20**, 363–70. doi: 10.1017/S1368980016001981.
51. Andersen G, Koehler P, Somoza V (2011) Metabolic effects of bread fortified with wheat sprouts and bioavailability of ferulic acid from wheat bran. In *Flour and Breads and their Fortification in Health and Disease Prevention*, pp. 507-517 [Preedy VR, Watson RR, Patel VB, editors]. Academic Press. doi: 10.1016/B978-0-12-380886-8.10046-7
52. Wakeel, A., S. Arif, M. A. Bashir, Z. Ahmad, H. U. Rehman, A. Kiran, S. Ibrahim and M. R. Khan (2018). "Perspectives of folate biofortification of cereal grains." *Journal of Plant Nutrition* 41(19): 2507-2524.
53. Mozaffarian D, Angell SY, Lang T *et al.* (2018) Role of government policy in nutrition-barriers to and opportunities for healthier eating. *BMJ* 361, k2426. doi: 10.1136/bmj.k2426.
54. Miller KB (2020) Review of whole grain and dietary fiber recommendations and intake levels in different countries. *Nutr Rev* 78,29-36. doi: 10.1093/nutrit/nuz052.
55. Suthers R, Broom M, Beck E (2018) Key Characteristics of Public Health Interventions Aimed at Increasing Whole Grain Intake: A Systematic Review. *J Nutr Educ Behav* 50, 813-23. doi: 10.1016/j.jneb.2018.05.013.
56. Toups KE (2020) Global approaches to promoting whole grain consumption. *Nutr Rev* 78,54-60. doi:10.1093/nutrit/nuz067
57. National Health Surveillance Agency (2019) Planning and monitoring sheet of AR 2017-2020 themes. Sanitary requirements for cereals, starch, flour and bran products. <http://portal.anvisa.gov.br/documents/33880/4513945/4.15.pdf/116d04ee-c2ee-46bc-80fb-0f4b5189249d>. (Accessed November 2019) [In Portuguese]
58. Harriman C (2013) Shrinking the Price Gap for Whole Grains. *Proceedings Whole Grain Summit 2012*. AACC International. <https://www.cerealsgrains.org/publications/plexus/cfwplexus/library/books/Documents/WholeGrainsSummit2012/CPLEX-2013-1001-17B.pdf> (Accessed November 2019).

59. Verly E Jr, Darmon N, Sichieri R et al. (2020) Reaching culturally acceptable and adequate diets at the lowest cost increment according to income level in Brazilian households. *PLoS One* 15, e0229439. doi: 10.1371/journal.pone.0229439.
60. Lieffers JRL, Ekwaru JP, Ohinmaa A et al. (2018) The economic burden of not meeting food recommendations in Canada: The cost of doing nothing. *PLoS One* 13, e0196333. doi: 10.1371/journal.pone.0196333.
61. Murphy MM, Schmier JK (2020) Cardiovascular Healthcare Cost Savings Associated with Increased Whole Grains Consumption among Adults in the United States. *Nutrients* 12, 2323. doi: 10.3390/nu12082323
62. Willett W (2013) *Nutritional Epidemiology*, 3rd edn. England/New York: Oxford University Press.
63. Garden L, Clark H, Whybrow S et al (2018) Is misreporting of dietary intake by weighed food records or 24-hour recalls food specific? *Eur J Clin Nutr* 7, 1026-1034. doi: 10.1038/s41430-018-0199-6.

Table 1. Consumption of rice and bread by sociodemographic characteristics among São Paulo population aged 12 years or older based on the 2015 Health Survey of São Paulo.

Sociodemographic characteristics	Rice consumers ‡				Bread consumers §				Rice or bread consumers			
	White rice (n=1428)		Brown rice (n=56)		White bread (n=1110)		Whole-wheat bread (n=73)		White rice or white bread (n=1608)		Brown rice or whole-wheat bread (n=122)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Overall population	80.8	78.1-83.3	3.3	2.4-4.6	62.8	59.9-65.7	4.6	3.4-6.2	91.6	89.7-93.2	7.5	5.9-9.4
Age group, years												
12-19	84.3	80.5-87.5	3.3	1.8-6.0	61.3	56.5-65.8	0.6	0.0-2.0***	92.0	88.9-94.3	3.6	2.1-6.3***
20-59	79.8	75.3-83.7	3.2	2.0-5.3	62.2	57.7-66.4	3.7	2.3-5.8	91.5	88.3-93.9	6.7	4.7-9.5
≥ 60	79.7	75.5-83.3	3.6	2.3-5.7	66.0	61.2-70.5	10.8	7.2-15.9	91.4	87.8-94.0	13.2	9.4-18.1
Sex												
Male	87.7	85.0-90.1***	1.8	1.1-2.9***	66.0	62.2-69.7*	3.5	2.5-5.0*	95.1	93.2-96.5***	5.2	3.9-7.0**
Female	73.9	69.8-77.6	4.9	3.3-7.0	59.6	55.3-63.8	5.6	3.8-8.3	88.1	84.8-90.7	9.7	7.3-12.8
Education level												
< High school graduate	85.3	82.3-87.8***	2.2	1.4-3.4	65.9	62.5-69.2*	3.4	2.3-5.0**	94.0	92.0-95.6**	5.3	4.0-7.0**
High school graduate / equivalent	81.1	76.7-85.3	3.6	2.0-6.4	64.0	58.3-69.3	3.4	1.6-7.3	92.7	89.3-95.1	6.5	3.9-10.6
College or some college	71.3	64.7-77.1	5.2	2.7-9.5	55.4	48.4-62.1	8.1	5.3-12.1	85.8	79.6-90.3	12.6	8.7-17.8
Family income <i>per capita</i>												
≤ 1 minimum wage †	82.2	78.6-85.3***	2.6	1.6-4.4	65.5	61.6-69.2	2.2	1.3-3.6***	93.3	90.9-95.1**	4.2	2.9-6.1***
> 1 and ≤ 3 minimum wages	83.6	79.4-87.1	2.5	1.4-4.4	62.9	58.0-67.5	4.2	2.7-6.6	92.2	89.1-94.5	6.4	4.4-9.1
> 3 minimum wages	61.2	48.7-72.4	6.8	3.1-14.3	52.0	38.5-65.3	12.3	7.0-20.7	80.0	65.3-89.5	18.3	11.2-28.3
Do not know	81.4	73.9-87.1	4.7	2.1-10.1	63.9	56.2-70.9	7.6	3.7-14.9	92.1	85.0-96.0	12.3	7.4-19.8
Ethnicity												
White and yellow	75.6	71.2-79.7***	3.7	2.3-5.9	62.8	58.5-66.9	5.9	4.0-8.6*	88.7	85.6-91.3***	9.1	6.7-12.4*
Black, brown, and indigenous	86.3	83.6-88.7	3.0	1.9-4.5	62.8	59.2-66.3	3.2	2.1-5.0	94.5	92.5-95.9	5.9	4.4-7.8

† Minimum wage was BRL 788.00 (equivalent to USD 253.00) in 2015

‡ Participants who reported the intake of white rice or brown rice in the 24-h dietary recall

§ Participants who reported the intake of white bread or whole-wheat bread in the 24-h dietary recall

*p-value < 0.05; ** p-value < 0.01; *** p-value < 0.001 in survey weighted chi-squared tests for prevalence of consumers vs. prevalence of nonconsumers

Table 2. Estimated survey-weighted mean energy and nutrient intake after replacing white rice for brown rice (model 1) on a proportional basis among São Paulo population aged over 12 years based on the 2015 Health Survey of São Paulo.

Energy and nutrients†	Observed		25% change‡		50% change		75% change		100% change		Absolute change§	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
More healthful grains (g/d)	10.1	1.0	50.9***	3.0	92.6***	4.2	134.8***	5.6	181.6***	6.5	171.5	6.6
Energy (kcal/d)	1891.4	33.8	1883.9	33.7	1876.3	33.6	1868.6	33.4	1860.0	33.3	-31.3	1.2
Carbohydrate (g/d)	241.2	4.4	239.1	4.3	236.9	4.3	234.7	4.2	232.3	4.2	-8.9	0.3
Available carbohydrate (g/d)	224.7	4.1	221.9	4.1	219.1	4.0	216.2	4.0	213.0***	3.9	-11.8	0.4
Dietary fiber (g/d)	16.5	0.3	17.1	0.4	17.8***	0.4	18.5***	0.4	19.3***	0.4	2.8	0.1
Total sugar (g/d)	84.2	2.1	84.3	2.1	84.4	2.1	84.6	2.1	84.7	2.1	0.1	0.0
Added sugars (g/d)	51.3	1.7	51.3	1.7	51.3	1.7	51.3	1.7	51.3	1.7	0.0	0.0
Protein (g/d)	79.1	1.7	79.1	1.7	79.0	1.7	79.0	1.7	78.9	1.7	-0.2	0.0
Total fat (g/d)	68.1	1.3	68.4	1.4	68.7	1.4	69.0	1.4	69.3	1.4	1.2	0.0
Saturated fatty acids (g/d)	22.4	0.5	22.4	0.5	22.5	0.5	22.5	0.5	22.6	0.5	0.2	0.0
Polyunsaturated fatty acids (g/d)	14.9	0.3	15.0	0.3	15.1	0.3	15.2	0.3	15.3	0.3	0.4	0.0
Monounsaturated fatty acids (g/d)	22.5	0.5	22.6	0.5	22.8	0.5	22.9	0.5	23.1	0.5	0.6	0.0
Vitamin B1 (mg/d)	1.7	0.0	1.7	0.0	1.6***	0.0	1.6***	0.0	1.6***	0.0	-0.2	0.0
Vitamin B2 (mg/d)	1.5	0.0	1.5	0.0	1.5	0.0	1.5	0.0	1.5	0.0	0.0	0.0
Vitamin B3 (mg/d)	31.4	0.8	31.3	0.8	31.1	0.8	31.0	0.8	30.8	0.8	-0.6	0.0
Vitamin B6 (mg/d)	1.6	0.0	1.6	0.0	1.6	0.0	1.6	0.0	1.6	0.0	0.0	0.0
Folate (DFE µg/d)	375.3	7.7	376.0	7.7	376.8	7.8	377.6	7.8	378.5	7.8	3.2	0.1
Vitamin E (mg/d)	7.5	0.2	7.5	0.2	7.6	0.2	7.7	0.2	7.8	0.2	0.3	0.0
Sodium (mg/d)	2843.0	84.3	2842.6	84.3	2842.4	84.3	2841.7	84.3	2841.2	84.3	-1.8	0.1
Calcium (mg/d)	671.0	49.6	670.9	49.6	670.9	49.6	670.8	49.6	670.7	49.6	-0.3	0.0
Potassium (mg/d)	2183.4	38.9	2188.1	39.1	2193.0	39.1	2198.0	39.2	2203.4	39.2	20.1	0.8
Iron (mg/d)	10.5	0.2	10.5	0.2	10.5	0.2	10.5	0.2	10.5	0.2	0.0	0.0
Selenium (µg/d)	68.5	1.8	68.1	1.8	67.8	1.8	67.4	1.8	67.0	1.8	-1.5	0.1
Magnesium (mg/d)	250.5	16.1	273.8***	16.4	297.6***	16.6	321.6***	17.0	348.3***	17.1	97.7	3.7
Zinc (mg/d)	10.7	0.3	10.7	0.3	10.8	0.3	10.9	0.3	11.0	0.3	0.3	0.0

DFE, dietary folate equivalents

† Values represent total daily energy and nutrients consumed by São Paulo residents (n=1741)

‡ Proportion of the population that had their white rice consumption replaced by brown rice

§ Observed vs. 100% change

Asterisks indicate statistical significance comparing whether modelled changes are 5% change or more from observed intakes. *p-value < 0.05; **p-value < 0.01; *** p-value < 0.001 in survey weighted t-tests

Table 3. Estimated survey-weighted mean energy and nutrient intake after replacing white bread for whole-wheat bread (model 2) on a proportional basis among São Paulo population aged over 12 years based on the 2015 Health Survey of São Paulo.

Energy and nutrients†	Observed		25% change‡		50% change		75% change		100% change		Absolute change§	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
More healthful grains (g/d)	10.1	1.0	22.2***	1.3	34.9***	1.7	47.6***	1.7	58.9***	1.8	48.8	1.6
Energy (kcal/d)	1891.4	33.8	1885.5	33.8	1879.4	33.7	1873.4	33.6	1867.9	33.5	-23.5	0.8
Carbohydrate (g/d)	241.2	4.4	239.9	4.4	238.5	4.4	237.1	4.3	235.9	4.3	-5.3	0.2
Available carbohydrate (g/d)	224.7	4.1	223.1	4.1	221.4	4.1	219.7	4.1	218.2	4.1	-6.5	0.2
Dietary fiber (g/d)	16.5	0.3	16.8	0.3	17.1	0.4	17.4***	0.4	17.7***	0.4	1.2	0.0
Total sugar (g/d)	84.2	2.1	84.2	2.1	84.3	2.1	84.4	2.1	84.4	2.1	0.3	0.0
Added sugars (g/d)	51.3	1.7	51.3	1.7	51.3	1.7	51.3	1.7	51.3	1.7	0.1	0.0
Protein (g/d)	79.1	1.7	79.1	1.7	79.1	1.7	79.2	1.7	79.2	1.7	0.1	0.0
Total fat (g/d)	68.1	1.3	68.1	1.3	68.1	1.3	68.1	1.3	68.1	1.3	0.0	0.0
Saturated fatty acids (g/d)	22.4	0.5	22.4	0.5	22.3	0.5	22.3	0.5	22.3	0.5	0.0	0.0
Polyunsaturated fatty acids (g/d)	14.9	0.3	14.8	0.3	14.8	0.3	14.7	0.3	14.7	0.3	-0.2	0.0
Monounsaturated fatty acids (g/d)	22.5	0.5	22.4	0.5	22.4	0.5	22.4	0.5	22.3	0.5	-0.2	0.0
Vitamin B1 (mg/d)	1.7	0.0	1.7	0.0	1.6***	0.0	1.6***	0.0	1.6***	0.0	-0.2	0.0
Vitamin B2 (mg/d)	1.5	0.0	1.5	0.0	1.4***	0.0	1.3***	0.0	1.3***	0.0	-0.3	0.0
Vitamin B3 (mg/d)	31.4	0.8	31.7	0.8	31.9	0.8	32.2	0.8	32.4	0.8	1.0	0.0
Vitamin B6 (mg/d)	1.6	0.0	1.5***	0.0	1.5***	0.0	1.4***	0.0	1.4***	0.0	-0.2	0.0
Folate (DFE µg/d)	375.3	7.7	368.5	7.7	361.4	7.6	354.4***	7.6	348.1***	7.5	-27.1	0.9
Vitamin E (mg/d)	7.5	0.2	7.7	0.2	7.9***	0.2	8.1***	0.2	8.3***	0.2	0.9	0.0
Sodium (mg/d)	2843.0	84.3	2833.3	84.3	2821.7	84.2	2810.5	83.9	2800.7	83.7	-42.3	3.0
Calcium (mg/d)	671.0	49.6	680.4	49.7	690.0	49.7	699.5	49.7	708.1	49.6	37.1	1.6
Potassium (mg/d)	2183.4	38.9	2185.6	39.0	2188.0	39.0	2190.3	39.0	2192.4	39.0	9.1	0.3
Iron (mg/d)	10.5	0.2	10.3	0.2	10.1	0.2	9.8***	0.2	9.6***	0.2	-0.9	0.0
Selenium (µg/d)	68.5	1.8	68.3	1.8	68.1	1.8	67.9	1.8	67.7	1.8	-0.8	0.0
Magnesium (mg/d)	250.5	16.1	254.7	16.2	259.1	16.2	263.5***	16.2	267.4***	16.2	16.9	0.6
Zinc (mg/d)	10.7	0.3	10.8	0.3	10.9	0.3	11.0	0.3	11.1	0.3	0.5	0.0

DFE, dietary folate equivalents

† Values represent total daily energy and nutrients consumed by São Paulo residents (n=1741)

‡ Proportion of the population that had their white bread consumption replaced by whole wheat bread

§ Observed vs. 100% change

Asterisks indicate statistical significance comparing whether modeled changes are 5% change or more from observed intakes. *p-value < 0.05; **p-value < 0.01; *** p-value < 0.001 in survey weighted t-tests

Table 4. Estimated survey-weighted mean energy and nutrient intake after replacing white rice for brown rice and white bread for whole-wheat bread (model 3) on a proportional basis among São Paulo population aged over 12 years based on the 2015 Health Survey of São Paulo.

Energy and nutrients†	Observed		25% change‡		50% change		75% change		100% change		Absolute change§	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
More healthful grains (g/d)	10.1	1.0	63.0***	3.6	117.4***	5.0	172.3***	6.2	230.3***	7.3	220.2	7.3
Energy (kcal/d)	1891.4	33.8	1878.1	33.6	1864.3	33.4	1850.6	33.1	1836.6	32.9	-54.8	1.7
Carbohydrate (g/d)	241.2	4.4	237.7	4.3	234.2	4.3	230.6	4.2	226.9***	4.1	-14.2	0.4
Available carbohydrate (g/d)	224.7	4.1	220.3	4.0	215.8	4.0	211.2***	3.9	206.5***	3.8	-18.3	0.6
Dietary fiber (g/d)	16.5	0.3	17.4***	0.4	18.4***	0.4	19.4***	0.4	20.5***	0.4	4.0	0.1
Total sugar (g/d)	84.2	2.1	84.4	2.1	84.6	2.1	84.8	2.1	85.0	2.1	0.8	0.0
Added sugars (g/d)	51.3	1.7	51.3	1.7	51.3	1.7	51.3	1.7	51.3	1.7	0.0	0.0
Protein (g/d)	79.1	1.7	79.1	1.7	79.1	1.7	79.0	1.7	79.0	1.7	-0.1	0.0
Total fat (g/d)	68.1	1.3	68.4	1.4	68.7	1.4	69.0	1.4	69.3	1.4	1.2	0.0
Saturated fatty acids (g/d)	22.4	0.5	22.4	0.5	22.4	0.5	22.5	0.5	22.5	0.5	0.2	0.0
Polyunsaturated fatty acids (g/d)	14.9	0.3	14.9	0.3	15.0	0.3	15.1	0.3	15.1	0.3	0.3	0.0
Monounsaturated fatty acids (g/d)	22.5	0.5	22.6	0.5	22.7	0.5	22.8	0.5	22.9	0.5	0.4	0.0
Vitamin B1 (mg/d)	1.7	0.0	1.6***	0.0	1.6***	0.0	1.5***	0.0	1.4***	0.0	-0.3	0.0
Vitamin B2 (mg/d)	1.5	0.0	1.5	0.0	1.4***	0.0	1.3***	0.0	1.3***	0.0	-0.3	0.0
Vitamin B3 (mg/d)	31.4	0.8	31.5	0.8	31.6	0.8	31.7	0.8	31.8	0.8	0.4	0.0
Vitamin B6 (mg/d)	1.5	0.0	1.5	0.0	1.5	0.0	1.4***	0.0	1.4***	0.0	-0.2	0.0
Folate (DFE µg/d)	375.3	7.7	369.3	7.7	363.0	7.6	356.8	7.6	351.4***	7.5	-23.9	0.9
Vitamin E (mg/d)	7.5	0.2	7.8	0.2	8.0***	0.2	8.3***	0.2	8.6***	0.2	1.1	0.0
Sodium (mg/d)	2843.0	84.3	2832.9	84.3	2820.9	84.2	2809.2	83.9	2798.9	83.7	-44.1	3.0
Calcium (mg/d)	671.0	49.6	680.4	49.7	689.9	49.7	699.3	49.7	707.8***	49.6	36.9	1.6
Potassium (mg/d)	2183.4	38.9	2190.4	39.1	2197.6	39.2	2204.9	39.2	2212.5	39.3	29.1	1.0
Iron (mg/d)	10.5	0.2	10.3	0.2	10.0	0.2	9.8***	0.2	9.6***	0.2	-0.9	0.0
Selenium (µg/d)	68.5	1.8	67.9	1.8	67.4	1.8	66.8	1.8	66.2	1.8	-2.3	0.1
Magnesium (mg/d)	250.5	16.1	278.0***	16.5	306.2***	16.7	334.6***	17.1	365.2***	17.3	114.6	4.0
Zinc (mg/d)	10.7	0.3	10.9	0.3	11.1	0.3	11.3***	0.3	11.5***	0.3	0.8	0.0

DFE, dietary folate equivalents

† Values represent total daily energy and nutrients consumed by São Paulo residents (n=1741)

‡ Proportion of the population that had their white rice consumption replaced by brown rice and white bread consumption replaced by whole wheat bread

§ Observed vs. 100% change

Asterisks indicate statistical significance comparing whether modeled changes are 5% change or more from observed intakes. *p-value < 0.05; **p-value < 0.01; *** p-value < 0.001 in survey weighted t-tests

Figure 1. Estimated survey weighted percent change in population mean intake of nutrients* per day according to substitution models based on the 2015 Healthy Survey of São Paulo. White bars represent the replacement of all white rice consumed by the population for brown rice (model 1). Light gray bars represent the substitution of all the white bread consumed by the population for whole-wheat bread (model 2). Dark gray bars represent the replacement of all white rice and white bread consumed by the population for brown rice and whole-wheat bread, respectively (model 3). Dashed gray lines represent the cut-off points for strong changes (10% or -10% change). Error bars represent standard error.

*Only nutrients that changed more 5% comparing observed and modelled intakes were presented.

Figure 2. Estimated survey-weighted percentage of more healthful grain food intake from total grain foods intake in pre-modelled (observed) and post-modelled (replacement performed in 25%, 50%, 75%, 100% of the São Paulo population) according to substitution model: model 1) white rice replaced for brown rice; model 2) white bread was replaced for whole-wheat bread; model 3) white rice was replaced for brown rice, and white bread was replaced for whole-wheat bread, 2015 Healthy Survey of São Paulo. Bars represent standard error. Dashed gray lines represent the recommendation for whole grain to total grain intake.