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## Development and evaluation of a new dietary index assessing nutrient security by aggregating probabilistic estimates of the risk of nutrient deficiency in two French adult populations

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4

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19

20 **Abstract**

21 Although micronutrient deficiencies affect 2 billion people worldwide, no index focusses on  
22 measuring the risk of overt nutrient deficiency. We aimed to develop an index that could capture  
23 the nutrient dimension of nutritional security, a nutrient security index (SecDiet), and evaluate its  
24 apparent validity. The SecDiet (range: 0-1) is based on the square-weighted average of the  
25 probabilities that the intake of 12 critical nutrients exceeds the threshold value associated with a  
26 risk of overt deficiency. Using adult populations from a French representative survey (INCA3,  
27 n=1,774) and a large cohort (NutriNet-Santé, n=104,382), the content and construct validity of  
28 the SecDiet was evaluated by estimating associations of the SecDiet with its components and  
29 with socio-demographic characteristics that are known to be associated with low micronutrient  
30 intakes and statuses. The SecDiet was high in the overall population ( $0.93\pm 0.09$  in INCA3) and  
31 markedly skewed towards 1 (i.e. lower risk of insufficient intake). It correlated positively with its  
32 12 components ( $r=0.17-0.78$ , all  $P_s<0.001$ ). The SecDiet was associated with monthly income  
33 ( $P=0.002$ ), perception of financial situation, professional situation, food insufficiency and security  
34 statuses (all  $P_s<0.001$ ) in the INCA3 population and with monthly income, professional situation,  
35 and level of education (all  $P_s<0.001$ ) in the NutriNet-Santé population. Unlike a broader nutrient-  
36 based quality index taken as comparison, the SecDiet mean decreased and the tail of its  
37 distribution notably extended downwards in at-risk sub-populations, thus revealing its specific  
38 sensitivity. The SecDiet could be used to screen sub-groups or study the determinants of  
39 nutrient insecurity in large population surveys.

## 40 **Introduction**

41 Micronutrient deficiency is a form of malnutrition, in the same way as under-nourishment or over-  
42 nourishment<sup>(1)</sup>. However, unlike the other two forms of malnutrition, it is sometimes less visible  
43 and may appear in addition to other form of malnutrition, including obesity<sup>(2)</sup>. It is considered as a  
44 major public health issue as it affects 2 billion people worldwide and has serious and sometimes  
45 irreversible health impacts<sup>(3,4)</sup>. Even in high income countries, nutrient deficiency remains the other  
46 side of the coin of the nutritional quality of the diet, and there are growing concerns with respect  
47 to vulnerable sub-populations.

48 Assessing the risk of micronutrient deficiency using nutrient intake data would be an effective way  
49 to estimate the risk in a population and take public health actions consequently<sup>(5)</sup>. However, to our  
50 knowledge, no index currently focuses specifically on assessing the risk of developing nutritional  
51 deficiency. There are many diet quality indices that assess the potential impacts of diet on the  
52 health of individuals and study adherence to food-based dietary guidelines<sup>(6,7)</sup>. These indices are  
53 generally based on food-based indicators and/or nutrient-based indicators<sup>(8)</sup>.

54 Increasing importance has been given to food-based indices for defining diet quality because there  
55 is a growing evidence that long-term health is more realistically and confidently reflected by the  
56 overall characteristics of a diet<sup>(9)</sup>. However, these scores are not focused on nutrient intake and  
57 do not allow to directly study the risk of micronutrient deficiency. By contrast, nutrient-based  
58 assessments remain important in terms of fundamental relationships in nutrition, and notably the  
59 detection of poor diet quality due to insufficient nutrient intake, which is important for short-term  
60 health.

61 Nutrient-based indices are generally based on nutrient adequacy ratios (NAR) and mean  
62 adequacy ratios (MAR)<sup>(8,10,11)</sup> or on the probability of adequacy of nutrient intakes using a  
63 probabilistic approach<sup>(12-15)</sup>. They may be more difficult to implement than food-based indices,

64 because they require extensive dietary records and food composition tables<sup>(16)</sup>. They need to refer  
65 to recommended intakes of selected nutrients but there are different criteria that can be used to  
66 define nutrient requirements and then estimate these reference values<sup>(13)</sup>. Nutrient requirements  
67 are usually defined using higher nutritional criteria than those which prevent the risk of onset of  
68 clinical signs of deficiency. Indeed, the requirements can be set so as to maintain a sufficient store  
69 of the nutrient, or to maximize metabolic/physiological markers<sup>(13)</sup> and may even also take account  
70 of the long-term risks of developing a chronic disease<sup>(17)</sup>.

71 Therefore, existing diet quality indices are more designed to measure overall diet quality and  
72 associations with long-term health outcomes rather than nutritional status and the acute risk of  
73 nutrient deficiency. There is a need for such an index that aggregates risk estimates of  
74 micronutrient deficiency; a nutrient security index, that uses more stringent reference values that  
75 are associated with the appearance of clinical signs of deficiency. Such an indicator also appears  
76 critical for studying ongoing nutritional transition which changes the risk of nutrient shortage.

77 Our objective was to develop a score that focusses on the risk of nutritional deficiency in adults,  
78 by only selecting micronutrients for which a serious clinical deficiency is referenced, and using a  
79 probabilistic approach to estimate the risk of developing such a deficiency. The content and  
80 construct validity of this index was then assessed using data from two French surveys, one from  
81 a national representative population and a second with a large number of participants which  
82 offered a wide variety of sociodemographic profiles.

## 83 **Methods**

### 84 *Population data*

85 The data used for this study came from the third Individual and National Study on Food  
86 Consumption Survey (INCA3, 2014-2015) and the NutriNet-Santé cohort study (2009, ongoing).

87 The third Individual and National Study on Food Consumption Survey 3 (INCA3) is a French  
88 nationwide and representative cross-sectional survey, which has been fully described  
89 elsewhere<sup>(18)</sup>. INCA3 study was carried out in accordance with the Declaration of Helsinki  
90 guidelines and was approved by the 'Comité Consultatif sur le Traitement de l'Information en  
91 matière de Recherche dans le domaine de la Santé' (Advisory Committee on Information  
92 Processing in Health Research). Verbal consent was obtained from, witnessed and formally  
93 recorded for all subjects. Briefly, dietary data were collected using three non-consecutive validated  
94 24-h dietary recalls over a 3-wk period. Professional investigators were responsible for collecting  
95 the dietary records by telephone, and participants were not aware of the days of recall. The  
96 nutrient contents of food items came from the 2016 database of the *French Centre d'Information*  
97 *sur la Qualité des Aliments* (CIQUAL). Sociodemographic questionnaires were also completed,  
98 by administered face-to-face questionnaires. Under-reporters for energy intake (EI) were excluded  
99 using the Black's cut-offs based on the Goldberg method<sup>(19)</sup>. Basal metabolic rate (BMR) was  
100 estimated using Henry's equations<sup>(20)</sup>. Participants were not considered under-reporters for a ratio  
101  $EI:BMR > PAL \times \exp(-1.96 \times S/100)$  where PAL represents the physical activity level, and S a factor  
102 taking into account the variability of EI and BMR and depends on the number of dietary recalls.  
103 The study sample was initially composed of 2,121 adults (18-79y) and after exclusion of under-  
104 reporters the final sample contained 1,774 adults (749 men and 1,025 women).

105 The NutriNet-Santé study is an ongoing French web-based cohort which started in 2009 and has  
106 previously been fully described elsewhere<sup>(21)</sup>. The NutriNet-Santé study is conducted in

107 accordance with the Declaration of Helsinki guidelines and was approved by the Institutional  
108 Review Board of the French Institute for Health and Medical Research (IRB Inserm no.  
109 0000388FWA00005831) and the 'Commission Nationale de l'Informatique et des Libertés' (CNIL  
110 no. 908450 and 909216). Electronic informed consent is obtained from each participant (EudraCT  
111 no. 2013-000929-31). All questionnaires are completed online via a web-based interface. At  
112 inclusion and every six months, participants are required to complete online three 24h dietary  
113 records over a 2-wk period. These web-based 24h dietary records have been validated against  
114 dietary records filled during an interview with a dietitian and against blood and urinary  
115 biomarkers<sup>(22-24)</sup>. Portion sizes are estimated using validated photographs<sup>(25)</sup>. The nutrient  
116 contents of food items come from a published food composition table<sup>(26)</sup>. As for the INCA3 study,  
117 under-reporters for energy intake were excluded using the same method<sup>(19)</sup>, but basal metabolic  
118 rate was estimated using Schofield's equations<sup>(27)</sup>. Participants also complete questionnaires on  
119 health, sociodemographic characteristics, anthropometrics and physical activity. The sample used  
120 during this study contained 104,382 adults over 18y (22,649 men and 81,733 women) and their  
121 dietary intake referred to 24h records collected over a 2-y period following inclusion in the cohort.

122 We chose to use data from these two populations in order to obtain firstly a representative sample  
123 of the French population (INCA3) for SecDiet score description purposes, and secondly a  
124 population where we could characterize the behaviour of this score in more deprived sub-  
125 populations because of the large number of participants (NutriNet-Santé).

#### 126 *Development of an index assessing the nutrient Security of Diet (SecDiet)*

127 The SecDiet index has been designed to assess the risk of nutrient deficiency due to insufficient  
128 intakes of nutrients. In this study, the SecDiet has been developed for an adult population. It is  
129 built on the probabilistic approach<sup>(28)</sup> and computes, at an individual level, the probability for each  
130 nutrient of having an intake sufficiently high to avoid nutrient deficiency using the probability  
131 distribution of the standard normal distribution of nutrient requirements, and taking into account



132 the mean intake  $y$ , the day-to-day variability of intake  $SD_y^2$ , the number of days of dietary record  
133  $n$ , the inter-individual variability  $SD_r^2$  and the nutrient reference value  $r^{(14,29)}$ , as follows:

134 
$$F\left(\frac{y - r}{\sqrt{SD_r^2 + \frac{SD_y^2}{n}}}\right)$$

135 where  $F(x)$  is the function returning the probability that an observation from the standard normal  
136 distribution is lower than  $x$ . The probability for a nutrient ranges from 0 to 1, where 1 represents  
137 a 100% probability that the usual intake is adequate.

138 The nutrient reference value was derived from what we defined as the 'deficiency threshold' (DT)  
139 corresponding to the minimal intake to avoid nutritional deficiency, which would therefore be the  
140 minimal criterion that could be used to set the requirement for this nutrient. We assumed that at  
141 an intake equal to the DT, ~97.5% of the population would have an intake sufficient to avoid  
142 nutritional deficiency and ~2.5% would be at risk of developing a nutritional deficiency. We then  
143 defined the 'average deficiency threshold' (aDT) corresponding to the intake with which 50% of  
144 the population would be at risk of having a nutritional deficiency. Assuming a normal distribution  
145 of the individual threshold centred at the aDT, the aDT was therefore defined as  $DT/(1+2CV)$ . The  
146 CV was assumed to be similar to the CV of the average requirement.

147 Only nutrients for which a deficiency has been described in adults due to a primary insufficient  
148 intake and not secondary to a medical condition were included in the SecDiet. The inclusion of  
149 nutrients and the setting of deficiency thresholds were decided after a comprehensive review of  
150 the literature, notably concerning the principal nutrient recommendations in public dietary  
151 guidelines<sup>(17,30-33)</sup>. The nutrients included, because of the existence of deficiency due to insufficient  
152 intakes, were thus vitamin A, thiamin, riboflavin, niacin, folate, vitamin B12, vitamin C, iodine, iron,  
153 selenium, zinc, calcium, and deficiency thresholds were defined for adults based on experimental

154 or epidemiologic studies as found reported in French, European and international dietary  
155 guidelines <sup>(30–35)</sup> and meta-analyses studies <sup>(36–38)</sup>. Deficiency thresholds are usually much lower  
156 than the Reference Intakes which can be used in nutrient-based indexes, because Reference  
157 intakes are often based on criteria that are not easily interpretable in terms of health impact, or  
158 sometimes even unrelated to biological markers (such as *Adequate Intake* based on observed  
159 intake), whereas a deficiency threshold directly corresponds to the risk of an overt deficiency. For  
160 some nutrients, the onset of clinical signs of deficiency can be related to a certain amount of  
161 nutrient intake (e.g. scurvy may appear for intake of vitamin C below 10mg/day), and this intake  
162 was defined as the DT. In contrast, for some other nutrients (namely, thiamine, riboflavin, niacin,  
163 folate), there was not enough literature to derive a DT, therefore we defined it as the lower  
164 reference nutrient intake (which is the intake covering the standard requirements of 2.5% of the  
165 population). The selection of nutrients, their associated deficiency, and deficiency thresholds are  
166 shown in Table 1 and described in full in Supplemental Method 1.

167 The SecDiet score was then calculated as the sum of the squares of probabilities of nutrient  
168 adequacies divided by the number of nutrients included in the calculation. Squaring the  
169 probabilities was chosen in order to give more weight to the lowest probabilities among those of  
170 the different nutrients included in the score, the aim being to increase its sensitivity to the risk of  
171 one individual component over the other that would be expected to be close to the unity. Finally,  
172 the SecDiet ranges from 0 to 1 where 1 represents the lowest risk of insufficient nutrient intakes  
173 leading to nutrient deficiencies.

#### 174 *Evaluation of the validity of the SecDiet score*

175 Content validity assesses whether the index covers all dimensions of what it is supposed to  
176 measure<sup>(39)</sup>. This was evaluated after a thorough review of the literature on dietary references  
177 issued by the main health and food safety agencies<sup>(17,30–33)</sup>. Correlations between score  
178 components and the SecDiet were evaluated, as well as between the SecDiet and total energy

179 intake to determine whether the SecDiet was able to assess certain quality features that would be  
180 independent of (energy-related) quantity.

181 Construct validity determines whether a score correctly measures what it is meant to measure, in  
182 this case nutrient security. We evaluated variations of the SecDiet across various  
183 sociodemographic subgroups that are known to be more prone to nutritional deficiency. These  
184 subgroups were the lowest income category<sup>(40)</sup>, people with food insufficiency or food  
185 insecurity<sup>(41,42)</sup> and unemployed persons and students<sup>(43,44)</sup>. We hypothesized that the SecDiet  
186 score for most individuals would be lower in these groups, which might be reflected by a lower  
187 group mean and also a downwardly elongated distribution tail in these groups, compared to other  
188 groups.

189 The sociodemographic characteristics studied were professional occupations and monthly  
190 household incomes for the INCA3 and NutriNet-Santé populations and perception of financial  
191 situation, food insufficiency status and food insecurity status for INCA3 population only. For the  
192 present study, the professional occupation variable was rearranged into three categories:  
193 unemployed people, students and other occupations (grouping those with a professional activity  
194 and retired individuals). The monthly household income was calculated per consumption unit  
195 using the following weighting: 1 consumption unit (CU) was attributed for the first adult in the  
196 household, 0.5 CU for other persons aged  $\geq 14$ y, and 0.3 CU for children aged  $< 14$ y<sup>(45)</sup>. Perception  
197 of financial situation were obtained from a questionnaire designed to determine how a household  
198 evaluates its financial well-being. Food security and food insufficiency statuses came from the  
199 U.S. Household Food Security Survey Module (HFSSM)<sup>(46)</sup>. The food insufficiency status was  
200 derived from the preliminary question in the HFSSM survey and evaluates whether a household  
201 has had enough to eat during the past 12 months, while the food security status was obtained  
202 from the US Household Food Security Survey Module six-item short form.

203 *Comparison with an overall diet quality index, the PANDiet score.*

204 The behaviour of the SecDiet score within sociodemographic characteristics was compared to that  
205 of a nutrient-based diet quality index, the PANDiet score, in order to determine if the SecDiet is  
206 able to capture specific dimensions of nutrient intakes that are related to nutrient security, more  
207 than would a classical nutrient-based diet quality index.

208 The development and the validation of the PANDiet score is fully developed elsewhere<sup>(14)</sup>. It is  
209 based on the same probabilistic method than the SecDiet but differs in the choice of nutrients,  
210 nutrient reference values and computation of the final score. The probability is also calculated for  
211 each nutrient but the nutrient value is mainly based on national nutrient reference intakes for  
212 French adults<sup>(33)</sup> with more nutrients included.

213 The PANDiet score is based on two sub-scores, the Adequacy Sub-score, which is the average  
214 of probabilities of adequacy for 27 nutrients for which the usual intake should be above a reference  
215 value, multiplied by 100, and the Moderation Sub-score, which is the average of probabilities of  
216 adequacy for 6 nutrients for which the usual intake should not exceed a reference value, multiplied  
217 by 100. The PANDiet score is the average of the Adequacy Sub-score and the Moderation Sub-  
218 Score and ranges from 0 to 100 where a higher score indicates a better diet quality. The nutrients  
219 included and their associated reference values are presented in Supplemental Method 2.

## 220 *Statistical analyses*

221 The weighting schemes proposed in INCA3 were used to account for the complex survey design.  
222 Spearman correlation coefficients were used to assess correlations between the SecDiet score  
223 and other variables. The NutriNet-Santé population was divided into deciles of SecDiet and the 1<sup>st</sup>  
224 decile of SecDiet was further stratified into deciles in order to reveal the characteristics of first ten  
225 percentiles of SecDiet, corresponding to the lowest SecDiet score and hence the population the  
226 most at risk of nutritional deficiency. Categorical variables are presented as percentages and  
227 differences across deciles and across first ten percentiles were determined using  $\chi^2$  tests.

228 Descriptive statistics (mean, SD, range, quartiles, 5<sup>th</sup> and 95<sup>th</sup> percentiles) were used to describe  
229 the distribution of the SecDiet and the PANDiet in the population and across the sociodemographic  
230 characteristics studied and presented using boxplots. Kruskal-Wallis non-parametric tests were  
231 performed to assess significant differences between the SecDiet, the PANDiet and  
232 sociodemographic variables. Pairwise multiple comparisons within sociodemographic variables  
233 categories were assessed using the Dwass-Steel-Critchlow-Fligner (DSCF) test.

234 All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA.).  
235 Weighting schemes were considered using a weight statement. Significance was set at  $P < 0.05$ .

236 **Results**

237 Distribution of the SecDiet score in study populations

238 In the INCA3 population, components of the SecDiet were correlated to each other and with the  
239 overall SecDiet ( $r=0.17$  to  $r=0.78$  with the SecDiet, all  $P_s<0.001$ ). The components with highest  
240 correlation coefficients were iodine ( $r=0.78$ ), riboflavin ( $r=0.74$ ), folate and calcium ( $r=0.70$ ) and  
241 vitamin A ( $r=0.68$ ), when compared to the lowest coefficients observed for thiamin ( $r=0.17$ ) or  
242 niacin ( $r=0.20$ ). The SecDiet was positively correlated with total energy intake ( $r=0.44$ ) and with  
243 the PANDiet score ( $r=0.50$ ) (Supplemental Table 1).

244 The distributions of the SecDiet in the INCA3 and NutriNet-Santé populations are presented in  
245 Figure 1 and were similar, with a distribution strongly skewed towards the upper bound of the  
246 score (i.e. 1).

247 In the INCA3 population, the mean SecDiet score was  $0.93 \pm 0.09$ . The lowest probabilities of  
248 adequacy were found for vitamin A ( $0.89 \pm 0.18$ ) and iodine ( $0.90 \pm 0.15$ ) (Table 2), i.e., individual  
249 components among the most strongly correlated with the overall score. In the NutriNet-Santé  
250 population, the mean SecDiet score was  $0.96 \pm 0.06$ . The lowest probability of adequacy was  
251 found for iodine ( $0.87 \pm 0.20$ ) (Table 3). In both populations, the SecDiet score was lower in women  
252 than in men ( $0.91$  vs  $0.94$  in INCA3 and  $0.95$  vs  $0.97$  in NutriNet-Santé, respectively).

253

254 Sociodemographic characteristics of individuals with a relatively low SecDiet score

255 We characterized the sociodemographic characteristics of the deciles and first ten percentiles of  
256 the SecDiet in the NutriNet-Santé population (Table 4). The CV of the SecDiet was very low,  
257 except for the 1<sup>st</sup> decile (11%) and 1<sup>st</sup> percentile (13%). More women and individuals who were  
258 younger, had a lower level of qualifications or of monthly income were found in lower SecDiet

259 score (all  $P$ s<0.001, except for sex across first 10<sup>th</sup> percentiles where  $P$ =0.465). Compared to the  
260 10<sup>th</sup> decile, individuals in the 1<sup>st</sup> decile were more often single (28.4% vs 14.6%) or living as an  
261 unmarried couple (29.8% vs 19.2%). Individuals in the 1<sup>st</sup> percentile were predominantly single  
262 (36.3%). Individuals with lower SecDiet score were more likely to be unemployed (11.8% in the  
263 1<sup>st</sup> percentile, 9.1% in the 1<sup>st</sup> decile vs 4.2% in the 10<sup>th</sup> decile), students (21.9% in the 1<sup>st</sup> percentile,  
264 16.0% in the 1<sup>st</sup> decile vs 4.1% in the 10<sup>th</sup> decile) and employees (27.2% in the 1<sup>st</sup> percentile,  
265 25.2% in the 1<sup>st</sup> decile vs 14% in the 10<sup>th</sup> decile).

266  
267 The SecDiet score of groups in which a higher risk of nutrient deficiency was expected and  
268 comparison with the PANDiet score

269 The SecDiet score was plotted according to the monthly income per household unit and the  
270 professional occupation in the INCA3 and the NutriNet-Santé populations (Figure 2). In both  
271 populations, the SecDiet decreased with lower monthly income. In the INCA3 population, the  
272 SecDiet decreased from  $0.94 \pm 0.07$  for the highest income bracket to  $0.91 \pm 0.11$  for the lowest  
273 income bracket ( $P$ =0.002, Supplemental Table 2). In the NutriNet-Santé population, the SecDiet  
274 decreased from  $0.97 \pm 0.05$  for the highest income bracket to  $0.94 \pm 0.08$  for the lowest income  
275 bracket ( $P$ <0.001, Supplemental Table 3). Regarding the professional situation, the SecDiet was  
276 lower among the unemployed people ( $0.91 \pm 0.09$ ) vs other occupations ( $0.93 \pm 0.09$ ) but did not  
277 differ significantly for students ( $0.92 \pm 0.11$ ) vs other occupations in the INCA3 population  
278 (Supplemental Table 4). In the NutriNet-Santé population, the SecDiet score was lower among  
279 the unemployed people ( $0.94 \pm 0.08$ ) and students ( $0.93 \pm 0.08$ ) compared to other occupations  
280 ( $0.96 \pm 0.06$ ) ( $P$ <0.001) (Supplemental Table 5).

281 The differences between the SecDiet and the PANDiet scores were studied in the INCA3  
282 population by comparing their behaviours according to the perception of financial situation, the  
283 food insufficiency and food insecurity statutes (Figure 3).

284 Both the SecDiet and the PANDiet scores decreased with lower perception of financial situation.  
285 However, the decrease was more important for the SecDiet. The difference of the SecDiet  
286 between the “Financially comfortable” status ( $0.94 \pm 0.08$ ) and the “Can’t manage without debts”  
287 status ( $0.85 \pm 0.14$ ) represented a 9.6% decrease, whereas between the same two statutes, the  
288 decrease of the PANDiet was of 2.9% (Supplemental Table 6). Furthermore, it was important to  
289 note that the distribution of the SecDiet spread downwards in subpopulations with the lowest  
290 financial situations compared to the PANDiet score (Figures 3(a) and 3(b)). Indeed, the SecDiet  
291 CV was 16.5% in the lowest financial situation class and 8.5% in the highest financial situation  
292 class. The PANDiet and SecDiet scores were both significantly different across food insufficiency  
293 status groups ( $P < 0.001$ ), with higher scores for food sufficiency status compared to qualitative  
294 and quantitative food insufficiency statutes (Supplemental Table 7). The SecDiet score was higher  
295 for food security status ( $0.93 \pm 0.08$ ) compared to moderate food insecurity ( $0.89 \pm 0.13$ ) and  
296 severe food insecurity ( $0.89 \pm 0.10$ ), which both had similar SecDiet score ( $P < 0.001$ ). The PANDiet  
297 score was only significantly different for moderate food insecurity ( $63.07 \pm 5.73$ ) compared to food  
298 security ( $64.53 \pm 5.73$ ) ( $P = 0.002$ ) (Supplemental Table 8).

299 As highlighted by the boxplot representations, the main difference between the SecDiet and the  
300 PANDiet score was the specific spreading of the boxplots towards lower SecDiet scores (i.e.  
301 decrease in the 5<sup>th</sup> percentile) for food insufficiency and food insecurity statutes, which was not  
302 observed with the PANDiet.

303

304 **Discussion**



305 The aim of this study was to evaluate the validity of a new dietary index that describes the nutrient  
306 security of diet, the SecDiet. This index consists in an aggregate probabilistic assessment of the  
307 risk of deficiency for 12 micronutrients that are of potentially considerable importance to public  
308 health. After an in-depth examination, the SecDiet displayed a good content and construct validity.  
309 Unlike an overall nutrient-based diet quality index, the SecDiet is particularly sensitive to situations  
310 that are known to increase nutritional insecurity.

311 We decided to include these 12 micronutrients after a review of the literature regarding the reality  
312 and severity of selective deficiencies of all micronutrients<sup>(17,30,31,47)</sup>. The SecDiet includes the most  
313 widespread micronutrient deficiencies, which are iron, iodine, folate, vitamin A and zinc  
314 deficiencies<sup>(3)</sup>. The lower reference values were defined as the minimal intake below which clinical  
315 signs of deficiency might appear and were taken from international expert consensus reports. The  
316 SecDiet score is therefore appropriate for use in other countries, including low- and middle-income  
317 countries, because it is mostly not based on national reference values. However, the parameters  
318 were based on reference values for adults so are not readily applicable to other populations such  
319 as children or pregnant women. For two nutrients, namely iron and iodine, we were able to  
320 recalibrate the estimation of the risk of deficiency on the national prevalence of anaemia  
321 (haemoglobin <13 g/dl for men and <12 g/dl for women)<sup>(48)</sup> and goitre<sup>(49)</sup>. Indeed, although the  
322 reference values employed offer a good reflection of the minimal intake required to prevent  
323 deficiency (based on data in the literature) it appears that these thresholds overestimate the risk  
324 when compared to the figures regarding the actual prevalence of deficiency. To be adaptable to  
325 other populations and settings, worldwide prevalence estimates for anaemia<sup>(50)</sup> and goitre could  
326 be used<sup>(51)</sup>, or estimates for the country under study, if these data are available. This approach is  
327 interesting because it involves theoretical information that links individual dietary records to the  
328 actual average risk estimates observed directly in the population.

329 We found that the SecDiet score was positively correlated to all its components, but coefficients  
330 of correlations revealed that all components did not make the same contribution to this score.  
331 These differences indicate that some nutrients have little influence on variations of the SecDiet  
332 score, presumably because current intakes in these populations are high compared to the  
333 reference threshold used here to estimate the risk of overt deficiency. By contrast, other nutrients  
334 were more strongly correlated with the SecDiet score and were also those with the lowest means  
335 (vitamin A, riboflavin, folate, iodine and calcium), suggesting a higher risk of developing a clinical  
336 deficiency of these nutrients. It appears that the SecDiet score was not independent of energy  
337 intake; a higher energy intake being associated with a lower risk of developing nutritional  
338 deficiency, as had been expected. The SecDiet is therefore not fully and specifically a diet quality  
339 index, inasmuch as it is also associated with (energy) quantity. This was to be expected, since the  
340 SecDiet is rather an aggregate estimate of the risk of deficiency.

341 Lower SecDiet scores were found in people with low monthly incomes and low perceptions of their  
342 financial situation. It is widely acknowledged that poverty is one of the main causes of  
343 undernutrition worldwide, and that low- and middle-income countries have the highest prevalence  
344 of micronutrient deficiencies<sup>(3)</sup>. Indeed, low socioeconomic status is generally associated with poor  
345 diet quality, which can be explained by several factors such as food prices and access, education  
346 in nutrition or the time required for cooking<sup>(52)</sup>. Several studies have shown that adults with lower  
347 socioeconomic status have lower plasma ascorbic acid concentrations<sup>(53)</sup> and lower intakes of  
348 micronutrients such as calcium and iron<sup>(54)</sup>. Here we have identified a situation of acute nutritional  
349 risk in the most deprived part of the general population. The SecDiet score was also lower in  
350 unemployed people and students, which is in line with studies reporting lower micronutrient intakes  
351 among students<sup>(44,55,56)</sup> and lower calcium intakes in households where the family head is  
352 unemployed<sup>(57)</sup>. Low-income households are generally constrained to choose discount products  
353 and energy-dense foods with low micronutrient contents<sup>(43,52)</sup>. Likewise, when characterizing

354 individuals with a low SecDiet score, we also found more people with lower levels of education  
355 and monthly income, as well as more women, younger adults and single or unmarried couples.  
356 Single women with children and a low income have been reported to have lower nutrient intakes,  
357 which could be secondary to giving nutritional priority to their children<sup>(58,59)</sup>.

358 As expected, the SecDiet score was lower among adults living in households suffering from food  
359 insecurity or food insufficiency. Indeed, it has been seen in the US that, in food-insufficient families,  
360 younger adults had lower calcium intakes, and older adults had lower intakes of iron and zinc  
361 when compared to adults in food-sufficient families. Both younger and older adults had lower  
362 serum concentrations of vitamin A compared to adults in food-sufficient families<sup>(41)</sup>. A study in  
363 Canada found that adults in food insecure households had a higher prevalence of inadequacy for  
364 vitamin A, zinc, folate, vitamin B12 and iron but this was dependent on sex and age category<sup>(42)</sup>.  
365 However, it is not surprising that low SecDiet score is associated with both low socioeconomic  
366 status and food insufficiency and food insecurity because these characteristics may be correlated  
367 to each other. A study in the UK found that participants living in food insecurity tended to have  
368 more problems making ends meet and were often students, younger, males and had a low level  
369 of education<sup>(60)</sup>.

370 By contrast, the PANDiet score did not show the same range of variation than the SecDiet  
371 regarding sociodemographic characteristics. If it also decreased with lower socioeconomic status,  
372 the lower tail of the distribution did not drop as it was observed with the SecDiet. Therefore, the  
373 SecDiet appears to be more specific than a broad index of dietary quality to detect situations with  
374 higher risk of nutrient deficiency. The two scores were positively, but not entirely, correlated  
375 ( $r=+0.50$ ), meaning that the SecDiet score is associated with overall nutrient adequacy but  
376 confirming that it describes a situation that is more specific, based on fewer nutrients and another  
377 type of hazard (lower threshold).

378 The SecDiet score nevertheless has certain limitations. Because of a lack of data and scientific  
379 evidence, it was necessary to derive some minimal thresholds from estimates of standard  
380 requirements by defining the deficiency threshold as the intake covering requirement for only 2.5%  
381 of the population. This was the case for thiamin, riboflavin, niacin, folate. These minimal intakes  
382 could be refined in future when specific studies are available. Regarding the construction of the  
383 score, the probabilistic approach is a method that has been recommended and previously  
384 validated<sup>(13,14)</sup> for assessing risk of inadequacy based on nutrient requirements and intakes, but  
385 we needed to assume a normal distribution around the average deficiency threshold (which is the  
386 intake at which the individual risk of a nutritional deficiency would be 50%) and to define a CV  
387 corresponding to CV used for nutrient requirements. The distribution model and parameters  
388 remains theoretical, although neither more nor less than in all generic probabilistic-based nutrient  
389 risk assessment methods<sup>(12,13)</sup>. Similar to those methods, normality of the distribution of the DT is  
390 assumed except for iron. It may also be important to note that this score only provides tools to  
391 measure the risk of micronutrient deficiency in the general population due to insufficient intake  
392 and not to a medical condition (such as malabsorption issues or being under a treatment  
393 interfering with micronutrient metabolism), and therefore does not cover all possible situations  
394 leading to micronutrient deficiency. Indeed, the main objective of the SecDiet was to be applied to  
395 a given population so as to study the risk of micronutrient deficiency solely attributable to  
396 insufficient food intake, independently of a particular health status of certain individuals.

397 In this study, dietary supplements consumption was not considered but this may not have changed  
398 the observed results since, in France, it has been shown that dietary supplements consumption  
399 only slightly improves nutrient adequacy<sup>(61)</sup>. Furthermore, it has been shown in the NutriNet-Santé  
400 study that consumers of dietary supplements rather belonged to higher socio-professional  
401 category and had lower prevalence of inadequate nutrient intake compared to non-consumers of  
402 dietary supplements<sup>(62)</sup>. So dietary supplements are generally consumed by those who need it the

403 least. Our results highlighted that low SecDiet score, and therefore higher risk of nutritional  
404 deficiency, was observed in individuals with lower-socioeconomic status, which are less prone to  
405 consume dietary supplements.

406 Further studies should consist in validating the criteria using data that could demonstrates the  
407 associations between the SecDiet score and measurements of biomarkers or clinical signs  
408 indicative of individual micronutrient deficiencies in a more disadvantaged population.  
409 Furthermore, such data could be used to set a cut-off point for discriminating individuals at risk of  
410 deficiency. It would also provide an opportunity to recalibrate the score so that it precisely matches  
411 the population-based risk of deficiency. However, it is often more difficult to obtain data from the  
412 most disadvantaged individuals in nationwide population surveys because they may be homeless,  
413 unemployed or not-speaking the national language<sup>(54)</sup>. When assessing nutritional status from  
414 dietary surveys, discarding under-reporters has the advantage of avoiding that nutrient  
415 insufficiency is over-estimated. The fact that the SecDiet was associated with energy intake in our  
416 samples confirms that underestimate of energy intake would result in a downward bias of nutrient  
417 security. In the application of this method, therefore, care must be taken to minimize under-  
418 reporting, especially in people with low energy requirement. The Goldberg/Black cutoffs/methods  
419 that we used has limitation, but has been widely used and remain a standard for identifying under-  
420 reporters. One limitation of this method is the identification of under-reporters for individuals with  
421 high energy requirement<sup>(19)</sup>. This type of error is however the one that would have the least  
422 implication on the bias of the SecDiet.

423 Micronutrient deficiency is also referred to as hidden hunger because unlike other types of  
424 malnutrition, it is frequently less visible<sup>(3,5)</sup> so the SecDiet might offer an effective tool to screen  
425 those who are more at risk of micronutrient deficiency in a representative population and identify  
426 the socioeconomic characteristics that are more predictive of nutritional insecurity. So as to further  
427 validate the method, further studies could also interestingly focus on specific populations with an

428 expected higher food and nutrition insecurity, such as for instance older adults in assisted living  
429 facilities or college campus. Dedicated studies on the latter population would confirm and better  
430 characterize the nutritional risk that we have identified in the large general samples in this study.  
431 Lastly, this score could also be very useful when studying different diet models or simulating  
432 possible future diet changes. Indeed, sustainable diets have been advocated to ensure human  
433 and planetary health<sup>(63,64)</sup>, but adherence to them requires substantial dietary changes that reduce  
434 the intake of certain nutrients, particularly those from animal-based foods. However, the degree  
435 to which this might create a real short-term risk for health that could partly offset the benefits for  
436 long-term health remains uncertain. It is therefore important to characterize the true acute risk in  
437 this setting and determine detailed characteristics of the diet that modulate this risk.

438 In conclusion, we propose here a new index based on the probabilistic risk of micronutrient  
439 deficiency. While the present study used data from French populations, the SecDiet could be  
440 applied in other countries because it is mostly not based on national dietary requirements. We  
441 were able to show that the SecDiet score was indeed associated with low socioeconomic status  
442 and to identify populations with an expected higher risk of nutrient insecurity. The SecDiet would  
443 therefore be a useful tool to study the risk of micronutrient deficiency in a vast representative  
444 population or in more specific sub-populations in which nutritional insecurity is suspected, and it  
445 might also be used as a safeguard parameter when studying prospective dietary transitions.

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461 **Conflict of Interest**

462 None

463 **Authorship**

464 M.S., J-F.H., and F.M. designed the research; M.S. and E.K-G. conducted the research, analysed  
465 the data and performed statistical analyses; H.F., M.T., S.H., J-F.H. and F.M. provided  
466 methodological tools and support; M.S. and F.M. interpreted the results; M.S. wrote the first draft  
467 of the manuscript and all authors provided critical comments on the manuscript. M.S. and F.M.

468 have primary responsibility for the final content and all authors read and approved the final  
469 manuscript.



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## Tables

**Table 1.** Nutrients included as components in the SecDiet score and associated deficiency and threshold values.

Nutrient	Deficiency	Threshold (DT)	CV	50% of risk (aDT)
Vitamin A <sup>(30)</sup>	Xerophthalmia	300 µg RE or 270 µg RE	15%	231 µg RE or 208 µg RE
Thiamin <sup>*(31)</sup>	Beriberi	0.18 mg/1000kcal	20%	0.13 mg/1000kcal
Riboflavin <sup>*(31)</sup>	Ariboflavinosis	1.0 mg	10%	0.83 mg
Niacin <sup>*(31)</sup>	Pellagra	4.35 mg NE/1000kcal	10%	3.63 NE/1000kcal
Folate <sup>*(31)</sup>	Megaloblastic anaemia	175 µg	15%	135 µg
Vitamin B12 <sup>(32)</sup>	Megaloblastic anaemia	1 µg	15%	0.77 µg
Vitamin C <sup>(30)</sup>	Scurvy	10 mg	10%	8.3 mg
Iodine <sup>†(31)</sup>	Goitre	150 µg	20%	107 µg
Selenium <sup>(34)</sup>	Keshan disease	21 µg or 16 µg	15%	16.2 µg or 12.3 µg
Bioavailable iron <sup>†(33)</sup>	Anaemia	1.74 mg <sup>‡</sup>	40%	0.95 mg <sup>†</sup>
Bioavailable zinc <sup>(35)</sup>	Zinc deficiency	1.6 mg or 1.3 mg	15%	1.23mg or 1.0 mg
Calcium <sup>(36–38)</sup>	Fracture risk (long-term)	500 mg	15%	385 mg

DT, deficiency threshold; CV, coefficient of variation of the individual threshold; aDT, average deficiency threshold; RE, retinol equivalent; NE, niacin equivalent; EAR, Estimated Average Requirement.

\* Because of insufficient data to define an intake at which clinical signs of deficiency may appear for these nutrients, the thresholds were defined as the intake covering the requirements of 2.5% of the population, defined as EAR(1-2CV) (see Supplemental Table 1).

† These thresholds parameters were then further corrected to calibrate the estimated average risk using figures for the national prevalence of goitre for iodine and of anaemia for iron. For iodine, the recalibrated DT was set at 100 µg and the aDT at 71.3 µg. For iron, the recalibrated DT was set at 0.70mg and the aDT at 0.38 (see Supplemental Method 1).

‡ This value applies to men and non-menstruating women. Requirements for menstruating women were estimated by considering menstrual losses using a Monte-Carlo simulation (see Supplemental Method 1).

**Table 2.** SecDiet statistics and probabilities of adequacies for nutrients in the French adult population from the INCA3 survey (n=1,774).

	All (n=1,774)				Men (n=749)				Women (n=1,025)			
	Mean	SD	Median	Q1-Q3	Mean	SD	Median	Q1-Q3	Mean	SD	Median	Q1-Q3
SecDiet (0-1)	0.93	0.09	0.96	0.90 – 0.99	0.94	0.08	0.97	0.93 – 0.99	0.91	0.09	0.95	0.87 – 0.99
Probabilities of adequacy of the SecDiet score (0-1)												
Vitamin A	0.89	0.18	0.96	0.87 – 1.00	0.89	0.21	0.96	0.87 – 1.00	0.90	0.16	0.97	0.86 – 1.00
Thiamin	1.00	0.01	1.00	1.00 – 1.00	1.00	0.01	1.00	1.00 – 1.00	1.00	0.01	1.00	1.00 – 1.00
Riboflavin	0.94	0.12	1.00	0.94 – 1.00	0.96	0.11	1.00	0.97 – 1.00	0.92	0.13	0.99	0.89 – 1.00
Niacin	1.00	0.01	1.00	1.00 – 1.00	1.00	0.01	1.00	1.00 – 1.00	1.00	0.01	1.00	1.00 – 1.00
Folate	0.94	0.13	1.00	0.94 – 1.00	0.96	0.11	1.00	0.97 – 1.00	0.92	0.13	0.99	0.89 – 1.00
Vitamin B12	0.97	0.05	1.00	0.96 – 1.00	0.98	0.05	1.00	0.97 – 1.00	0.97	0.06	0.99	0.95 – 1.00
Vitamin C	0.97	0.05	1.00	0.97 – 1.00	0.98	0.05	1.00	0.98 – 1.00	0.97	0.05	0.99	0.96 – 1.00
Iodine	0.90	0.15	0.97	0.87 – 1.00	0.93	0.14	0.98	0.92 – 1.00	0.87	0.16	0.94	0.82 – 1.00
Selenium	0.99	0.02	1.00	1.00 – 1.00	0.99	0.02	1.00	1.00 – 1.00	0.99	0.02	1.00	1.00 – 1.00
Iron	0.97	0.07	0.99	0.96 – 1.00	0.98	0.05	1.00	0.98 – 1.00	0.95	0.08	0.99	0.94 – 1.00
Zinc	0.99	0.05	1.00	1.00 – 1.00	0.99	0.05	1.00	1.00 – 1.00	0.98	0.05	1.00	0.99 – 1.00
Calcium	0.94	0.14	0.99	0.94 – 1.00	0.95	0.13	1.00	0.96 – 1.00	0.92	0.15	0.99	0.90 – 1.00

**Table 3.** SecDiet statistics and probabilities of adequacies for nutrients in the French adult population from the NutriNet-Santé study (n=104,382).

	All (n=104,382)				Men (n=22,649)				Women (n=81,733)			
	Mean	SD	Median	Q1-Q3	Mean	SD	Median	Q1-Q3	Mean	SD	Median	Q1-Q3
SecDiet (0-1)	0.96	0.06	0.98	0.95 – 0.99	0.97	0.05	0.99	0.97 – 1.00	0.95	0.07	0.98	0.94 – 0.99
Probabilities of adequacy of the SecDiet score (0-1)												
Vitamin A	0.98	0.06	1.00	0.99 – 1.00	0.98	0.06	1.00	0.99 – 1.00	0.98	0.06	1.00	0.99 – 1.00
Thiamin	1.00	0.00	1.00	1.00 – 1.00	1.00	0.00	1.00	1.00 – 1.00	1.00	0.00	1.00	1.00 – 1.00
Riboflavin	0.96	0.12	1.00	0.99 – 1.00	0.98	0.08	1.00	1.00 – 1.00	0.96	0.13	1.00	0.99 – 1.00
Niacin	1.00	0.02	1.00	1.00 – 1.00	1.00	0.02	1.00	1.00 – 1.00	1.00	0.02	1.00	1.00 – 1.00
Folate	0.97	0.11	1.00	0.99 – 1.00	0.98	0.08	1.00	1.00 – 1.00	0.96	0.11	1.00	0.99 – 1.00
Vitamin B12	0.98	0.08	1.00	0.99 – 1.00	0.98	0.07	1.00	0.99 – 1.00	0.98	0.08	1.00	0.98 – 1.00
Vitamin C	0.99	0.03	1.00	1.00 – 1.00	0.99	0.04	1.00	1.00 – 1.00	0.99	0.03	1.00	1.00 – 1.00
Iodine	0.87	0.20	0.94	0.84 – 0.99	0.91	0.16	0.97	0.90 – 1.00	0.85	0.21	0.93	0.83 – 0.99
Selenium	1.00	0.02	1.00	1.00 – 1.00	1.00	0.02	1.00	1.00 – 1.00	1.00	0.02	1.00	1.00 – 1.00
Iron	0.99	0.04	1.00	0.99 – 1.00	0.99	0.03	1.00	1.00 – 1.00	0.99	0.04	1.00	0.99 – 1.00
Zinc	1.00	0.02	1.00	1.00 – 1.00	1.00	0.03	1.00	1.00 – 1.00	1.00	0.02	1.00	1.00 – 1.00
Calcium	0.97	0.11	1.00	0.99 – 1.00	0.98	0.09	1.00	1.00 – 1.00	0.97	0.11	1.00	0.99 – 1.00



**Table 4.** Sociodemographic characteristics according to deciles (1<sup>st</sup>, 5<sup>th</sup>, 10<sup>th</sup>) and lower percentiles (1<sup>st</sup>, 5<sup>th</sup>, 10<sup>th</sup>) of the SecDiet score in the French adult population from the NutriNet-Santé study (n=104,382).

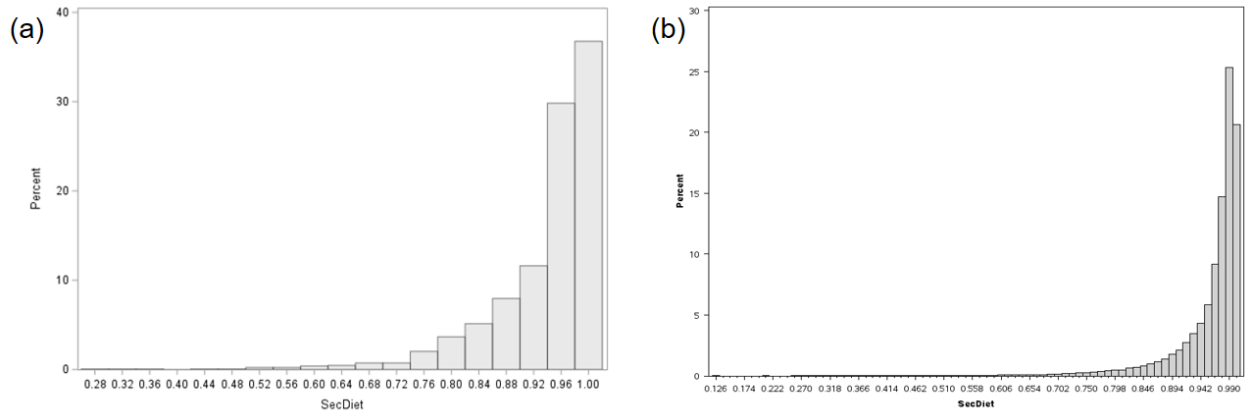
	Deciles of SecDiet				Percentiles of SecDiet			
	1st decile (n=10,438)	5th decile (n=10,438)	10th decile (n=10,438)	P <sup>†</sup>	1st percentile (n=1,043)	5th percentile (n=1,044)	10th percentile (n=1,043)	P <sup>‡</sup>
SecDiet <sup>*</sup>	0.80 ± 0.09 11.25%	0.98 ± 0.00 0.00%	1.00 ± 0.00 0.00%		0.60 ± 0.08 13.33%	0.82 ± 0.01 1.22%	0.88 ± 0.00 0.00%	
Sex, %				<0.001				0.465
Men	13.81	20.37	35.47		14.67	13.22	15.72	
Women	86.19	79.63	64.53		85.33	86.78	84.28	
Age group, %				<0.001				<0.001
<30 y	42.29	25.39	15.59		53.50	43.01	37.97	
30-45 y	30.03	29.72	29.48		26.85	29.98	29.72	
45-60 y	18.79	26.94	31.44		13.52	19.25	21.67	
>60 y	8.89	17.95	23.49		6.14	7.76	10.64	
Matrimonial status, %				<0.001				<0.001
Single	28.38	17.47	14.59		36.34	26.82	24.93	
Married	32.07	47.84	56.65		22.91	33.43	35.09	
Unmarried couple	29.81	24.50	19.18		30.78	30.36	30.49	
Separated/Divorced	8.56	8.31	7.42		8.92	8.62	8.44	
Widowed	1.17	1.87	2.14		0.96	0.77	1.05	
Not available	0.01	0.02	0.02		0.10	0.00	0.00	
Level of qualifications, %				<0.001				<0.001
Secondary education	21.66	18.80	18.44		26.54	20.64	19.56	
Bachelor's degree	23.27	17.52	14.13		27.40	22.95	21.77	
Higher education	55.07	63.68	67.43		46.06	56.41	58.67	
Monthly income per household unit				<0.001				<0.001
<€900 €	20.42	9.54	6.27		27.04	20.50	17.55	
€900-1200 €	8.46	6.47	5.27		8.44	8.14	7.86	
€1200-1800 €	25.19	24.71	24.77		23.78	27.87	25.89	
€1800-2300 €	11.50	14.02	15.05		7.96	10.54	11.89	
€2300-2700 €	6.18	9.03	10.40		4.31	5.75	7.57	
€2700-3700 €	8.47	14.37	17.25		6.90	8.24	9.88	
>€3700 €	4.91	9.80	12.09		3.84	4.02	5.66	
Not available	14.89	12.06	8.89		17.74	14.94	13.71	
Occupational categories				<0.001				<0.001
Employee	25.21	17.77	14.00		27.23	23.75	22.05	
Manual worker	1.66	1.22	1.42		2.21	2.39	1.15	
Farmer	0.19	0.22	0.46		0.10	0.29	0.38	
Managerial staff	15.97	23.41	25.82		12.18	15.04	18.98	
Self-employed	2.26	1.69	1.45		1.73	2.39	1.92	
Intermediate profession	14.16	17.30	18.34		9.78	15.42	16.20	
Student	16.00	8.02	4.09		21.86	16.09	13.14	
Retired	8.53	18.16	25.36		5.56	7.38	10.64	
Unemployed people	9.08	5.91	4.20		11.79	9.96	8.63	
Other without occupation	6.70	6.16	4.84		7.29	6.99	6.71	
Other non-specified	0.19	0.10	0.04		0.29	0.19	0.10	
Not available	0.06	0.04	0.00		0.00	0.10	0.10	

\* Mean ± SD, CV

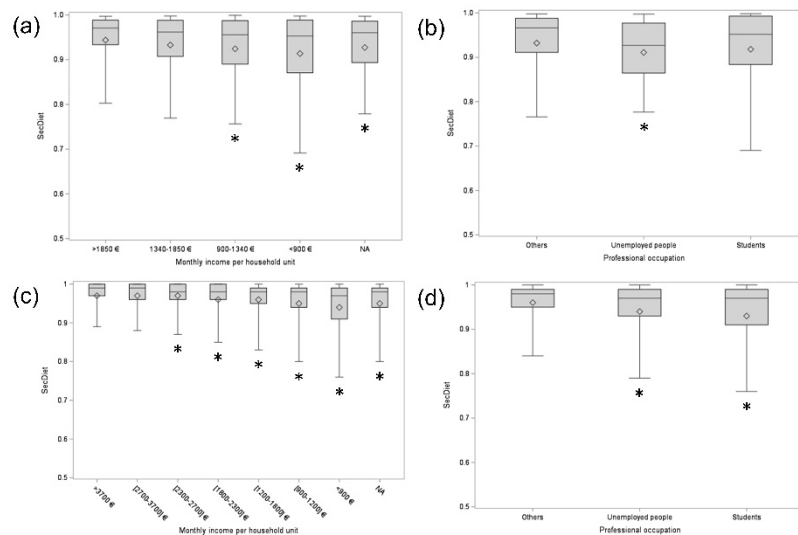
† P values are from  $\chi^2$  test between deciles of SecDiet.

‡ P values are from  $\chi^2$  test between first ten percentiles of SecDiet.

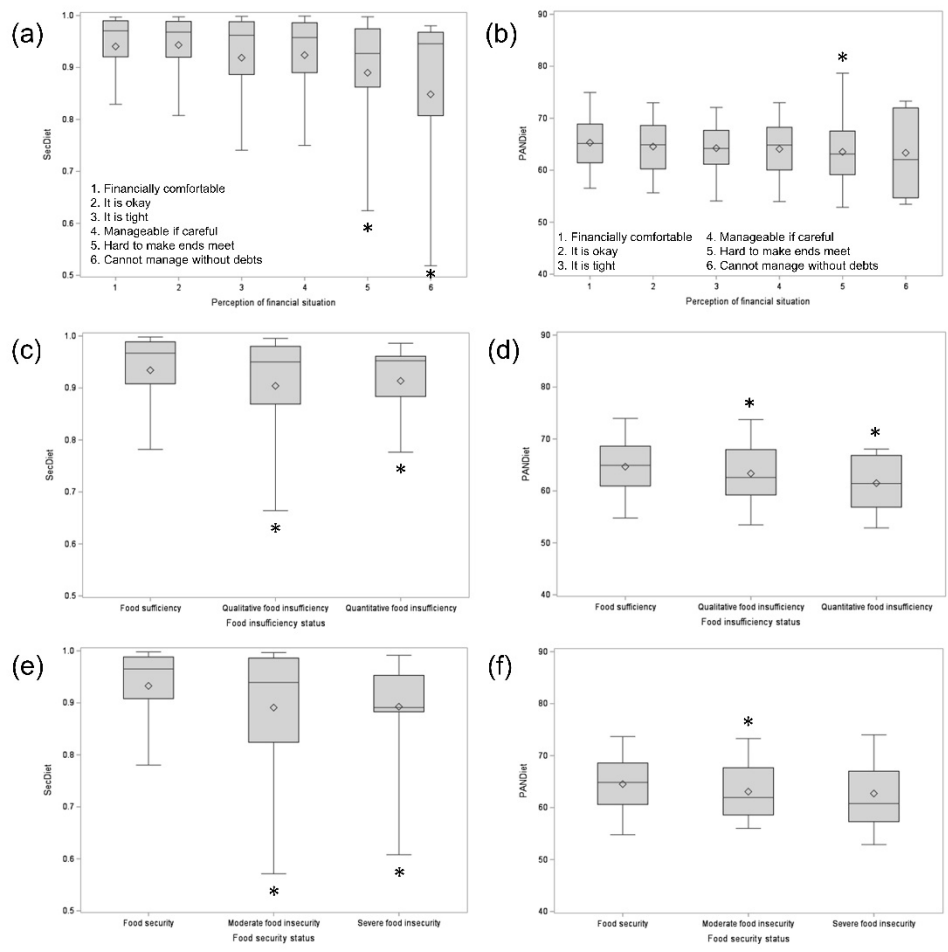
## Figure legends



**Figure 1.** Distribution of the SecDiet score in (a) the INCA3 population (n=1,774) and (b) the NutriNet-Santé population (n=104,382).



**Figure 2.** SecDiet score according to monthly income per household unit ((a) and (c)) and professional occupation ((b) and (d)) in the INCA3 population (n=1,774) and the NutriNet-Santé population (n=104,382), respectively. \* Significantly different from the reference (“>1850€” or “>3700€” respectively for monthly income per household unit in the INCA3 population or the NutriNet-Santé population, “Others occupation” for professional occupation) assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons (significance was set at  $P < 0.05$ ). NA, not available.



**Figure 3.** (a) SecDiet and (b) PANDiet scores according to the perception of financial situation; (c) SecDiet and (d) PANDiet scores according to food insufficiency status; (e) SecDiet and (f) PANDiet scores according to food security status in the INCA3 population (n=1,774). \* Significantly different from the reference (“Financially comfortable” for perception of financial situation, “Food sufficiency” for food insufficiency status, “Food security” for food security status) assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons (significance was set at  $P < 0.05$ ).

## Supplementary Material

**Supplemental Method 1.** Selection of nutrients and reference values to calculate the SecDiet score.

### **Nutrients included:**

**Vitamin A:** Vitamin A is essential to ensure normal vision, growth and development. The main outcome related to vitamin A deficiency is xerophthalmia, which in the most extreme case can lead to irreversible blindness. IOM and EFSA have set their recommendations based on the intake necessary to ensure adequate stores<sup>(1-3)</sup>. Only the WHO has defined a minimum daily intake necessary to prevent xerophthalmia, in the absence of clinical or subclinical infection, without ensuring liver storage. This mean requirement has been estimated as 300µg RE/day for men and 270µg/day for women<sup>(4)</sup>. These reference values were used as the deficiency threshold (DT) for vitamin A, with a CV of 15%.

**Thiamin:** Thiamin is an essential vitamin because of its role as a coenzyme in the metabolism of carbohydrates and branched-chain amino acids. Thiamin deficiency manifests itself in the form of beriberi disease or as Wernicke-Korsakoff syndrome. Reference values are mainly based on erythrocyte transketolase activity, which is used as a marker of thiamin status<sup>(1-3,5)</sup>. However, these reference values do not involve the onset of deficiency symptoms, so we defined an estimated deficiency threshold (eDT). This eDT was calculated as the intake covering the requirements of 2.5% of the population and is therefore estimated as  $eDT = EAR(1 - 2CV) = RDA \frac{1-2CV}{1+2CV}$ . The EFSA has set the EAR at 0.3mg/1000kcal/day and the RDA at 0.4mg/1000kcal/day with a CV of 20%<sup>(1)</sup>. The eDT is therefore set at 0.18mg/1000kcal/day. This threshold is quite consistent with studies that observed clinical signs of deficiency at intakes below 0.2 mg/1000kcal, as reported by the NCM<sup>(5)</sup>.

**Riboflavin:** Riboflavin is a precursor of coenzymes that acts in numerous oxidation-reduction reactions in metabolic pathways and energy production. The clinical signs of riboflavin deficiency, ariboflavinosis, are nonspecific, and can take different forms such as a sore throat, cheilosis, angular stomatitis, etc. An adequate riboflavin intake has been determined using different indicators such as urinary riboflavin excretion, erythrocyte glutathione reductase activity coefficient or plasma riboflavin<sup>(2-5)</sup>. The EFSA used the inflection point of the urinary riboflavin excretion curve, which is a sign of body saturation, and set the EAR at 1.3 mg/day and the RDA at 1.6 mg/day with a CV of 10%<sup>(1)</sup>. In the same way as for thiamin, reference values were not set at the onset of clinical signs of deficiency and an eDT was calculated and set at 1.0 mg/day using EFSA reference values.

**Niacin:** Niacin is a precursor of the coenzymes involved in the metabolism of glucose, amino acids and fatty acids. Pellagra is the disease that appears in case of niacin deficiency. Niacin requirements are estimated using the urinary excretion of niacin metabolites and are expressed as niacin equivalent to take account of the conversion of tryptophan into niacin<sup>(2,3,5)</sup>. The EFSA based its reference values using depletion-repletion studies and set the EAR at 1.3 mg NE/MJ

(5.5 mg NE/1000kcal), based on the rationale that this intake is sufficient to prevent depletion and maintain niacin body stores. Assuming a CV of 10%, the RDA was set at 1.6 mg NE/MJ (6.6 mg NE/1000kcal). The EFSA also noted that there were no signs of niacin deficiency with intakes of at least 1 mg/NE/MJ (4.4 mg NE/1000kcal) for a minimal daily energy intake of 8.4 MJ/day (2000kcal/day)<sup>(1)</sup>. Since the reference values were not based on the appearance of clinical signs of deficiency, an eDT was estimated, based on the EFSA reference values, and set at 1.0 mg/NE/MJ (4.35 mg/1000kcal), which is in line with the minimum intake indicated by EFSA and NCM<sup>(1,5)</sup>.

Folate: Folate acts as a coenzyme in the metabolism of nucleic and amino acids and is also fundamental for the normal functioning of the methionine cycle. The main clinical sign of folate deficiency in adults is megaloblastic anaemia. In pregnant women, folate intakes need to be increased to reduce risk of neural tube defects. The requirements for folate are based on the minimum amounts needed to maintain adequate levels of biomarkers such as serum or erythrocyte folates or plasma homocysteine<sup>(1,2,4)</sup>. Since the reference values were not based on the appearance of clinical signs of deficiency, an eDT was estimated based on the EFSA reference values. The EFSA has set an EAR of 250 µg/day and a RDA of 330 µg/day with a CV of 15%, based on a depletion-repletion study<sup>(1)</sup>. The eDT was therefore set at 175 µg/day.

Vitamin B12: Vitamin B12 plays an essential role in normal blood formation and neurological function. It acts as a coenzyme in the reaction that converts homocysteine to methionine and is also implicated in the metabolism of fatty acids and amino acids. The earliest symptom of vitamin B12 deficiency is similar to that of folate deficiency and takes the form of megaloblastic anaemia, but additional neurological dysfunction may eventually occur. The requirements for vitamin B12 are based on evaluating several biomarkers of vitamin B12 status<sup>(1-3)</sup>. The NNR determined that the lowest dietary intake needed to prevent anaemia is 1 µg/day<sup>(5)</sup> and this value was selected as the threshold for the calculation of the SecDiet, with a CV of 15%.

Vitamin C: Vitamin C acts as an enzyme cofactor and antioxidant. The clinical form of vitamin C deficiency is scurvy and occurs with a body pool lower than 300 mg and a plasma ascorbate concentration lower than 11 µmol/L. Scurvy can be prevented by an intake of 10 mg/day of vitamin C<sup>(1,2,4)</sup>. This value was selected as the threshold for the calculation of the SecDiet with a CV of 10% (CV assumed by the EFSA<sup>(1)</sup>).

Iodine: Iodine is an essential component for the synthesis of thyroid hormones which are crucial for numerous physiological functions (growth, development of neurological and cognitive functions, protein synthesis, etc.). The consequence of iodine deficiency is impaired thyroid function that may lead to thyroid hypertrophy resulting in goitre, mental retardation or cretinism. Iodine requirements are mainly based on thyroid iodine accumulation and turnover<sup>(1-3)</sup>. The EFSA has defined an Adequate Intake based on the prevalence of goitre. A European epidemiological study found that the lowest prevalence of goitre was observed with a urinary iodine concentration above 100 µg/L, which corresponds to an iodine intake at around 150 µg/day. An Adequate Intake of 150 µg/day was thus defined for adults<sup>(1)</sup>. The Adequate Intake was taken as the deficiency

threshold, with a CV of 20%. However, it appears that this threshold overestimated the risk of iodine deficiency so, using the national prevalence of goitre (which is approximately 10% in France<sup>(6)</sup>), we readjusted the estimation of the risk of deficiency (by dividing the deficiency threshold by an adequate factor of 1.5) in order to obtain a probability of adequacy of 0.9 in the French national representative survey INCA3. The recalibrated DT was therefore set at 100 µg/day with a CV of 20%.

Selenium: Selenium, via selenoproteins, plays a role, among others, in the metabolism of thyroid hormones and in the defences against oxidative stress. Selenium requirements are defined as the intake needed to maximize the activity of plasma selenoprotein glutathione peroxidase<sup>(2,3)</sup>. Selenium deficiency leads to Keshan disease, which was first observed in Chinese regions where soil selenium concentrations are low. Epidemiological studies were used to establish a population basal requirement for selenium and concluded that Keshan disease was not present in regions where the mean intake of selenium for adults was higher than 19.1 µg/day for males and 13.3 µg/day for females. These thresholds were adapted to use a standard reference body weight of 65 kg for men and 55kg for women. The population minimum intake of selenium defined by the FAO is therefore 21 µg/day for males and 16 µg/day for females<sup>(4,7)</sup>, and this was taken as the reference for the SecDiet with a CV of 15%.

Iron: Most of the body's iron reserves are found in hemoglobin and muscle myoglobin and contribute to oxygen transport. Iron deficiency causes anaemia, which is the most common nutritional deficiency worldwide, and corresponds to low haemoglobin concentrations. Iron deficiency can also lead to depleted stores when serum ferritin concentrations are low. Iron intake requirements are based on the modelling of obligatory losses while taking account of iron absorption<sup>(1,2)</sup>. Although the requirements are not based on iron deficiency, we considered that those based on obligatory losses were adequate to define the deficiency threshold. We therefore considered the Anses recommendations that are based on the modeling of obligatory losses but applied to bioavailable iron. For men and non-menstruating women, an EAR of 6 mg/d, RDA of 11 mg/d and CV of 40% defined by Anses were therefore used for iron<sup>(3)</sup>. Assuming iron absorption of 16%, the EAR and RDA correspond respectively to 0.95 mg/day and 1.74 mg/day of bioavailable iron. The deficiency threshold was therefore set at 1.74 mg/d of bioavailable iron, with a CV of 40%. For menstruating women, the distribution of their requirements is not normal and was modelled using a lognormal function by adding basal iron losses (normally distributed) to menstrual losses (exponentially distributed,  $\lambda = \ln(2)/0.28$ ) with a Monte-Carlo simulation on 1000 individuals in the same way as the calculation of the PANDiet<sup>(8)</sup>. Since the combination of basal and menstrual losses followed a lognormal distribution, it was considered that the logarithm of physiological requirements followed a normal distribution ( $\mu = 0.18$ ,  $\sigma = 0.34$ ). As for iodine, the threshold used overestimated the risk of iron deficiency, so based on the prevalence of anaemia in the French population (2% among men and 5.1% among women<sup>(9)</sup>) we readjusted it by dividing by a factor of 2.5 for men and non-menstruating women and 2.8 for menstruating women in order to obtain a probability of adequacy of 0.98 for men and 0.95 for women in the French national representative survey INCA3. The corrected DT was set at 0.70 mg/day with a CV of 40% for men and non-menstruating women. For menstruating women, the DT was set at 0.83 mg/day.

Bioavailable iron was estimated using a mathematical model. Nonhaeme iron absorption is dependent on individual concentration of serum ferritin and on dietary factors such as vitamin C, meat, fish and poultry, tea, phytate and calcium intakes. Haeme iron absorption is only dependent on serum ferritin levels. The following equation was used to calculate nonhaeme iron absorption<sup>(10)</sup>:

$$\begin{aligned} \text{Ln Absorption (\%)} &= 6.294 - 0.709 \ln(\text{SF}) + 0.119 \ln(\text{C}) + 0.006 \ln(\text{MFP} + 0.1) \\ &- 0.055 \ln(\text{T} + 0.1) - 0.247 \ln(\text{P}) - 0.137 \ln(\text{Ca}) - 0.083 \ln(\text{NH}) \end{aligned}$$

For haeme iron absorption, the following equation was used<sup>(11)</sup>:

$$\text{Log Absorption (\%)} = 1.9897 - 0.3092 \times \log(\text{SF})$$

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

Because no data were available on the serum ferritin status of individuals, the serum ferritin level was set at 15 mg/L corresponding to the cut-off value for low ferritin stores. However, this hypothesis overestimates the absorption, since iron absorption is maximal at low ferritin stores.

Zinc: Zinc is essential for growth and development and has a catalytic role in various enzymatic processes. There are no specific clinical signs of deficiency in adults but skin lesions, diarrhoea, alopecia, impaired immune system may appear. In children, growth retardation is the main clinical sign. A vegetarian diet may lead to low zinc status because of the high content in plant-based foods of phytates that reduce zinc absorption. There are no adequate biomarkers for zinc status from which to derive requirements. Zinc requirements were thus estimated using a factorial approach considering physiological requirements, by estimating total daily losses and zinc absorption<sup>(1,2,4,12)</sup>. We estimated the deficiency threshold for bioavailable zinc from estimates of obligatory losses. For men, urinary and sweat losses, integumental losses and losses in semen are estimated respectively at 0.63 mg/d, 0.54 mg/d and 0.1 mg/d. For women, urinary and sweat losses, integumental losses and menstrual losses are estimated respectively at 0.44 mg/d, 0.46 mg/d and 0.1 mg/d<sup>(5,13)</sup>. Losses from the intestine could not be precisely determined because they depend on the quantity of zinc absorbed, and this was estimated to be 0.3 mg/d. It was therefore considered that total endogenous losses reached 1.6 mg/d for men and 1.3 mg/d for women and these two values were retained to define the deficiency threshold, with a CV of 15%.

The following mathematical model was used to calculate bioavailable zinc from dietary zinc and phytate intakes<sup>(14)</sup>:

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

TAZ: total absorbed zinc (mmol), TDZ: total dietary zinc (mmol) and TDP: total dietary phytate (mmol).

**Calcium:** Calcium is an essential and structural component of the skeleton and more than 99 percent of total body calcium is present in the bones and teeth. When intakes are inadequate, calcium is resorbed from the skeleton in order to maintain normal circulating concentrations, making it difficult to estimate calcium nutritional status and requirements. On the long term, this resorption reduces bone mineral density and chronic calcium deficiency can lead to osteopenia and osteoporosis and an increased risk of fractures. Calcium requirements are difficult to estimate because of calcium homeostasis and the absence of short-term clinical manifestations of calcium deficiency. Health agencies have therefore based their requirements on balanced studies<sup>(1,2,12)</sup>. Over the long term, it is assumed that intake should not be lower than 500 mg/d for adults to maintain a consistent balance<sup>(5,12)</sup> and several meta-analyses have concluded that there was no significant association between calcium intake and fracture risk with a calcium intake higher than 500 mg/d<sup>(15-17)</sup>. This value of 500 mg/d was retained for our study to define the deficiency threshold, with a CV of 15%.

### **Nutrients not included:**

**Pantothenic acid:** Pantothenic acid is widely found in foods and isolated pantothenic acid deficiency has almost never been observed, except under experimental conditions<sup>(2,4,12)</sup>.

**Vitamin B6:** Vitamin B6 is frequently found in foods and vitamin B6 deficiency is extremely rare; it has only been observed during depletion with very low level of vitamin B6 or in association with other B-vitamin deficiencies<sup>(2,4,12)</sup>.

**Vitamin B8:** No deficiency has been observed in healthy humans under normal conditions but only in individuals receiving total parenteral nutrition without biotin or those consuming raw egg whites over a long period<sup>(2,4,12)</sup>.

**Vitamin D:** Vitamin D deficiency can occur in the form of rickets in children and osteomalacia in adults. Despite its fundamental role in human metabolism, vitamin D was not considered for the calculation of the SecDiet because it can be synthesized endogenously in adequate quantities through exposure to the sun and the requirements are generally determined based on low sun exposure<sup>(1,3,12)</sup>. It would therefore be inaccurate to evaluate the risk of vitamin D deficiency by only considering food intake, so it was not included in the SecDiet.

**Vitamin E:** Vitamin E deficiency is very rare and has only been observed in individuals with medical conditions that alter its absorption or metabolism. Vitamin E deficiency due to a low intake has never been described in healthy individuals<sup>(2,4,5)</sup>.

**Vitamin K:** Vitamin K plays a role in blood coagulation. Vitamin K deficiency can be found in infants that are exclusively breast-fed and can cause bleeding, but has not been observed in adults, except when a pathology interferes with absorption of the vitamin<sup>(2,4,12)</sup>.

**Copper:** Copper deficiency is rare in humans and has only been observed in patients receiving prolonged total parenteral nutrition, in the case of genetic mutations affecting copper metabolism<sup>(1,2)</sup> or in patients who have undergone bariatric surgery<sup>(18)</sup>.

**Manganese:** Clinical signs of manganese deficiency have not been clearly described in humans and it has only been observed in few cases of patients receiving parenteral nutrition<sup>(1,2,12)</sup>.



Phosphorus: Phosphorus is widespread in foods. Phosphorus deficiency is unlikely to be caused by an inadequate phosphorus intake, but only in the event of metabolic disorders or in patients receiving parenteral nutrition<sup>(1,2,12)</sup>.

Potassium: Potassium is found in all foods and potassium deficiency is not caused by an inadequate potassium intake but can be caused by increased potassium losses (diarrhea, vomiting, abuse of laxatives and diuretics)<sup>(1,12)</sup>.

Sodium: Sodium deficiency is rare in healthy adults. Nowadays there are more concerns about excess intakes rather than insufficient intakes<sup>(2,12,19)</sup>.

Magnesium: Magnesium deficiency may be observed in some diseases or with chronic alcoholism, or in the case of a low magnesium intake combined with important losses (prolonged diarrhea, excessive urinary magnesium losses) but otherwise overt deficiency is not common in healthy adults<sup>(2,4,12)</sup>.

Chromium: There is insufficient scientific evidence of how essential chromium is in humans; chromium deficiency has only been observed in patients receiving total parenteral nutrition without chromium supplementation<sup>(1,2)</sup>.

Fluoride: Fluoride plays an important role in the prevention of caries and an insufficient fluoride intake increases the risk of dental caries. However, fluoride is not considered as an essential nutrient<sup>(1,2)</sup>.

Molybdenum: Molybdenum deficiency has not been observed in healthy humans<sup>(1,2)</sup>.

**Supplemental Method 2.** The PANDiet score is expressed as the average of an adequacy subscore (AS – accounting for 27 nutrients) and a moderation subscore (MS – accounting for six nutrients, plus 12 potential penalty values). DHA and EPA+DHA are weighted by a factor of 1/2 as DHA is present twice. Niacin equivalents were calculated as the sum of dietary niacin and 1/60 dietary tryptophan. The upper reference value for sugars excludes lactose. The tolerable upper intake limit for vitamin A concerns retinol only. Version 3.1 of the PANDiet is based on the dietary reference intake from the 2016 Anses opinion<sup>(3)</sup> and the overall construction of the score has been described elsewhere<sup>(20,21)</sup>.

PANDiet score			
Average of Adequacy and Moderation subscores			
Adequacy subscore			
Nutrient	Reference value (/day)	Variability	Source
Protein	0.66 or 0.8 g/kg bw	12.5%	(22,23)
LA	3.08% EIEA	15%	(24)
ALA	0.769% EIEA	15%	(24)
DHA	0.192 g	15%	(24)
EPA + DHA	0.385 g	15%	(24)
Fibre	23 g	15%	(3)
Vitamin A	570 or 490 µg	15%	(3)
Thiamin	0.3 mg/1000 kcal	20%	(1)
Riboflavin	1.3 mg	10%	(1)
Niacin	5.44 mg NE/1000kcal	10%	(3)
Pantothenic acid	3.62 or 2.94 mg	30%	(3)
Vitamin B-6	1.5 or 1.3 mg	10%	(25)
Folate	250 µg	15%	(3)
Vitamin B-12	3.33 µg	10%	(3)
Vitamin C	90 mg	10%	(3)
Vitamin D	10 µg	25%	(3)
Vitamin E	5.8 or 5.5 mg	40%	(3)
Calcium	860 (<= 24 y.o) or 750 (>24 y.o.)	15% or 13%	(3)
Copper	1.0 or 0.8 mg	15%	(3)
Iodine	107 µg	20%	(3)
Bioavailable iron	See Supplemental Method 1		(3)
Magnesium	5 mg/kg bw	15%	(3)
Manganese	1.56 or 1.39 mg	40%	(3)
Phosphorus	Calcium (mmol) / 1.65 c.f. phosphorus section in de Gavelle et al. (8)	7.5% + CV Calcium (mg)	(1)
Potassium	2692 mg	15%	(1)
Selenium	54 µg	15%	(3)
Bioavailable zinc	0.642 + 0.038 b.w.	10%	(3)

Moderation subscore			
Nutrient	Reference value (/day)	Variability	Source
Protein	2.2 g/kg bw	12.5%	(3)
Total fat	44% EIEA	5%	(3)
SFA	12% EIEA	15%	(3)
Carbohydrates	60.5% EIEA	5%	(3)
Sugars	100 g	15%	(3)
Sodium	3482 or 2618 mg	40%	(3)

Tolerable Upper Intake Limits		Source
Vitamin A	3000 µg	(3)
Niacin	900 mg	(3)
Vitamin B6	25 mg	(3)
Folate	1170 µg	(3)
Vitamin D	100 µg	(3)
Vitamin E	300 mg	(3)
Calcium	2500 mg	(3)
Copper	10 mg	(3)
Iodine	600 µg	(3)
Dissociable magnesium	250 mg	(3)
Selenium	300 µg	(3)
Zinc	25 mg	(3)

bw, body weight; LA, linoleic acid; EIEA, energy intake excluding alcohol; ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; NE, niacin equivalent; CV, coefficient of variation; SFA, saturated fatty acids.

**Supplemental Table 1:** Spearman rank correlation coefficients (r) between the SecDiet score and its probabilities of adequacy, the PANDiet score and total energy intake in the French adult population, INCA3, n=1,774.

	SecDiet score	Calcium	Zinc	Iron	Selenium	Iodine	Vitamin C	Vitamin B12	Folate	Niacin	Riboflavin	Thiamin	Vitamin A
Probabilities of adequacy													
Vitamin A	0.68† (0.65, 0.70) **	0.43 (0.39, 0.47) **	0.31 (0.27, 0.35) **	0.21 (0.17, 0.26) **	0.26 (0.21, 0.30) **	0.40 (0.36, 0.44) **	0.24 (0.19, 0.28) **	0.27 (0.23, 0.32) **	0.48 (0.44, 0.51) **	0.07 (0.03, 0.12) *	0.44 (0.40, 0.48) **	0.10 (0.05, 0.14) **	1
Thiamin	0.17 (0.13, 0.22) **	0.13 (0.08, 0.17) **	0.08 (0.03, 0.12) *	0.11 (0.06, 0.15) **	0.09 (0.04, 0.14) *	0.15 (0.11, 0.20) **	0.15 (0.10, 0.19) **	0.06 (0.01, 0.11) *	0.16 (0.12, 0.21) **	0.18 (0.13, 0.23) **	0.16 (0.12, 0.21) **	1	
Riboflavin	0.74 (0.71, 0.76) **	0.64 (0.61, 0.66) **	0.52 (0.48, 0.55) **	0.42 (0.38, 0.45) **	0.38 (0.34, 0.42) **	0.61 (0.58, 0.64) **	0.29 (0.25, 0.33) **	0.46 (0.42, 0.49) **	0.56 (0.53, 0.59) **	0.17 (0.12, 0.21) **	1		
Niacin	0.20 (0.16, 0.25) **	0.14 (0.09, 0.18) **	0.14 (0.09, 0.19) **	0.20 (0.15, 0.24) **	0.09 (0.05, 0.14) **	0.17 (0.13, 0.22) **	0.11 (0.07, 0.16) **	0.12 (0.07, 0.16) **	0.15 (0.10, 0.19) **	1			
Folate	0.70 (0.68, 0.73) **	0.49 (0.45, 0.52) **	0.37 (0.33, 0.41) **	0.40 (0.36, 0.44) **	0.37 (0.32, 0.40) **	0.53 (0.49, 0.56) **	0.43 (0.39, 0.46) **	0.31 (0.27, 0.35) **	1				
Vitamin B12	0.51 (0.48, 0.55) **	0.38 (0.34, 0.42) **	0.48 (0.44, 0.51) **	0.33 (0.28, 0.37) **	0.28 (0.24, 0.32) **	0.36 (0.32, 0.40) **	0.14 (0.09, 0.18) **	1					
Vitamin C	0.42 (0.38, 0.46) **	0.24 (0.20, 0.28) **	0.21 (0.17, 0.25) **	0.30 (0.26, 0.34) **	0.24 (0.19, 0.28) **	0.25 (0.21, 0.29) **	1						
Iodine	0.78 (0.76, 0.79) **	0.58 (0.55, 0.61) **	0.40 (0.36, 0.44) **	0.38 (0.34, 0.42) **	0.38 (0.34, 0.42) **	1							
Selenium	0.41 (0.37, 0.45) **	0.35 (0.31, 0.39) **	0.27 (0.22, 0.31) **	0.21 (0.16, 0.25) **	1								
Iron	0.51 (0.48, 0.55) **	0.30 (0.26, 0.34) **	0.51 (0.47, 0.54) **	1									
Zinc	0.54 (0.50, 0.57) **	0.49 (0.45, 0.52) **	1										
Calcium	0.70 (0.68, 0.73) **	1											
Total energy intake	0.44 (0.40, 0.47) **												
PANDiet score	0.50 (0.46, 0.53) **												

† Spearman rank correlation coefficient with 95% confidence interval. \*, P<0.05; \*\*, P<0.001

**Supplemental Table 2:** The SecDiet score and its probabilities of adequacy according to monthly income per household unit in the French adult population from the INCA3 survey, n=1,774

	Monthly income per household unit (€)										P <sup>†</sup>
	>1850 € (n=607)		1340-1850 € (n=402)		900-1340 € (n=355)		<900 € (n=281)		Not available (n=129)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.94	0.07	0.93	0.08	0.92	0.10	0.91	0.11	0.93	0.07	0.002
Median	0.97		0.96		0.96*		0.95*		0.96*		
Q1-Q3	0.93-0.99		0.91-0.99		0.89-0.99		0.87-0.99		0.89-0.99		
PANDiet (0-100)	64.96	4.83	64.60	5.85	64.08	6.00	64.05	7.33	63.63	5.41	0.058
Median	65.09		64.45		64.81		64.14		63.90		
Q1-Q3	61.70-68.17		60.95-68.71		59.96-68.27		59.60-68.72		58.58-66.78		
Probabilities of adequacy for SecDiet (0-1)											
Vitamin A	0.92	0.14	0.91	0.15	0.90	0.19	0.84	0.27	0.91	0.15	-
Thiamin	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.00	-
Riboflavin	0.96	0.10	0.95	0.12	0.93	0.16	0.93	0.14	0.94	0.08	-
Niacin	1.00	0.01	1.00	0.01	1.00	0.00	1.00	0.02	1.00	0.00	-
Folate	0.96	0.10	0.95	0.10	0.92	0.17	0.94	0.13	0.92	0.14	-
Vitamin B12	0.98	0.04	0.97	0.06	0.97	0.06	0.97	0.06	0.97	0.04	-
Vitamin C	0.98	0.05	0.97	0.05	0.97	0.05	0.97	0.06	0.97	0.05	-
Iodine	0.91	0.15	0.90	0.15	0.90	0.16	0.89	0.18	0.92	0.11	-
Selenium	0.99	0.02	0.99	0.02	0.99	0.03	0.99	0.03	0.99	0.03	-
Iron	0.97	0.05	0.96	0.08	0.96	0.07	0.96	0.08	0.97	0.04	-
Zinc	0.99	0.04	0.99	0.06	0.98	0.05	0.98	0.06	0.99	0.04	-
Calcium	0.96	0.09	0.95	0.12	0.94	0.15	0.9	0.21	0.92	0.13	-

\* Significantly different from the reference (>1850 €), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at P<0.05.

† P for Kruskal-Wallis non-parametric test.

**Supplemental Table 3:** The SecDiet score and its probabilities of adequacy according to monthly income per household unit in the French adult population from the NutriNet-Santé study, n=104,382.

	Monthly income per household unit (€)																P <sup>†</sup>
	>3700 € (n=9938)		2700 - 3700 € (n=14 382)		2300 - 2700 € (n=9129)		1800 - 2300 € (n=14 986)		1200 - 1800 € (n=25 632)		900 - 1200 € (n=6740)		<900 € (n=11277)		Not available (n=12297)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.97	0.05	0.97	0.05	0.97	0.05	0.96	0.06	0.96	0.06	0.95	0.07	0.94	0.08	0.95	0.07	
Median	0.99		0.99		0.98*		0.98*		0.98*		0.98*		0.97*		0.98*		<0.001
Q1-Q3	0.97-1.00		0.96-1.00		0.96-1.00		0.96-1.00		0.95-0.99		0.94-0.99		0.91-0.99		0.94-0.99		
PANDiet (0-100)	62.50	6.96	61.99	7.00	61.52	7.03	61.26	7.24	60.31	7.14	59.47	7.14	59.31	7.55	60.94	7.49	
Median	61.99		61.36*		60.86*		60.60*		59.73*		58.82*		58.64*		60.39*		<0.001
Q1-Q3	57.54-67.02		57.04-66.47		56.64-65.97		56.25-65.83		55.36-64.76		54.41-63.83		53.99-63.99		55.75-65.71		
Probabilities of adequacy for SecDiet (0-1)																	
Vitamin A	0.99	0.05	0.99	0.05	0.98	0.05	0.98	0.05	0.98	0.06	0.98	0.06	0.97	0.09	0.98	0.07	-
Thiamin	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	-
Riboflavin	0.98	0.09	0.98	0.10	0.97	0.10	0.97	0.11	0.96	0.12	0.95	0.14	0.93	0.17	0.95	0.15	-
Niacin	1.00	0.02	1.00	0.02	1.00	0.01	1.00	0.01	1.00	0.02	1.00	0.03	1.00	0.03	1.00	0.03	-
Folate	0.98	0.07	0.98	0.07	0.98	0.08	0.97	0.09	0.97	0.11	0.95	0.13	0.94	0.15	0.96	0.12	-
Vitamin B12	0.98	0.06	0.98	0.06	0.98	0.06	0.98	0.07	0.98	0.07	0.98	0.07	0.97	0.11	0.97	0.09	-
Vitamin C	1.00	0.02	0.99	0.03	0.99	0.03	0.99	0.03	0.99	0.03	0.99	0.04	0.98	0.05	0.99	0.04	-
Iodine	0.90	0.16	0.89	0.17	0.88	0.18	0.88	0.19	0.86	0.20	0.84	0.22	0.81	0.25	0.84	0.22	-
Selenium	1.00	0.02	1.00	0.02	1.00	0.01	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.03	1.00	0.02	-
Iron	0.99	0.03	0.99	0.03	0.99	0.04	0.99	0.04	0.99	0.04	0.99	0.05	0.98	0.06	0.99	0.05	-
Zinc	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.02	1.00	0.03	1.00	0.03	0.99	0.03	1.00	0.03	-
Calcium	0.98	0.08	0.98	0.09	0.98	0.09	0.97	0.09	0.97	0.11	0.96	0.12	0.94	0.14	0.96	0.12	-

\* Significantly different from the reference (">3700€"), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at P<0.05.

† P for Kruskal-Wallis non-parametric test.

**Supplemental Table 4:** The SecDiet score and its probabilities of adequacy according to professional situation in the French adult population from the INCA3 survey, n=1,774

	Professional situation						<i>P</i> <sup>†</sup>
	Other occupations (n=1600)		Unemployed people (n=112)		Students (n=62)		
	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.93	0.09	0.91	0.09	0.92	0.11	
Median	0.97		0.93*		0.95		<0.001
Q1-Q3	0.91-0.99		0.86-0.98		0.88-0.99		
PANDiet (0-100)	64.66	5.63	62.72	7.24	63.11	6.49	
Median	64.92		61.06*		64.36*		<0.001
Q1-Q3	60.89-68.74		59.06-66.92		59.43-67.72		
Probabilities of adequacy for SecDiet (0-1)							
Vitamin A	0.90	0.17	0.87	0.19	0.83	0.31	-
Thiamin	1.00	0.01	1.00	0.01	1.00	0.01	-
Riboflavin	0.94	0.12	0.94	0.10	0.92	0.14	-
Niacin	1.00	0.01	1.00	0.01	1.00	0.00	-
Folate	0.95	0.12	0.90	0.18	0.92	0.17	-
Vitamin B12	0.97	0.06	0.98	0.04	0.98	0.04	-
Vitamin C	0.97	0.05	0.97	0.05	0.97	0.07	-
Iodine	0.90	0.15	0.88	0.16	0.90	0.19	-
Selenium	0.99	0.02	0.99	0.03	1.00	0.02	-
Iron	0.96	0.07	0.96	0.06	0.98	0.04	-
Zinc	0.98	0.05	0.99	0.03	0.99	0.02	-
Calcium	0.94	0.12	0.89	0.24	0.92	0.20	-

\* Significantly different from the reference ("Others occupations"), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at P<0.05.

† P for Kruskal-Wallis non-parametric test.

**Supplemental Table 5:** The SecDiet score and its probabilities of adequacy according to professional situation in the French adult population from the NutriNet-Santé study, n=104,382.

	Professional situation						P <sup>†</sup>
	Other occupations (n=89 238)		Unemployed people (n=6371)		Students (n=8773)		
	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.96	0.06	0.94	0.08	0.93	0.08	
Median	0.98		0.97*		0.97*		<0.001
Q1-Q3	0.95-0.99		0.93-0.99		0.91-0.99		
PANDiet (0-100)	61.18	7.20	59.62	7.49	59.05	7.33	
Median	60.58		59.05*		58.39*		<0.001
Q1-Q3	56.15-65.75		54.34-64.27		53.95-63.36		
Probabilities of adequacy for SecDiet (0-1)							
Vitamin A	0.98	0.06	0.98	0.07	0.97	0.09	-
Thiamin	1.00	0.00	1.00	0.01	1.00	0.00	-
Riboflavin	0.97	0.11	0.95	0.15	0.92	0.18	-
Niacin	1.00	0.02	1.00	0.03	1.00	0.03	-
Folate	0.97	0.10	0.95	0.14	0.94	0.15	-
Vitamin B12	0.98	0.07	0.97	0.11	0.97	0.10	-
Vitamin C	0.99	0.03	0.99	0.05	0.99	0.04	-
Iodine	0.87	0.19	0.83	0.23	0.8	0.25	-
Selenium	1.00	0.02	1.00	0.03	1.00	0.03	-
Iron	0.99	0.04	0.98	0.05	0.98	0.06	-
Zinc	1.00	0.02	1.00	0.03	0.99	0.04	-
Calcium	0.97	0.10	0.95	0.13	0.95	0.14	-

\* Significantly different from the reference ("Others occupations"), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at P<0.05.

† P for Kruskal-Wallis non-parametric test.

**Supplemental Table 6:** The SecDiet score and its probabilities of adequacy according to perception of financial situation in the French adult population from the INCA3 survey, n=1,774

	Perception of financial situation														P <sup>†</sup>
	Financially comfortable (n=298)		It's okay (n=663)		It's tight (n=195)		Manageable if careful (n=496)		Hard to make ends meet (n=102)		Can't manage without debts (n=19)		Refusal to answer (n=1)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.94	0.08	0.94	0.06	0.92	0.09	0.92	0.10	0.89	0.14	0.85	0.14	0.96	.	
Median	0.97		0.97		0.96		0.96		0.93*		0.95*		0.96		<0.001
Q1-Q3	0.92-0.99		0.92-0.99		0.89-0.99		0.89-0.99		0.86-0.97		0.81-0.97		-		
PANDiet (0-100)	65.31	5.19	64.56	5.40	64.26	5.18	64.09	6.23	63.55	8.00	63.36	7.55	54.25	.	
Median	65.16		64.90		64.19		64.84		63.12*		62.05		54.25		<0.001
Q1-Q3	61.45-68.90		60.27-68.62		6.116-67.68		60.06-68.27		59.16-67.53		54.71-72.00		-		
Probabilities of adequacy for SecDiet (0-1)															
Vitamin A	0.92	0.17	0.92	0.14	0.86	0.23	0.89	0.18	0.82	0.27	0.82	0.18	0.96	.	-
Thiamin	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	0.99	0.01	1.00	.	-
Riboflavin	0.95	0.10	0.96	0.08	0.92	0.14	0.93	0.14	0.90	0.20	0.86	0.22	0.98	.	-
Niacin	1.00	0.01	1.00	0.00	1.00	0.00	1.00	0.02	1.00	0.01	1.00	0.00	1.00	.	-
Folate	0.94	0.14	0.96	0.08	0.95	0.09	0.93	0.14	0.90	0.22	0.84	0.18	0.95	.	-
Vitamin B12	0.97	0.06	0.98	0.04	0.97	0.05	0.97	0.06	0.96	0.08	0.94	0.11	1.00	.	-
Vitamin C	0.98	0.04	0.98	0.04	0.98	0.04	0.97	0.06	0.95	0.07	0.91	0.19	0.96	.	-
Iodine	0.90	0.18	0.91	0.14	0.91	0.13	0.90	0.15	0.87	0.20	0.80	0.19	0.96	.	-
Selenium	0.99	0.01	0.99	0.02	0.99	0.02	0.99	0.02	0.98	0.04	0.98	0.03	1.00	.	-
Iron	0.97	0.05	0.97	0.04	0.96	0.06	0.96	0.08	0.94	0.12	0.91	0.16	0.99	.	-
Zinc	0.99	0.04	0.99	0.03	0.98	0.06	0.98	0.06	0.97	0.07	0.91	0.17	1.00	.	-
Calcium	0.97	0.07	0.95	0.09	0.89	0.21	0.93	0.15	0.89	0.22	0.87	0.19	0.97	.	-

\* Significantly different from the reference ("Financially comfortable €"), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at P<0.05.

† P for Kruskal-Wallis non-parametric test.



**Supplemental Table 7:** The SecDiet score and its probabilities of adequacy according to food insufficiency status in the French adult population from the INCA3 survey, n=1,774

	Food insufficiency status						P <sup>†</sup>
	Food sufficiency (n=1512)		Qualitative food insufficiency (n=227)		Quantitative food sufficiency (n=35)		
	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.93	0.08	0.90	0.11	0.91	0.10	
Median	0.97		0.95*		0.95*		<0.001
Q1-Q3	0.91-0.99		0.87-0.98		0.88-0.96		
PANDiet (0-100)	64.67	5.71	63.37	6.13	61.51	6.08	
Median	64.92		62.59*		61.43*		<0.001
Q1-Q3	60.95-68.63		59.23-67.96		56.87-66.84		
Probabilities of adequacy for SecDiet (0-1)							
Vitamin A	0.90	0.17	0.84	0.24	0.90	0.14	-
Thiamin	1.00	0.01	1.00	0.01	1.00	0.01	-
Riboflavin	0.95	0.12	0.91	0.17	0.93	0.12	-
Niacin	1.00	0.01	1.00	0.01	1.00	0.00	-
Folate	0.94	0.12	0.92	0.16	0.93	0.17	-
Vitamin B12	0.97	0.05	0.96	0.07	0.97	0.05	-
Vitamin C	0.98	0.05	0.97	0.05	0.92	0.15	-
Iodine	0.90	0.15	0.89	0.15	0.89	0.18	-
Selenium	0.99	0.02	0.99	0.03	1.00	0.02	-
Iron	0.97	0.06	0.95	0.11	0.94	0.11	-
Zinc	0.99	0.05	0.98	0.07	0.98	0.07	-
Calcium	0.94	0.12	0.90	0.21	0.94	0.12	-

\* Significantly different from the reference ("Food sufficiency"), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at P<0.05.

† P for Kruskal-Wallis non-parametric test.

**Supplemental Table 8:** The SecDiet score and its probabilities of adequacy according to food security status in the French adult population from the INCA3 survey, n=1,774.

	Food security status						<i>P</i> <sup>†</sup>
	Food security (n=1654)		Moderate food insecurity (n=73)		Severe food insecurity (n=47)		
	Mean	SD	Mean	SD	Mean	SD	
SecDiet (0-1)	0.93	0.08	0.89	0.13	0.89	0.10	<0.001
Median	0.97		0.94*		0.89*		
Q1-Q3	0.91-0.99		0.82-0.99		0.88-0.95		
PANDiet (0-100)	64.53	5.73	63.07	6.00	62.72	7.28	0.002
Median	64.84		61.93*		60.78		
Q1-Q3	60.61-68.58		58.58-67.69		57.30-67.02		
Probabilities of adequacy for SecDiet (0-1)							
Vitamin A	0.90	0.18	0.84	0.24	0.81	0.19	-
Thiamin	1.00	0.01	1.00	0.01	1.00	0.01	-
Riboflavin	0.95	0.12	0.90	0.17	0.91	0.12	-
Niacin	1.00	0.01	1.00	0.01	1.00	0.01	-
Folate	0.94	0.12	0.89	0.22	0.91	0.15	-
Vitamin B12	0.97	0.05	0.96	0.06	0.98	0.05	-
Vitamin C	0.97	0.05	0.96	0.05	0.95	0.13	-
Iodine	0.90	0.15	0.88	0.16	0.88	0.17	-
Selenium	0.99	0.02	0.98	0.05	0.99	0.02	-
Iron	0.97	0.06	0.93	0.11	0.95	0.11	-
Zinc	0.99	0.05	0.97	0.05	0.97	0.11	-
Calcium	0.94	0.14	0.92	0.15	0.91	0.13	-

\* Significantly different from the reference ("Food security"), assessed by Dwass-Steel-Critchlow-Fligner (DSCF) test for pairwise multiple comparisons; significant at  $P < 0.05$ .

† *P* for Kruskal-Wallis non-parametric test.

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