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REVIEW ARTICLE

The Future of Bread in View of its Contribution to Nutrient Intake as a Starchy Staple Food

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Abstract

The growing, ageing, more urbanized and more sedentary global population urges for increased, more nutritious and more secure food supply. To combat undernutrition, adequate nutrient intake is required. Staple foods, especially starch based ones, like (pseudo)cereals, roots and tubers, are by definition contributing for a very large extent to our nutrient intake. It is important therefore that the contribution of ready to consume staple foods to the recommended intakes of nutrients are compared. This can be done in a transparent and simple way by calculating the nutrient contribution of ready to eat staple foods to the recommended daily allowances (RDA) or daily reference intakes (DRI). By using online nutrition tables from the USA and Europe, and DRI by USA and RDA by European food authorities, the potential nutrient contributions of staple foods were calculated. It can be concluded that consumption of ready to eat staple foods from the bread category and lentils overall contribute most to the recommended nutrient intakes. In view of its convenience, bread, especially whole grain bread is the staple food of choice to combat the future food supply challenges ahead.

Keywords Staple foods · Nutrient intake · Undernutrition · Trend

Global Changes in Future Food Supply

Food supply has always been a concern for mankind. Challenges in the future food supply are not easy to predict, but with a high likelihood, the following changes are going to happen:

- The global population will grow to 9 or 10 billion people in 2050 [1].
- Urbanization will increase from 50% now to 70% in 2050 [2].
- The ageing population (>60 y) will increase to 418 million in 2050 [3].
- Further reduction in physical activity will occur: until 2030 a drop in required energy for human physical activity is predicted of 35% in the UK (from 1961 onwards), of 46% in the USA (from 1965 onwards) up to a 51% drop in China (from 1991 onwards [4]).
- Increased pressure on resource: wheat yields have been increased from 1962 to 2006 on average by 5.7% annually between 1962 and 2006, but the average annual increase is now levelling off to a predicted 1.7% annual growth until 2050 [5].

As a consequence of these changes, the following challenges are likely to occur:

- More food is needed to feed the growing population, whilst the food supply cannot keep pace with this population growth. Shortage in food supply is likely, especially if the growth in meat consumption continues [6], as for meat production disproportionately more cereals are required. Next to increasing crop yields, increasing the sustainability of the food supply chain is an important approach to secure food supply for the growing population. Reducing food waste, increasing land use efficiency (by reducing meat and increasing staple food consumption), but also

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increasing the digestibility of food, are ways to make the food supply chain more sustainable and secure for the future [7].

- Due to the increased urbanization people have less opportunity to grow food themselves and even own preparation at home can be troublesome since collection of firing material like wood is difficult. This requires food that is more convenient to prepare and consume.
- The large reduction in human physical activity as a result of less physical work and more sedentary life (television, computer; ageing population) [4], could result in reduced food consumption. In turn, to meet the recommended daily intakes of nutrients, the nutrient density in food needs to be elevated. If people would adapt their food consumption to the reduced physical activity, the pressure on food supply could be lessened. Unfortunately, the increase in obesity we are currently experiencing is partly caused by maintaining the consumption pattern while physical activity has reduced.
- Climate change will pose further challenges on our food security in the future, but the magnitude of this is not clear and limited amount of literature was encountered. Elevated CO_2 concentrations will increase protein deficiency by 10% *i.e*, 148 million additional protein deficient people in 2050 [8]. It is predicted that the reduction in the iron and zinc concentration in food crops due to increased CO_2 concentration, results in an additional 1.07 billion disability-adjusted life years over the period between 2015 and 2050 [9].

While the food and nutrient supply is under pressure, to feed an increasing global population, that becomes more urbanized and that is ageing and less physically active, it is of prime importance that our diet becomes more nutritious and that our food supply becomes more sustainable and secure. If not, undernutrition will become a larger health threat than it is already today.

As staple foods contribute most to our energy and nutrient intake [6], this article will focus on their potential contribution to the nutritient intake. Before zooming in on this, undernutrition as one of our main health issues will be discussed.

Undernutrition: An Underestimated Health Threat

Although obesity and overweight with 2.3 billion people affected worldwide [10] receive a lot of attention as an important health issue, undernutrition affects globally more people and is a more costly health threat for the world population, both in developing countries and the developed countries. Overt malnutrition which is mainly energy and protein intake related, affects ca. 800 million people [6], while 1.6–2 billion people are at risk for hidden malnutrition, *i.e*, micronutrient deficiencies [11]. Reduction of food intake as a consequence of reduced physical activity [4] will further increase the risk of micronutrient deficiencies.

The prevalence of stunting in children under five is globally projected in 2020 to be ca. 24% [12], whereas worldwide prevalence of childhood overweight and obesity is estimated to reach 9.1% in 2020 [13]. Undernutrition is a well-known health issue in developing countries, but recent reviews indicate serious undernutrition problems in developed countries in elderly homes (6–15% [14]) and hospitals (up to 50% [15]). While availability of food with adequate nutrient contents is the main cause of the undernutrition in children, insufficient consumption of food by less appetite and consumption of food with low nutrient contents but high in energy are the main causes of undernutrition of elderly or ill people.

Although obesity and undernutrition seem to be opposites, both can go hand in hand. Scientific literature is limited, but a few small scale studies have shown that there is higher prevalence of stunting in children of obese mothers who consume foods with low nutrient density [16], there is elevated stunting and anemia of children from obese mothers [17] and there is increased micronutrient deficiency in obese people [18, 19]. In a study with Mexican children, 25–50% of the obese children were chronically undernourished as evidenced by their stunting [20].

One important way to combat undernutrition is to increase the consumption of food with adequate nutrient contribution to the diet. Therefore it is important to compare foods with respect to their nutrient contribution to the recommended intakes.

Nutrient profiling should be transparent, simple and relevant to make clear comparisons between foods. Methods to assess the nutrient density of raw materials for food or prepared foods have received quite some attention and the pitfalls of complex algorithms, biased selection criteria for nutritional importance for inclusion or exclusion are excellently reviewed by Drewnowski and Fulgoni [21]. As current data on energy are mostly calculated and not taking the effect of the food matrix on digestibility and hence the true energy absorption into account [7] expressing nutrient density on energy basis, will introduce considerable errors. Despite their pledge for simple and transparent nutrient profiling, Drenowski and Fulgoni [21] use complex calculations to determine nutrient scores, so there is still a need for more straightforward profiling.

Most of the nutrition density evaluations are concerning the full breadth of unprocessed and processed foods, making comparisons from one category of foods with another category difficult [21]. Overviews of nutrient contribution by ready to eat staple foods, were not encountered in literature.

Further, in non-scientific publications often nutrient densities of raw materials in dry form without processing are compared. Mostly these comparisons are not relevant and invalid as many foods, especially staple foods, cannot be consumed unprocessed.

The composition of foods will vary due to compositional variability and analytical differences. Also recommended daily intakes may vary from region to region. As a consequence the contributions to the nutrient intake will vary. Therefore the potential contributions of staple foods to the recommended intakes from a few regions need to be compared to be able to draw more generic conclusions. These comparisons should be based on simple, straightforward and transparent calculations.

Various online nutrient tables are nowadays available. In many the amount of detail in nutrient values and the breadth of foods, especially processed foods is limited. Therefore two nutrition tables with sufficient detail and breadth from two different regions were used in this review. By making use of USA Food Nutrition Table and the Dutch Nutrition Table, the potential contributions to nutrient intake by the most important staple foods were calculated based on the recommended daily intake of the nutrients that are nutritionally relevant according to the advice of the US and EU health authorities [22, 23]. These comparisons are transparent, straightforward and simple, so general conclusions can be drawn about the potential contributions to nutrient intake by ready to eat staple foods.

Data Collection

Staple food can be defined as a food that is eaten routinely, and in such quantities that it constitutes a dominant portion of a standard diet of a population, supplying a large fraction of the needs for energy and of nutrients [6, 24]. This article focusses on starchy staple foods such as rice, wheat, maize (corn), pseudocereals (millet, sorghum, teff, quinoa), roots and tubers (potatoes, cassava, yams, taro), and excludes animal products such as meat, milk, eggs, cheese and fish. Ready to eat cereals and granola are according to the FAO definition not regarded as staple foods, so these foods were not included in the analyses.

Food composition data of all the ready to consume staple foods (cooked or baked, *i.e*, not on a dry basis) were collected from the online USDA National Nutrient Database for Standard Reference [25] and the Nederlands Voedingsstoffenbestand [Nevo; 26] by searching on the starchy staple food names and their synonyms. In addition, in the USDA National Nutrient Database for Reference, the food groups that could contain staple foods were completely searched. In order to focus on general starchy staple food compositions and to avoid the risk of not being representative, specific foods with commercial names were excluded. The quality of the data is extensively discussed in both references to the food tables. In short, data come from scientific and institutional publications and information provided by industry. Unfortunately the data are only validated to a limited extent and the nutrition table with scientifically validated data (Souci Fachmann Kraut; www.sfk-online.net/) does contain too limited data on prepared staple foods to be useful for this review. In addition to this one needs to keep in mind that not all nutrients are 100% available and that nutrient content data are higher than nutrient bioavailiability data [7]. Despite the limited validation, the data from the databases are used for nutritional policies of the USA and EU authorities and legal enforcement of food declarations by food authorities and are regarded here as sufficiently valid enough to use them in the comparisons in this review. Although some data are based on single observations, most data are averages from more than 2 up to 55 different sources. Prepared staple foods available in the food composition tables varied from processed cereals, pseudocereals, lentils, tubers to plantain. Despite the provenance of the data from USA and EU, also data of a broad range of staple foods that were not endogenous to these two regions were available it the nutrition tables. Processing methods to prepare the staple foods for consumption were mainly baking and boiling. In bread processing salt and yeast will have increased the micronutrient content. In the USDA National Nutrient Database no information was available on processed cassava and therefore the composition of the raw cassava had to be taken. It reported that further processing like boiling decreases its nutritional value and the vitamin levels can be reduced between 25 and 60% [26]. The data for raw cassava are therefore an overestimation. Further, only foods were selected that were not enriched with vitamins and minerals, except for bread. Bread from the Netherlands in which salt was used enriched with iodine [27]. Therefore the data on iodine were excluded in all staple foods. In the case of the bread data from the USA it was not indicated if the flours were enriched with vitamins and minerals. From the data of chapatti (code 28306 in [25]), wheat bread (code 18064 in [25]), white bread (code 18069 in [25]), naan (code 28307 in [25]) and raisin bread (code 18047 [25]) it could be derived that the products were enriched with iron, thiamin, riboflavin and niacin. Using the levels of enrichment of these micronutrients as given in the Code of Federal Regulations §137.165 on enriched flour [28] and assuming that 62.5% of the breads consisted of white flour, the amounts of micronutrient enrichments were subtracted, to estimate the non-enriched levels of these micronutrients. For raisin bread a level of 12.5% of raisins was estimated (based on the potassium levels of flour and raisins) and the fortified flour level was adjusted accordingly. If a negative micronutrient level resulted, the corrected level of wheat bread (18064) was used. As calcium enrichment is not compulsory in the USA [28], calculation of the non-enriched levels is difficult. It can be calculated however, that in the case calcium enrichment took place this would result in a maximum increase in contribution of 1.2% to the average contribution of all minerals to the DRI. This will not alter significantly the comparison with the average mineral contribution of other starchy staple foods.

Recommended Daily Intakes of Nutrients

The USA dietary reference intakes (DRI) and adequate intake (AI [22]), or the EU recommended daily allowances (RDA [23]) and recent scientific opinions on intakes of fibre [29] and protein [30] were used to select the nutritionally relevant nutrients and to calculate the contribution to the intake of this nutrient if 100 g of the staple food would be consumed. The maximum RDA or AI excluding those for pregnant or lactating women, were selected, which were mainly those for adult men. For the EU protein AI, a body weight of 70 kg was used. The guidelines are shown in Table 1. Although there are recommendations for cobalamine and C22:6 n-3 cis decosahexaenoic acid (DHA) intake in Europe, the Nevo Table did not contain sufficient data of these two nutrients to have them incorporated in this analysis.

Table 1 USA dietary reference intakes (DRI) and adequate intake (AI [22]) and the EU recommended daily allowances [23] of nutrients and recent scientific opinions on intakes of fibre [29] and protein [30]

RDI/AI		USDA	EFSA
Energy	kJ		8400
Energy	kCal		2000
Protein	g	56	58
Carbohydrate	g	130	
Fiber, total dietary	g	38	25
Calcium	mg	1300	800
Iron	mg	18	14
Magnesium	mg	420	375
Phosphorus	mg	1250	700
Potassium	mg	4700	2000
Sodium	mg	1500	2400
Zinc	mg	11	10
Copper	mg	0.9	1
Manganese	mg	2.3	
Selenium	μg	55	55
Fluoride	μg	4000	
Iodine	μg		150
Retinol equivalent (A)	μg		800
Vitamin C	mg	90	80
Thiamin (B1)	mg	1.2	1.1
Riboflavin (B2)	mg	1.3	1.4
Niacin (B3)	mg	16	16
Pantothenic acid (B5)	mg	5	
Vitamin B6	mg	1.7	1.4
Folate (B9)	μg	400	200
α-tocopherol (Vitamin E)	mg	15	12
Vitamin D	μg	20	5
Vitamin K	μg	120	75

The highest levels are taken, which were in most cases for men. For protein [30] a body weight of 70 kg was taken

Protein quality, especially the presence and quantity of essential amino acids, is nutritionally important. As there are no recommended intake levels set by the EU and USA authorities, they have not been included. Despite that some nutrients (fluoride, vitamins B12, C and D) in the DRI or RDA are not present in most of the starchy staple foods, they were still kept in the calculations for transparency reasons.

Contribution to the recommended nutrient intake by consumption of 100 g prepared product was calculated to enable a direct comparison of the foods as consumed, rather than nutrient density on energy basis. The energy content of food and to a lesser extent the weight of food, slightly, but significantly affect satiety [31] and as a consequence they influence intake. This would favour a comparison of nutrient intake on energy basis. However, when nutrient content is calculated on energy basis, data become less transparent and comparisons between foods are more complicated. For example wholemeal bread (233 kcal/100 g, 6.6% fibre [27]) contains 50% more fibre on an energy basis than boiled potatoes (83 kcal/100 g, 1.6% fibre [27]). In contrast, on a ready to eat basis, wholemeal bread contains 413% more fibre than potatoes. In other words, to eat the same amount of fibre as wholemeal bread one would need to eat more than 4 times the amount of boiled potatoes. Therefore comparison of intakes on energy basis was not preferred in this review. As a consequence of the approach to use the food as is and not on an energy basis, the moisture content of the prepared foods will have a major influence on the contribution to the nutrient intake.

Intakes of staples may vary substantially from 90 g *per* day for bread in the UK [32] to 2000 g for sweet potato and sago pudding in rural Papua New Guinea [33]. It was therefore chosen to express the nutrient content *per* 100 g.

The weighted average contribution to the recommended intakes of minerals and vitamins were calculated, *i.e*, when data on one nutrient were not available in the nutrition tables, the averages were only calculated on the reported data. In this way it is possible to make simple comparisons. Although some vitamins and minerals will be nutritionally more important than others, for transparency and bias reasons, all vitamins and minerals were treated equal and no complex calculations were used to obtain a nutritional score.

Next to the previous comparisons on 100 g basis, comparisons were made between the average amount of wholemeal bread consumed *vs* the weights of other starchy staple foods required to match the DRI of AI of nutrients or nutrient groups.

Potential Contribution of Staple Foods to Recommended Nutrient Intakes

In Supplementary Tables 1 and 2 the contribution of staple foods to the recommended nutrient intakes is given. Large variations exist in the contributions of the macronutrients protein (1–24% of AI for USA data and 1–21% of AI for EU data), carbohydrates (15–40% of AI; USA data), energy (4–16% for AI; EU data) and fibre (1–21% of AI for USA data and 3–33% of AI for EU data). There is also substantial variation within the contribution to the DRI or RDA of groups of micronutrients of minerals (3–26% of DRI for USA data and 3–25% of RDA for EU data) and of vitamins (1–15% of DRI for USA data and 1–8% for EU data). Despite the lower RDA levels for many vitamins in the EU, the vitamin levels in starchy staples in the Nevo Food composition table are far less than the vitamin levels in staples according to the USDA food composition table. This explains the lower contribution of staple foods to the recommended intake level in the EU compared with those from the USA.

If one classifies the staples in categories (bread, lentils, pasta/noodles, pseudocereals/corn, rice, tubers and plantain; Figs. 1 and 2) it is possible to get a clear overview of the potential contribution of the staples to the nutrient intake if 100 g product is consumed. The bread category contributes most to the macronutrients (protein and fibre; Fig. 1a and 2a; carbohydrate and energy not shown), followed by lentils. Similarly the contribution to the mineral intake by the bread category is the largest (USA; Fig. 1b) or one of the largest (EU; Fig. 2b). Lentils score higher on the mineral density if the EU standards are used. The bread category is also one of the most important staple category contributing to the vitamin intake (USA; Fig. 1b). According to the EU standards, the bread category has a similar contribution to the vitamin intake as the pseudocereals/corn category and less than plantain (Fig. 2b). An important reason for this difference is the water content of bread, which is about half (28–46%) of those of other staple foods (60–84%; data not shown).

Although sodium is one of the recommended minerals [22, 23], in view of its negative effects on health [34] the intake

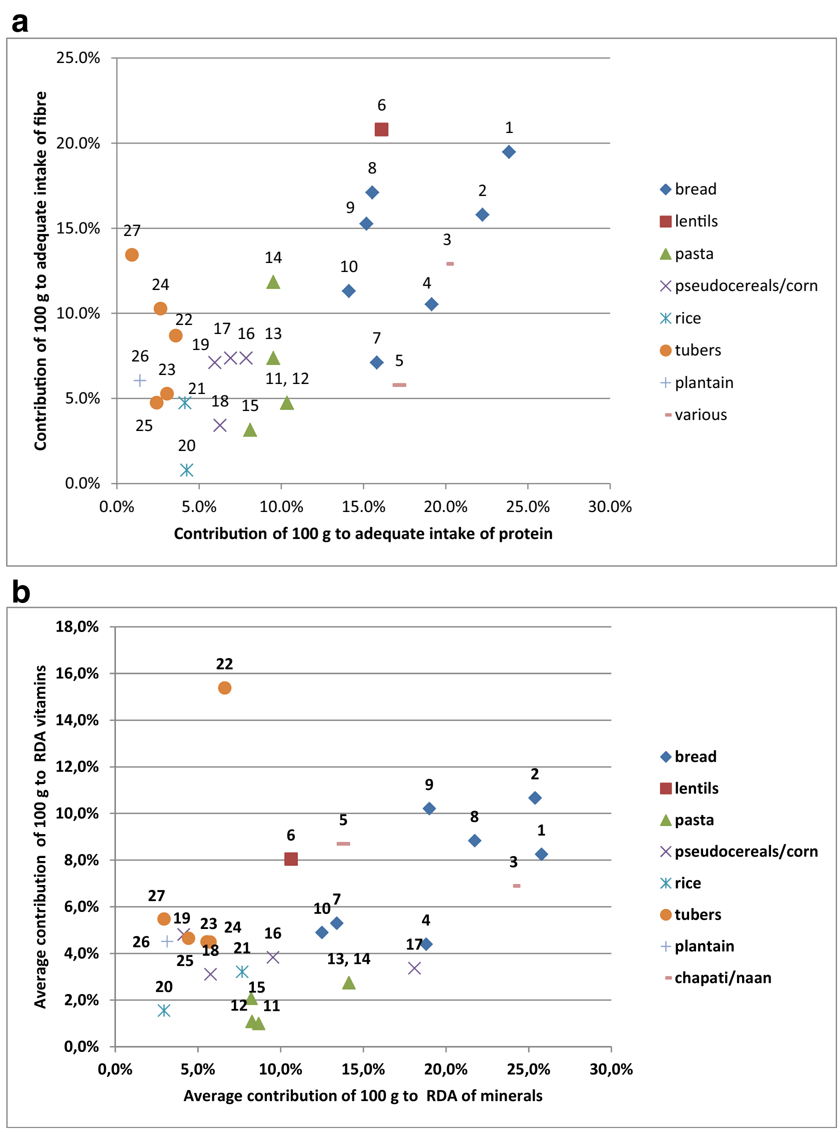

Fig. 1 Contribution of 100 g of staple foods to USA dietary reference intakes (DRI) and adequate intake (AI; based on Table 1 and [22]) of protein and fibre (**a**) and average vitamin and mineral contribution (**b**); numbering of the foods is indicated in Supplementary Table 1. Bread (◊), lentils (□), pasta (Δ), pseudocereals /corn (x), rice ( ), tubers (○), plantain (+), various (−)

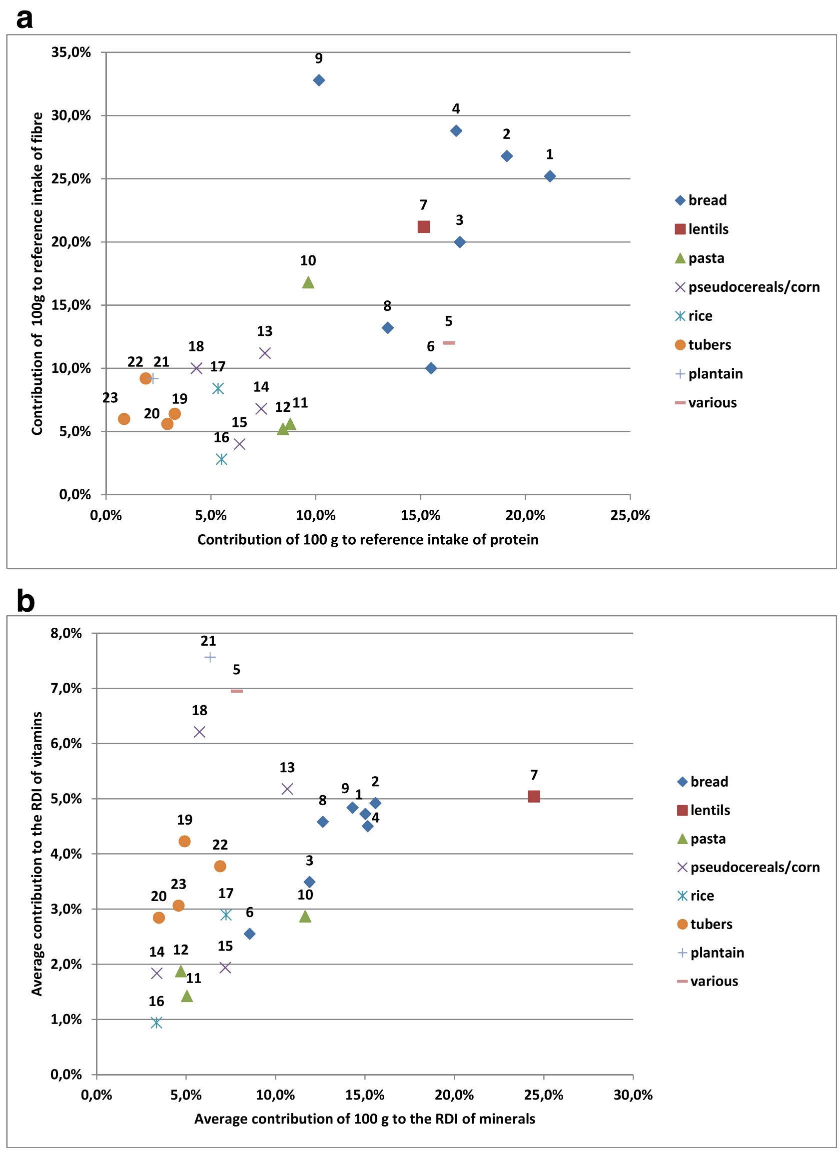

Fig. 2 Contribution of 100 g of staple foods to EU recommended daily allowances (RDA) and adequate intake (AI; based on Table 1 and [23, 29, 30]) of protein and fibre (**a**) and average vitamin and mineral contribution (**b**); numbering of the foods is indicated in Supplementary Table 2. Bread (◊), lentils (□), pasta (Δ), pseudocereals /corn (x), rice ( ), tubers (○), plantain (+), various (−)

should be reduced. All breads in this overview contain added salt and this significantly contributes to the DRI of sodium (23–40% of the USA data and 15–21% for the EU data). If salt would have been completely removed, this would decrease the average contribution to the mineral intake by bread, at maximum with 2%. The effect on the overall comparison between the staple foods will be small.

To visualise the differences in staple food volumes that match intakes of nutrients, the amounts of some staple foods required to match the RDI or AI of nutrients from 160 g of whole grain bread is provided in Table 2. 160 g (59 kg/person/year) is the average daily bread consumption across several European countries [32] and USA [35]. It should be kept in mind that not 100% of the bread consumed is whole grain bread. The overall trend is clear, however, that with the exception of lentils, more than double the amount of staple foods need to be consumed to match the contribution to the DRI and AI of protein, fibre, minerals and vitamins provided by whole grain bread. Surprisingly white bread scores quite well in comparison with most staple foods in the table. Also surprising is that 'super foods' like quinoa or teff need to be consumed 40% more up to 3.2 times more to match the contribution to DRI or AI from 160 g whole grain bread. On a dry matter teff excels most staple foods in nutrient content [36], but when evaluated on a cooked basis it loses its nutrient density because of its water uptake.

Therefore one can question what is so 'super' in their nutritional contribution. Finally, in a normal diet consumption of 1100–3200 g of staple food (white spaghetti, white rice or potatoes) to match the contribution to some nutrient intakes from 160 g of whole grain bread will be difficult to achieve.

Table 2 Contribution of 160 g of wholemeal bread to USA dietary reference intakes (DRI) and adequate intake (AI) of nutrients based on Table 1 and [22] and comparison of weight of some other staple foods required to contribute to the same level of DRI and AI of nutrients

	protein	fiber	minerals	vitamins
Contribution of 160 g to RDI or AI (%)				
18,075, Bread, whole-wheat, commercially prepared	36	25	41	17
Amount of staple food required to equal DRI or AI 160 g of 18,075 whole-wheat bread (g)				
16,070, Lentils, mature seeds, cooked, boiled, without salt	221	122	382	212
18,069, Bread, white, commercially prepared (includes soft bread crumbs)	225	356	303	322
20,421, Spaghetti, cooked, unenriched, without added salt	343	533	469	1710
20,125, Spaghetti, whole-wheat, cooked	374	213	287	622
20,410, Noodles, egg, cooked, unenriched, without added salt	439	800	494	822
20,137, Quinoa, cooked	453	343	426	445
20,143, Teff, cooked	515	343	224	507
20,451, Rice, white, medium-grain, cooked, unenriched	837	3200	1377	1100
20,041, Rice, brown, medium-grain, cooked	859	533	529	531
11,833, Potatoes, boiled, cooked without skin, flesh, with salt	1165	480	733	379

numbers in front of staple food are reference numbers of foods in [25] 25

The Future of Bread as a Nutritious Staple Food

The growing, ageing, more urbanized and more sedentary global population urges for increased, more nutritious and more secure food supply. Undernutrition is increasingly a health threat both in developing and developed countries. To combat this, adequate nutrient intake is required. Staple foods are by definition contributing for a very large extent to our nutrient intake. If the contribution of prepared staple foods to the recommended nutrient intake is reviewed, one can conclude that the most important staple food category to contribute to macronutrient, mineral and vitamin consumption is the bread category. Lentils form a good second option. Similar importance is found using the data (recommended intakes and food composition tables) from USA and EU.

It is surprising that on a consumable basis, even white bread is surpassing pasta, pseudocereals, rice and tubers in its contribution to many of the relevant nutrients. Eating the bread category wholemeal or multigrain bread potentially provides the largest contribution to the recommended intakes of nutrients. One point of attention is the relative large contribution to the RDI of sodium by the bread category. Obviously sodium is a nutrient to limit and its content should be further reduced.

As bread does not require further preparation and can be readily consumed, it is more convenient in an urbanized environment. It is already observed that bread consumption in areas where it was not a common staple food, is increasing. For example, in Africa wheat consumption *per* capita increased from 1980 to 2008 by 44% likely due to its convenience and reduced preparation time [37]. Also in Asia bread consumption is on the rise, for example in China baked goods consumption increased 45% between 2010 and 2015. A further growth is expected until 2020 by another 33% [38]. Another type of convenience is the concentration of nutrients which is highest in the bread category and lentils. As a consequence the volume that needs to be eaten is relatively low: to match the intake of some nutrients from 160 g of whole grain bread 1100–3200 g white spaghetti, white rice or boiled potatoes need to be consumed.

As there is a gap between nutrient content and nutrient bioavailability [7], there is also room for further increasing the bioavailability. One important aspect determining the bioavailiability are the effects of anti nutritional components. These components inhibit the digestibility or availability of nutrients and adequate processing is required to mitigate their negative effect [39–41]. Processing is not always adequate and some anti nutritional activity will remain [42] or even can be enhanced by processing [43]. Further research is required to increase digestibility of staple foods by mitigating the anti-nutritional factors.

Conclusions

As demonstrated bread is intrinsically beneficial to become even more important as the food that is able to cope with future food supply challenges. As a ready to eat staple it is convenient to consume and potentially can contribute significantly to the daily recommended intakes of protein, fibre, vitamins and minerals. Next to lentils it is outstanding in nutrient supply. Still some other challenges remain and need further exploration, such as increasing the sustainability of the supply chain by reducing waste, reducing the sodium content and improving the digestibility of baked goods.

Compliance with Ethical Standards

Conflict of Interest There is no conflict of interest by Peter L. Weegels regarding the manuscript.

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