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► To cite this version:

Mathieu Maillot, Adam Drewnowski, Florent Vieux, Nicole N. Darmon. Quantifying the contribution of foods with unfavourable nutrient profiles to nutritionally adequate diets. *British Journal of Nutrition*, 2011, 105 (8), pp.1133-1137. 10.1017/S0007114510004800 . hal-02647531

HAL Id: hal-02647531

<https://hal.inrae.fr/hal-02647531>

Submitted on 29 May 2020

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1 **TITLE PAGE**

2 **Title:** **Quantifying the contribution of foods with unfavourable nutrient profiles to**
3 **nutritionally adequate diets**

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6
7 **Authors**

8 Matthieu Maillot¹⁻², Adam Drewnowski³, Florent Vieux¹⁻², Nicole Darmon¹⁻².

9 ¹ INRA, UMR1260 « Nutriments Lipidiques et Prévention des Maladies Métaboliques », Marseille,
10 F-13385 France.

11 ² Univ Aix-Marseille 1, 2, Faculté de Médecine, IPHM-IFR 125, Marseille, F-13385 France

12 ³ Nutritional Sciences Program and Center for Public Health Nutrition, School of Public Health and
13 Community Medicine, University of Washington, Seattle, WA 98195-3410

14
15 **Corresponding author**

16 Nicole Darmon

17 UMR INRA 1260 / Universités AIX-MARSEILLE I & II

18 Nutriments Lipidiques & Prévention des Maladies Métaboliques

19 Faculté de Médecine de la Timone, 27 Bd Jean Moulin

20 13385 Marseille Cedex 05 - FRANCE

21 Tel: ++ 33- 4 91 29 40 97 – Fax: ++ 33- 4 91 78 21 01

22 E-Mail: nicole.darmon@univmed.fr

23
24 **Running title:** Nutrient profile shift to reach nutrient adequacy

25 **Keywords:** Standards, Classification, Linear models, Nutritive value, Foods

26 **Word counts:** 3057 (text + references)

27

28 Abstract

29 That “all foods can fit” into a healthy diet is a long-standing principle of dietetic practice. This
30 study quantified the relative contributions of foods to encourage and foods to limit, using new
31 techniques of individual diet optimization and nutrient profiling. Individual foods from every food
32 group were assigned into 4 nutrient profile classes based on the French SAIN,LIM system. Foods
33 with the most favourable nutrient profiles were in class-1 and foods with the least favourable
34 nutrient profiles were in class-4. An optimized diet, that met the recommendations for 32 nutrients
35 and that respected the existing eating habits, was designed for each adult in the nationally
36 representative INCA1 dietary survey (n=1,171). The relative proportions of the 4 nutrient profiling
37 classes were assessed before and after the optimization process. The contribution of fruits and
38 vegetables, whole grains, milk, and fish was significantly increased, whereas the contribution of
39 refined grains, meats, mixed dishes, sugars and fats was decreased. The optimized diets derived
40 more energy (30% vs 21% in the observed diets) from class-1 foods and less energy (41% vs 56%)
41 from class-4 foods. They also derived a higher amount of class-1 foods (61% vs 51%) and a lower
42 amount of class-4 foods (22% vs 32%). Thus, nutrient adequacy was compatible with the
43 consumption of foods with an unfavourable nutrient profile (one-fifth the basket weight) provided
44 that the diet also contained almost two-third of foods with the most favourable profile. Translating
45 these results into concrete and quantified advice may have very tangible public health implications.

46

47 **Introduction**

48 It is well established that healthful diets^(1,2) ought to contain low-fat dairy products, fish and lean
49 meats, beans and legumes, and plenty of vegetables and fruit⁽³⁻⁵⁾. However, much of dietary advice
50 is still based on nutrients to avoid. Consumers are advised to limit the intake of saturated fatty
51 acids, sugar, and sodium⁽⁶⁻⁸⁾ and to eat sparingly foods that contain those nutrients in excess^(1,4).
52 Missing from nutrition education messages are many processed foods⁽⁹⁾ and mixed foods belonging
53 to more than one food group⁽¹⁰⁾.
54 The 2005 Dietary Guidelines for Americans⁽¹¹⁾ identified nutrient density of foods as a novel
55 strategy for nutrition education and positive dietary guidance. Consumers selecting nutrient dense
56 foods and beverages would be able to satisfy daily nutrient requirements without exceeding their
57 daily energy needs⁽¹¹⁾. Supplemental “discretionary” calories, defined as the balance of calories
58 remaining after satisfying nutrient needs, could then be consumed in proportion to energy allowance
59 ⁽¹¹⁾. Nutrient dense foods were described as those that provided relatively more nutrients than
60 calories, whereas the amount of discretionary calories was set low⁽¹²⁾.
61 The new science of nutrient profiling⁽¹³⁻¹⁵⁾ can classify individual foods based on their overall
62 nutritional quality. Nutrient profiling can help distinguish between nutrient-rich foods that provide
63 more nutrients than energy and those foods that are energy-rich but nutrient-poor⁽¹⁶⁾. Given that
64 lower scoring foods can be more enjoyable and may provide energy at a lower cost⁽¹⁷⁾, calculating
65 their relative proportion in a healthy diet is a question of both public health and consumer
66 importance. Coupling the new techniques of nutrient profiling⁽¹⁴⁾ and individual diet
67 optimization⁽¹⁸⁾, the objective of the present study was to quantify the shift in food intakes from
68 different nutrient profile classes needed to reach nutritional adequacy, while taking into account
69 individual dietary patterns and preferences.

72 **Methods**

73 Dietary data

74 The data used in the present study were based on dietary data collected from 1171 adults (age > 18
75 years) in the cross-sectional dietary survey "Enquête Individuelle et Nationale sur les
76 Consommations Alimentaires" (INCA), conducted in 1999 by the French National Agency for Food
77 Safety⁽¹⁹⁾. Habitual food intakes were estimated using a 7-d food diary recorded by all participants.
78 Energy and nutrient intakes were calculated for each participant using the French food composition
79 database, previously described⁽²⁰⁾.

80 The SAIN, LIM nutrient profiling system

81 The SAIN, LIM scoring system was applied to each food in the food database. After exclusion of
82 drinking water, diet beverages, tea, coffee and fortified foods, the remaining 613 foods were
83 aggregated in 10 food-groups. The French SAIN,LIM system was described in details elsewhere⁽¹⁴⁾.
84 Briefly, it assigned each food to one of 4 classes, based on two independent subscores. The positive
85 SAIN subscore was the mean percent nutrient adequacy for 5 basic nutrients (proteins, fiber,
86 vitamin C, iron calcium), calculated per 100 kcal of food and a variable number of optional
87 nutrients applied to different food groups in the database. Vitamin D, vitamin E, alpha-linolenic
88 acid and monounsaturated fatty acids were used as optional nutrients for nuts and for foods
89 containing more than 97% of their energy as lipids while only vitamin D was used as optional
90 nutrient for all other foods. The negative LIM subscore was calculated as the mean % of maximal
91 recommended values for 3 nutrients to limit: saturated fatty acids (SFA), added sugar and sodium,
92 and was expressed per 100g.

93 Specific thresholds were derived for each subscore so that foods were assigned into 4 broad classes:
94 high SAIN and a low LIM (class-1: most favourable); low SAIN and a low LIM (class-2) high
95 SAIN and a high LIM (class-3); low SAIN and a high LIM (class-4: least favourable).
96 Most fruits and vegetable, eggs, milk, low fat-low dairy products, most fish and shellfish, potatoes,
97 legumes and whole grains were all class-1 foods (Table 1). Most refined cereals, including white

98 bread, together with some cereal-based products containing low amounts of SFA, sugar and salt
99 were class-2 foods. Many cheeses salted and/or smoked fatty fish, meats with an intermediate fat
100 content, and most nuts and vegetable oils were class-3 foods. Virtually all sweets and desserts,
101 animal fats, sweetened beverages, a high proportion of salted snacks, and mixed dishes, most deli
102 meats and fatty meats, full-fat dairy products and sweetened cereals were class-4 foods.

103 Diet optimization

104 We designed a set of 1171 individual-specific nutritionally adequate diets using a recently
105 developed individual diet modelling approach⁽¹⁸⁾. For each individual, a model started from his or
106 her observed diet (i.e. food intakes and nutrient intakes) to design an isocaloric optimized diet
107 respecting his or her food selections and a set of nutrient goals. Nutritional adequacy was ensured
108 by having each diet meet a set of constraints based on the French recommendations for 32 nutrients:
109 proteins, fibers, total carbohydrates, total lipids, essential fatty acids, 11 vitamins (including vitamin
110 D) and 9 minerals, and nutrients to limit. As previously described (18), the minimum levels
111 imposed for nutrients in the optimized diets were: at least the EAR when the observed intake was
112 lower than the EAR; at least the RDA when the observed intake was greater than the RDA; equal to
113 the observed intake level when it was between the EAR and the RDA. This was done to improve
114 the nutrient intakes of each individual in order to reach at least the EAR level for each nutrient,
115 while ensuring that the optimization process did not deteriorate any nutritional component of the
116 observed diets. This is consistent with the current consensus for diet planning of minimizing the
117 percentage of individual's with dietary intakes below the EAR⁽²¹⁾.

118 For the energy contribution of macronutrients and for essential fatty acids (including linolenic acid,
119 linoleic acid, DHA and EPA), the constraint levels were identical for all individuals but for fibers
120 and micronutrients, the lower constraint bounds depended on gender, age and the individual's
121 observed intake of these nutrients, as previously described⁽¹⁸⁾. The nutrients to limit were sodium,
122 free sugars, saturated fatty acids and cholesterol. For cholesterol the maximal constraint bound was
123 either 300 mg per day when the observed intake was below 300mg/d or the observed intake when it

124 was above 300mg/d. Safe upper limits for niacin, folate, ascorbic acid, vitamin A, B-6, E, D, zinc
125 and selenium were also included in each optimization model.

126 Consumption constraints ensured that each optimized diet corresponded as much as possible to the
127 dietary pattern and food preferences of each individual. An upper limit was placed on the quantity
128 of each food, calculating as the 95th percentile amount of the consumer distribution (except when
129 the observed intakes exceeded the 95th percentile).

130 Each optimized diet created by individual modelling came as close as possible to the corresponding
131 observed diet while simultaneously respecting multiple individual-specific constraints. For each
132 person, the optimization algorithm i) preferentially chose foods that the person habitually
133 consumed, ii) maintained quantities consumed as far as possible, and **iii)** if necessary to reach
134 **nutritional** adequacy, introduced novel foods but in the lowest amount possible and by preferentially
135 selecting foods with a high percentage of consumers in the French population (i.e. the most popular
136 ones). The energy content of the optimized diets was the same as in the observed diets, and the
137 weight of foods could not exceed 115% of the observed weight. Population-based consumption
138 constraints on foods and food groups were added to ensure social acceptability to the optimized
139 diets.

140 Statistical analysis

141 The relative **average** contributions of each **nutrient profiling** class to total weight and energy of the
142 optimized diets were calculated for each diet and tested between observed and optimized diets using
143 a paired Student t-test. The relative contributions of the 10 food groups to total weight were
144 similarly assessed and tested. SAS version 9.2 was used for diet modelling and for statistical
145 analysis, using a 5% alpha level for significance.

147 **Results**

148 **The mean weight of the optimized diets was 1,598g/d as compared to 1,425g/d for the observed**
149 **diets. The mean energy density of the optimized diets was accordingly reduced from 623 kJ/100g**

150 (149 kcal/100g) to 552 kJ/100g (132 kcal/100g). Table 1 shows the average contribution of each
151 food group to the total weight of observed and optimized diets. The total amount of fruits and
152 vegetable increased from 23.1% to 33.6%. Unrefined starches increased from 5.4% to 7.9%, and
153 refined cereals increased from 12.6% to 13.7%. Fresh dairy products such as yogurts and milk rose
154 from 13.2% to 15.6%, whereas the amount of fish rose from 2.5% to 4.1%. The optimization
155 process reduced the amounts of meat, cheese, added fats and sweets, the greatest drop being
156 observed for mixed dishes and salted snacks (from 13.9% to 5.5%). When a given food group was
157 increased, foods which had an augmentation mainly came from the SAIN,LIM class-1 (results not
158 shown). When a given food group was decreased, foods which had a diminution mainly came from
159 the SAIN,LIM classes 3-4 (results not shown).

160 Both the observed diets and the optimized diets were composed of foods from all four SAIN, LIM
161 classes (Figure 1). Following the optimization process, the energy contribution of class-1 foods
162 increased from 21% to 30% and that of class-4 foods decreased from 56% to 41% (Figure 1A).
163 Following the optimization process, the weight contribution of class-1 and class-2 foods increased
164 and that of class-3 and class-4 foods decreased (Figure 1B). The relative weight contribution of
165 class-1 foods increased from 51% to 61% and that of class-4 foods decreased from 32% to 22%.

167 Discussion

168 Foods from all nutrient profile classes can be part of nutritionally adequate diets. The present
169 results show that foods with the least favourable nutrient profiles can still contribute as much as
170 41% of energy to a nutritionally adequate food pattern, provided that nutrient dense foods with the
171 most favourable nutrient profile account for the majority of food weight (61%). The present data
172 used new techniques to quantify the relative contribution of different type foods to a nutritionally
173 adequate food pattern that, moreover, respected individual food choices. Early fears that nutrient
174 profiling would perpetuate the dichotomy between “good” and “bad” foods are not borne out by our
175 use of profiling methods and diet optimization techniques.

176 Nutrient profile systems can help quantify the relative amounts of foods that need to be reduced or
177 increased in order to achieve a healthy diet^(14,22). Moreover, they show that foods with an
178 unfavorable nutrient profile need not be avoided altogether. Indeed, only a partial replacement of
179 class-4 (and class-3) foods by class-1 (and class-2 foods) was needed to design a nutritionally
180 adequate diet for each person from our sample of French adults.

181 The present study has some limitations. First, the results of diet optimization depends on the design
182 of a particular model, including the constraints used to define nutritional adequacy⁽²³⁾. However, in
183 an earlier linear programming study, we used three different official sets of nutritional
184 recommendations and this did not change our conclusions about the foods and nutrients limiting the
185 design of optimal diets for young children in a developing country⁽²⁴⁾. Moreover, in the present
186 study, the use of individual diet modelling is likely to limit the risk of drawing conclusions that are
187 too specific to the model applied. Indeed, the present conclusions were based on the results obtained
188 from 1171 individual-specific models, each of them being unique in terms of objective function and
189 constraints⁽¹⁸⁾.

190 A second limitation is that the nutrient profiling approach may fail to correctly classify some key
191 foods^(25,26). Nevertheless, our results were fully consistent with studies from the UK⁽²²⁾ showing that
192 foods deemed as least healthy using the UK Food Standard Agency nutrient profile contributed as
193 much as 39% of energy to the most healthy diets (based on the Diet Quality Index), a figure in close
194 agreement with the present estimate of 41%. Given that the two studies, conducted in the UK and
195 France respectively, differed in methodology (observational and modelling studies, respectively),
196 such correspondence suggests that the amount of “discretionary” calories can be higher than
197 previously envisaged. According to MyPyramid, most discretionary calorie allowances are very
198 small, between 100 and 300 calories, that is to say between 5 and 15% of daily energy intakes⁽³⁾.
199 Limiting so much the amount of discretionary calories could be more restrictive than effectively
200 needed to reach nutritional adequacy.

201 Nutritionally adequate diets were in accordance with habitual dietary advice as they had a low
202 energy density and contained plenty of foods of plant origin and reasonable amounts of animal
203 products. The current debate on nutrient profiling leaves the consumer and the health professional
204 alike with the impression that only **the most** nutrient rich foods have a place in a healthy diet.
205 Based on sophisticated mathematical techniques, the present study **showed, to the contrary, that**
206 **foods from all SAIN,LIM classes could be a part of individually-tailored nutritionally adequate food**
207 **diets. In this population of French adults, current nutrient recommendations were compatible with**
208 **the consumption of one-fifth of energy-dense foods that were nutrient-poor (class-4), provided that**
209 **the diets also contained almost two-third of nutrient-dense foods (class-1).**
210 **In many countries, consumers already receive information about the nutrient profile of individual**
211 **foods and this is considered as a possible way of favourably influencing food choices. For instance,**
212 **in Sweden, the 'Green Keyhole' symbol has been in use since 1989, to help consumers identify low-**
213 **fat and high-fibre alternatives⁽²⁷⁾, and in France, the ministry of health is currently considering the**
214 **introduction of a healthy food label based on nutrient profiling⁽²⁸⁾. Thus, translating the results of**
215 **the present study into concrete and quantified advice to increase the consumption of food with a**
216 **favourable nutrient profile (to at least two-third the basket weight) at the expense of foods with an**
217 **unfavourable nutrient profile (to a maximum of one-fifth the basket weight), may have very**
218 **tangible public health implications.**
219 **All too often dietary advice is either vague or solely based around avoiding or severely restricting a**
220 **specific nutrient or food. Nutrient profiling models that accurately capture the nutrient density of**
221 **foods can be an effective platform for nutrition education.**

222 Acknowledgments

223 We declare that we have no conflicts of interest. We are grateful to Jean-Luc Volatier for providing
224 us access to the INCA database. This work was carried out with the financial support of the French
225 National Research Agency under the project ANR-07-PNRA-018, ALIMINFO. MM is supported
226 by the INRA divisions of Nutrition, Chemical Food Safety and Consumer Behaviour, and Social
227 Sciences, Agriculture and Food, Rural Development and Environment. AD is supported by NIH
228 grant R01 DK076608.

229 **Author's contributions:** MM and ND conceived the study. MM conducted data modeling and
230 statistical analyses. AD participated substantially in interpretation of the results and writing of the
231 report. All authors participated in the interpretation of the results and writing of the report.

232

233 Table 1. Number of foods from each food group in each SAIN,LIM class and average contribution
234 of each food group to total diet weight among observed and optimized diets.

235

236

237 Figure 1 Title.

238 Relative contributions of each nutrient profiling class to total diet energy (Panel A) and to total diet
239 weight (Panel B) among observed and optimized diets.

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310 écrans enfants, déposée par Mme Valérie Boyer et d'autres députés devant l'Assemblée Nationale.
311 n°2474.

312 Table1. Number of foods from each food group in each SAIN,LIM class and average contribution of each food group to total weight among observed
313 and optimised diets.

314

	Number of foods in each				Contribution to total diet			
	SAIN,LIM Class				weight, %			
	Class 1	Class 2	Class 3	Class 4	Observed		Optimised	
					Mean	SE	Mean	SE
Fruits & vegetable ¹	87	11	7	1	23.1	11.4	33.6*	7.4
Unrefined starches	13	5	0	2	5.4	3.6	7.9*	3.8
Refined starches	0	6	0	5	12.6	6.6	13.7*	4.7
Milk ² & yogurts	15	1	6	13	13.2	9.8	15.6*	7.1
Cheese	0	0	35	17	3.0	2.3	1.4*	1.1
Meats	34	1	26	40	11.9	5.5	7.9*	3.0
Fish	45	5	13	1	2.5	2.5	4.1*	1.9
Mixed dishes & salted snacks	18	11	18	46	13.9	9.2	5.5*	4.7
Added fats	9	0	18	11	2.4	1.3	1.3*	0.8
Sweets ³	1	5	4	83	11.9	8.6	9.1*	5.1

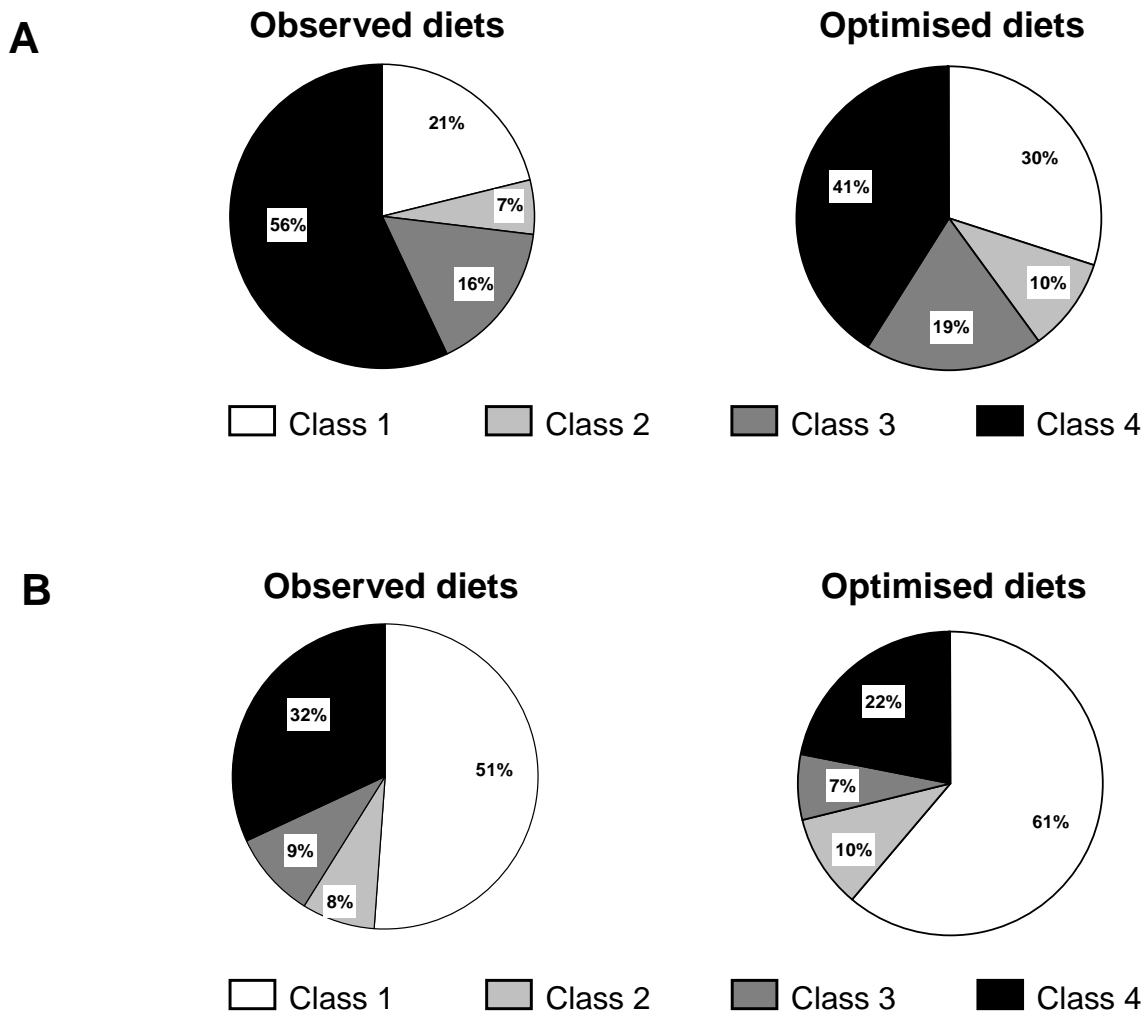
315 * Mean values are significantly different from that of observed diets.

316 ¹ The mean contribution of fruit juice to total weight was 3% and 2.5% in observed and modelled diets, respectively

317 ² The mean contribution of milk to total weight was 8.1% and 8.4% in observed and modelled diets, respectively

318 ³ The mean contribution of soft drinks to total weight was 2.5% and 1.4% in observed and modelled diets, respectively

319 Figure 1. Relative contributions of each nutrient profiling class to total diet energy (Panel A) and to
 320 total diet weight (Panel B) among observed and optimized diets.
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