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The bioavailability of iron, zinc, protein and vitamin A is highly variable in French individual diets: Impact on nutrient inadequacy assessment and relation with the animal-to-plant ratio of diets

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ABSTRACT

Nutritional adequacy depends on nutrient intakes and bioavailability which strongly varies with the plant- or animal-origin of foods. The aim was to estimate iron, zinc, protein and vitamin A bioavailability from individual diets, and investigate its relation with the animal-to-plant ratio (A/P) of diets. Bioavailability was estimated in 1899 French diets using diet-based algorithms or food-group specific conversion factors. Nutrient inadequacy was estimated based on i) bioavailability calculated in each individual diet and ii) average bioavailability assumed for Western-diets. Mean iron absorption, zinc absorption, protein quality and β-carotene conversion factor were 13%, 30%, 92%, and 17:1, respectively. Bioavailability displayed a high variability between individual diets, poorly explained by their A/P. Using individual bioavailability led to different inadequacy prevalence than with average factors assumed for Western-diets. In this population, the A/P does not seem sufficient to predict nutrient bioavailability and the corresponding recommended intakes. Nutritional adequacy should be assessed using bioavailability accounting for individual diets composition.

1. Introduction

The current food system has a substantial impact on the environment. A growing body of research suggests that food patterns change has a role in addressing the environmental impacts of diets (Garnett, 2011). There is a need to promote and consume sustainable diets, i.e. nutritionally adequate, culturally acceptable, economically affordable and with low environmental impact (FAO, 2010). With livestock sector representing 14.5% of all human-induced GHG emissions (Gerber et al., 2013), and animal-based products identified as the highest emitters in the diet (Masset, Soler, Vieux, & Darmon, 2014), the reduction of meat consumption has emerged as a main lever for mitigating the environmental impact of diet (Garnett, 2011; Perignon, Vieux, Soler, Masset, & Darmon, 2017). In parallel, public health authorities recommend to eat mostly foods of plant origin and to limit the consumption of red and processed meats (WCRF-AICR, 2007). However, animal products are a valuable source of nutrients. Hence reducing their consumption may lead to some nutritional deficiencies, especially for nutrients only found in animal products (e.g. vitamin B12), or for which the principal and/or best sources are animal (e.g. protein, iron and vitamin D) (Millward & Garnett, 2010). Nutritional adequacy actually depends on total nutrients intake but also on their bioavailability, defined as the proportion of an ingested nutrient that is absorbed and utilized through normal metabolic pathways (Gibson, 2007). The bioavailability is known to be modified by (i) host-related factors such as age, sex, genotype, nutritional status and health status, and (ii) dietary and culinary factors, including the chemical form of the nutrient, nature of the dietary matrix, food processing and cooking, presence of enhancers and inhibitors of absorption in the diet (Gibson, 2007). Most of those dietary factors are influenced by the animal-to-plant ratio of the diet. Hence, the bioavailability of several key nutrients, in particular iron, zinc, protein and vitamin A (VA), was reported to strongly depend on whether they are from plant- or animal-origin (Gibson, 2007; WHO-FAO, 2004; WHO/FAO/UNU, 2007). In a context of promotion of more sustainable diet, with reduced consumption of animal product to mitigate the environmental impact of diet, the question of bioavailability of these nutrients should be addressed. In particular,

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the transition towards diets with less animal-sourced foods might question the relevance of using established average bioavailability factors when assessing inadequate nutrient intakes.

The objective of the present study was to estimate iron, zinc, protein and VA bioavailability factors in each individual diet of adults participating in the last French national dietary survey, and study their relationship with the animal-to-plant ratio of the diet.

2. Material and methods

2.1. Population sample and food consumption data

Dietary intakes were derived from the 7-day food records of a nationally representative stratified random sample of French adults (n = 2624; age > 18 y) participating in the Second French Individual and National Study on Food Consumption cross-sectional dietary survey (*Étude Individuelle et Nationale sur les Consommations Alimentaires*, INCA2), conducted in 2006–2007 by ANSES (French agency for food, environmental and occupational health safety) (Lafay et al., 2009). After exclusion of energy under-reporters using Black equations (Black, 2000) and individuals consuming hypo-caloric meal substitutes, the present analysis was conducted on a final sample of 1899 adults, aged 47.1 ± 15.3 y of whom 1126 were women.

2.2. Food composition data

The CIQUAL (*Centre d'Information sur la Qualité des Aliments* – Information center on food quality) database associated with the INCA2 survey gives the detailed nutrient composition of all the foods declared to be consumed by the participants (n = 1342 foods and beverages, including water). To add the contents of food components required to estimate bioavailability, data were collected from other sources and matched with 402 food items selected among the most consumed by INCA2 participants. Phytate and amino acid contents were extracted from the WorldFood Dietary Assessment System 2 developed by the International Network for Food Data Systems (INFOODS) (International Network of Food Data Systems (INFOODS), 2016); the heme iron/total iron ratio was collected from the French Meat Information Center (Centre d'Information des Viandes & INRA, 2009) and completed by values from the literature for fish and poultry products (Kongkachuichai, Napatthalung, & Charoensiri, 2002); and the contents of pro-VA carotenoids other than β-carotene (α-carotene and β-cryptoxanthin) were extracted from the USDA National Nutrient Database for Standard Reference (SR25) (USDA, 2016). For foods containing several ingredients, food component contents were estimated according to the recipes provided with the INCA2 survey. The intakes of the 1342 foods declared to be consumed by INCA2 participants were aggregated into the 402 foods as described elsewhere (Perignon et al., 2016).

2.3. Calculation of bioavailability factors

The generic term of "bioavailability factors" used in the present study concerns different aspects of bioavailability depending on the nutrient concerned. It refers to i) the absorption efficiency for iron and zinc, ii) the conversion factor (accounting for absorption and bioconversion) for pro-VA carotenoids, and iii) the quality (accounting for digestibility and biological value) for protein. Bioavailability factors were estimated in each self-selected individual diet. Means ± SD were then estimated by gender and for the whole population.

2.3.1. Estimation of iron absorption

Non-heme iron absorption was estimated for each individual diet using the diet-based algorithm developed by Armah, Carriquiry, and Sullivan (2013), as follows:

$$\begin{aligned}\ln(\%\textit{non-heme iron absorption}) = {} & 6.294 - 0.709\ \ln(\mathrm{SF}) \\ & + 0.119\ \ln(C) + 0.006\ \ln(MFP \\ & + 0.1) - 0.055\ \ln(T + 0.1) \\ & - 0.247\ \ln(P) - 0.137\ \ln(Ca) \\ & - 0.083\ \ln(NH)\end{aligned}$$

SF: serum ferritin (μg/L), C: vitamin C (mg), MFP: meat, fish, and poultry (g), T: tea (number of cups), P: phytate (mg), Ca: calcium (mg), and NH: nonheme iron (mg).

Heme iron absorption was estimated for each individual diet using the following equation developed by Hallberg and Hulthén (2000):

$$\mathrm{Log}\ (\%\textit{heme iron absorption}) = 1.9897 - 0.3092 \times \log SF$$

Individual serum ferritin (SF) concentrations were not available and were set to 15 μg/L, i.e. the cut off value for an absence of iron stores (WHO-FAO, 2004), to estimate the maximum absorption from each individual diet and assess the sole influence of dietary factors.

The total iron absorption was then calculated as follows:

$$\textit{Total iron absorption} = \frac{(\textit{heme iron intake} \times \%\textit{heme iron absorption}) + (\textit{non heme iron intake} \times \%\textit{non heme iron absorption})}{\textit{total iron intake} \times 100}$$

2.3.2. Estimation of zinc absorption

The total amount of absorbed zinc was estimated for each individual diet using the following algorithm developed by Miller, Krebs, and Hambidge (2007):

$$\begin{aligned}TAZ = 0.5 \times \Bigg\{ & 0.13 + TDZ + 0.10\left(1 + \frac{TDP}{1.2}\right) \\ & - \sqrt{\left(0.13 + TDZ + 0.10\left(1 + \frac{TDP}{1.2}\right)\right)^2 - 4 \times 0.13 \times TDZ}\Bigg\}\end{aligned}$$

TAZ: total absorbed zinc (mmol), TDZ: total dietary zinc (mmol) and TDP: total dietary phytate (mmol). Zinc absorption was then calculated as the ratio TAZ/TDZ.

2.3.3. Estimation of pro-vitamin A carotenoids conversion factors

Retinol equivalents (RE) from three pro-vitamin A carotenoids (β-carotene, α-carotene and β-cryptoxanthin) were calculated for each individual diet using food or food-group specific conversion factors extracted from the literature. For β-carotene, a conversion factor (on a weight basis) of 21:1 was used for spinach (Tang, Qin, Dolnikowski, Russell, & Grusak, 2005), 14:1 for carrot (Parker, Swanson, You, Edwards, & Huang, 1999;Tang et al., 2005), 12:1 for fruits (de Pee et al., 1998; Khan et al., 2007), 27:1 for other vegetables (Haskell, 2012), 3.2:1 for maize (Muzhingi