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1 **Title:** The association between meat consumption and body mass index varies according to  
2 the socioeconomic status in a representative sample of French adults

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10 **Abstract:** There is a growing advocacy for reducing meat consumption in Western countries.  
11 However, healthier alternatives to meat may be more expensive, and populations with a low  
12 socioeconomic status (SES) may be more likely to replace meat by less healthy alternatives,  
13 which could reduce dietary quality and have negative effects on health outcomes such as  
14 weight gain. In the present study, we focused on the association between the body mass index  
15 (BMI), meat consumption and SES. We also studied the effect of interactions between meat  
16 consumption and SES on the consumption of food groups other than meat. We performed  
17 multivariate linear regressions based on a representative sample of the French adult  
18 population (n=1,300) collected in 2015. We found that among low-income households, one  
19 day less of meat consumption per month tended to be associated with a higher individual BMI  
20 ( $0.074 \pm 0.039$  kg/m<sup>2</sup>) in significant contrast with the inverse association found in richer  
21 households (combining medium- and high-income groups). This income-based difference in  
22 the meat-BMI relationship was particularly strong in male, younger (aged 18-44) and rural  
23 adults. This result is robust to alternative SES indicators: other income classifications, levels  
24 of completed education, and the occupation classification. Low-income and higher-income

25 households also had different eating habits associated with higher meat consumption: among  
26 low-income households, lower meat consumption was associated with higher consumption of  
27 ice cream and sorbet, while among higher income groups (>1 751 €/month), lower meat  
28 consumption was associated with lower consumption of high-fat and high-sugar food and  
29 beverage items, as well as cheese. Our study is the first to show that SES moderates the  
30 relationship between the level of meat consumption and BMI in a nationally representative  
31 sample. To understand whether promoting reduction in meat consumption could widen health  
32 inequalities, future works need to study the long-term effects of dietary changes on health as a  
33 function of SES.

34 **Key words:** Meat consumption; income; education; body mass index; France.

35 **Highlights:**

- 36 • Association between meat consumption and BMI depends on socioeconomic status  
37 (SES).
- 38 • Meat consumption was inversely associated with BMI among privileged individuals.
- 39 • The relation tended to disappear or become positive in individuals with a lower  
40 household income.
- 41 • These SES-based differences tended to be stronger in male, young, rural adults.
- 42 • Consumption of some unhealthy foods was associated with lower meat consumption  
43 among individuals with low SES.

## 44 **1. Introduction**

45 Nowadays, there is a growing advocacy to reduce meat consumption in Western countries for  
46 both environmental and health reasons. Livestock farming, especially the beef sector, causes  
47 higher greenhouse gas emissions than other agricultural activities, and cutting red meat in the  
48 diet is thus one possible way to reduce the environmental impact of the food system (1). High  
49 consumption of red meat and processed meat is also suspected to increase the prevalence of  
50 overweight and obesity, as well as the risk of type 2 diabetes, stroke, colorectal cancer, and all-  
51 cause mortality (2). Overall, lowering animal protein intakes and favoring plant protein in  
52 human diets appears to be crucial for a global sustainable food system.

53 Today, national dietary guidelines are already starting to include recommendations for upper  
54 levels of meat intake. In France for example, the recommended maximum intake of red meat is  
55 500g per week and that of processed meat is 25g per day (3). Recent studies also suggest that  
56 meatless diets are beneficial to health, reduce the body mass index (BMI), food-related non-  
57 communicable diseases, and overall mortality (4). Nevertheless, in Western countries, meat  
58 remains an important source of dietary protein and of indispensable nutrients including vitamin  
59 B12, zinc and iron, and it is therefore important to consider the impact that reducing meat  
60 consumption could have on the quality of diets of different populations. Specifically, we found  
61 no study that investigated how socioeconomic status (SES) affects the relationship between  
62 meat reduction in diet and nutritional outcomes.

63 In this study, we consider three classical dimensions of individual and household SES, each  
64 dimension being analyzed in specific regressions: household income, individual occupation,  
65 and individual education attainment (15). In the existing literature, associations between SES  
66 indicators and dietary quality have been identified. Indeed, individuals with lower SES tend to  
67 gain weight disproportionately (5). In addition to being associated with high obesity prevalence,  
68 low SES is known to be related to increased risk of disease and higher mortality (6). Low-SES

69 populations also tend to have diets of lower quality (5). While there is a lack of longitudinal  
70 studies linking dietary quality to health outcomes, dietary quality has been identified as a factor  
71 that could influence weight gain (7,8). In this context, consequences of meat reduction on  
72 overall dietary quality should be carefully considered. Because of constraints due to a lower  
73 budget or a smaller choice of healthy foods, low-SES populations might be more likely than  
74 high-SES to replace meat with fat and carbohydrates, since many alternative sources of protein  
75 (including fish, dairy products, and plant proteins) are more expensive or less convenient  
76 (legumes) than high-fat and high-sugar foods. Replacing animal protein with plant protein  
77 favors the nutritional adequacy of the diet when the plant protein comes from foods of high  
78 nutritional value such as whole grains, nuts, seeds, legumes, and vegetables (9). In contrast,  
79 diets rich in affordable “unhealthy” plant foods (fruit juices, sweetened beverages, refined  
80 grains, fried potatoes, sweets and desserts) are associated with increased risk of weight gain,  
81 type 2 diabetes, and coronary disease over time (10–12). Finally, a reduction in protein intake  
82 could also prompt individuals to increase their caloric intake via a physiological response  
83 referenced as the protein leverage hypothesis (13). Together with the loss of nutritional quality,  
84 these behaviors might further increase the risk of diet-related disease for low-SES population  
85 as a consequence of meat reduction. To avoid such risk, there is a need to better understand the  
86 nutritional effects of reducing meat consumption for different SES groups.

87 In the present study, we focused on the correlation between BMI, meat consumption and SES  
88 in a representative sample of the French adult population using data from the third wave of the  
89 French National Individual Survey on Food Consumption (INCA3) conducted in 2014-2015  
90 (14). This cross-sectional survey collected data on dietary consumption, anthropometric  
91 measurements (weight and height) and data concerning SES indicators such as income,  
92 occupational status, and education. Using these data, we evaluated if these particular SES  
93 characteristics modify the association between meat consumption and BMI. We also

94 investigated the possible influence of gender, age, and living area regarding the role of SES in  
95 the meat-BMI relationship. Finally, we investigated if the interaction between meat  
96 consumption and SES is associated with the consumption of food groups other than meat. Note  
97 that our aim is not to estimate a causal effect but rather to provide first insights on SES-based  
98 heterogeneity in the association between meat consumption and BMI. Indeed, potential  
99 endogeneity in the SES-BMI relationship (i.e., due to reverse causality problems and/or the  
100 omission of determinants of BMI that affect SES) might bias the estimates, understating or  
101 overstating certain results.

102

103 **2. Methods**

104 **2.1. Data and sample**

105 INCA3 is the most recent nationally representative cross-sectional individual survey conducted  
106 by the French National Agency for Food, Environment and Occupational Health & Safety  
107 (ANSES). It includes data on 3,157 adults aged 18 to 79 and 2,698 children aged 0 to 17 (14).  
108 This survey is particularly appropriate for our research question insofar as INCA3 has the  
109 advantage of providing detailed individual information on reported food and beverage  
110 consumption, economic and sociodemographic characteristics, and objective anthropometric  
111 measurements (height and weight) made using scales and stadiometers. As recommended by  
112 the survey administration, our statistical analyses are balanced using the weights provided in  
113 the INCA3 database to make the results representative of the French population.

114 We restricted our sample to non-pregnant and non-lactating adult individuals and excluded  
115 adults over (or equal to) the age of 65. Hence, all our analyses are representative of the French  
116 adult population aged from 18 to 64. This restricted sample includes about 1,300 individuals.

117 **2.2. Model and variables**

118 To investigate potential differences in the association between meat consumption and adult  
119 BMI according to the level of SES, we performed multivariate regressions using an ordinary  
120 least square (OLS) estimator. Specifically, we regressed the following OLS statistical model:

121 
$$Y_i = \beta_0 + \beta_1 SES_i^j + \beta_2 Meat_i + \beta_3 SES_i^j * Meat_i + \beta_4 X_i + \varepsilon_i \quad (\text{Eq. 1})$$

122 The dependent variable  $Y_i$  refers to the body mass indicator of an individual  $i$ , measured by the  
123 BMI. BMI is calculated by dividing the weight (in kg) by the square of height (in meters). In  
124 alternative estimations, we also use a binary dependent variable that takes the value 1 if an  
125 individual is classified as overweight or obese (i.e., a BMI higher than 25 kg/m<sup>2</sup>), 0 otherwise.

126 In the set of independent variables, we distinguish between the explanatory variables of interest  
127 ( $SES_i^j$  and  $Meat_i$ ) and the control variables ( $X_i$ ).  $Meat_i$  refers to the frequency of consumption  
128 of meat (including beef, pork, poultry, sheep, offal, sausages, terrines, and other mixtures),  
129 which is measured in days/month (initially estimated from a retrospective period of 12 months  
130 before the survey). Hence, meat consumption varies from 0 to 30 days/month.  $SES_i^j$  refers to  
131 the SES of an individual  $i$ . Three indicators of SES are considered and separately analyzed in  
132 specific regression models. The three SES indicators classified in categories  $j$  as follows: (i)  
133 monthly household income based on distribution tercile ( $j=0$ : less than 1,750 €/month;  $j=1$ :  
134 middle incomes;  $j=3$ : more than 3,850 €/month); (ii) completed education ( $j=0$ : no diploma;  
135  $j=1$ : a technical or professional diploma;  $j=2$ : a high school diploma;  $j=3$ : higher education  
136 grades); (iii) occupation groups, based on the international standard classification ( $j=0$ : workers  
137 engaged in occupations requiring manual labor or heavy machinery;  $j=1$ : workers engaged in  
138 skilled or semi-skilled jobs;  $j=2$ : professionals and workers engaged in executive,  
139 administrative or clerical duties;  $j=3$ : inactive).

140 In order to explore the association between BMI and meat consumption according to SES, we  
141 also introduced an interaction term between the two factors of interest ( $SES_i^j * Meat_i$ ). Thanks  
142 to this inclusion,  $\beta_1$  estimates the association between SES and BMI, when meat consumption  
143 is equal to 0. In other words, this fitted parameter measures the extent to which SES influences  
144 BMI in individuals who consume no meat.  $\beta_2$  estimates the association between meat  
145 consumption and BMI, when the SES indicator is equal to 0 (i.e., for the reference group  $j=0$ ,  
146 which is low income, no educational qualification, or low occupation index).  $\beta_3$  is the fitted  
147 trend of the association between meat consumption and each category  $j$  of SES (excluding the  
148 reference group). Then,  $\beta_0$  is the constant (i.e., the BMI fitted value considering that all  
149 independent variables are equal to 0),  $\varepsilon_i$  is fitted residuals (i.e., unexplained variations in the  
150 BMI), and  $\beta_4$  refers to the fitted parameters of the control variables  $X_i$ .

151 In the set of control variables,  $X_i$ , we included the main determinants of BMI excluding caloric  
152 intakes. Concretely, we controlled for demographic factors such as age group (18-44, or 45-  
153 64), sex, and household size (number of children and adults), as well as for environmental  
154 factors such as the degree of urbanicity of the living area (rural, small city, medium size city,  
155 large city, and the Paris agglomeration) and the region of residence. We also controlled for  
156 individual habits including daily smoking (a binary-response variable), an alcohol consumption  
157 score varying from 0 to 90 (which is the sum of days/month when an individual consumes wine,  
158 days/month when an individual consumes beer, and days/month when an individual consumes  
159 cider), and the levels (low, medium, or high) of physical activity (e.g. sport) and sedentary  
160 activity (e.g. time spent sitting in front of screens) directly calculated by the INCA  
161 administration using average daily time allocated to both types of activity. Finally, we  
162 systematically controlled for possible under- and over-reporting using the Goldberg/Black  
163 method provided by the INCA3 survey administration. Table 1 lists sample means for each  
164 independent variable (except for region dummies to limit the table size).

165 In addition to running Eq. 1 for the whole sample, we also investigated the potential presence  
166 of heterogeneous effects according to gender, age group and living area. Hence, we also  
167 regressed Eq. 1 focusing on a specific subsample (male vs. female, aged 18-44 vs. aged 45-64,  
168 and rural vs. urban). We tested the sensitivity of our results by replicating Eq. 1 but excluding  
169 from the sample individuals who potentially over- or under-reported consumption information  
170 (based on Black's adjustments). Finally, to better understand consumption pathways that transit  
171 from meat consumption to individual BMI, we executed another OLS model that regresses  
172 several food and beverage consumption items on meat consumption and covariates, as follows.

$$173 \quad F_i^t = \beta'_0 + \beta'_1 SES_i^j + \beta'_2 Meat_i + \beta'_3 SES_i^j * Meat_i + \beta'_4 X_i + \varepsilon'_i \quad (\text{Eq. 2})$$

174 In Eq. 2, the right side of the equation (independent variables) is fundamentally the same as Eq.  
175 1, but the dependent variable is now  $F_i^t$ , i.e., the consumption of an item  $t$  for an individual  $i$ ,

176 measured in days/month (initially estimated from a retrospective period of 12 months before  
177 the survey). We ran analyses for each food and beverage item available in INCA3 but here we  
178 report only those items whose consumption is inversely associated with meat consumption in  
179 at least one SES group (i.e., high-fat and high-sugar products, energy dense protein food such  
180 as dairy products and alternative sources of proteins). We made the decision to not report results  
181 on the consumption of other items (e.g., fish, carbohydrates, fruit and vegetables, or eggs)  
182 insofar as their association with the frequency of meat consumption was not significantly  
183 different across SES groups, and thus less interesting given the topic of the study.

184

**Table 1: Descriptive statistics across income groups**

	ALL ADULTS (aged 18-64)		LOW INCOME (<1750€ per month)		MIDDLE INCOME (1751- 3849€ per month)		HIGH INCOME (>3850€ per month)	
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
Body mass index (kg/m <sup>2</sup> )	25.69	0.19	26.01	0.42	26.06	0.28	24.91	0.32
Household monthly income (euros)	2633.38	65.88	1218.96	26.96	2486.94	19.77	4405.06	60.38
Meat consumptions (days/month)	20.05	0.36	18.53	0.73	21.23	0.55	20.49	0.59
Male (binary)	0.50		0.43		0.47		0.60	
Aged 18-44 (binary)	0.52		0.54		0.51		0.52	
Aged 45-64 (binary)	0.48		0.46		0.49		0.48	
Daily smoking (binary)	0.26		0.32		0.26		0.20	
Alcohol consumption index (0-to-90 score)	11.67	0.61	9.76	1.13	11.78	0.99	13.73	0.98
Medium level of physical activity (binary)	0.49		0.51		0.52		0.44	
High level of physical activity (binary)	0.15		0.13		0.15		0.16	
Medium level of sedentariness (binary)	0.41		0.41		0.43		0.39	
High level of sedentariness (binary)	0.47		0.50		0.42		0.50	
Lunch at home (binary)	0.54		0.60		0.55		0.45	
Number of adults per household	2.15	0.04	1.97	0.10	2.18	0.07	2.31	0.07
Number of children per household	0.76	0.05	0.58	0.09	0.75	0.09	0.96	0.08
Rural area (binary)	0.27		0.23		0.36		0.22	
Small city [2000-20000[ inhabt. (binary)	0.17		0.18		0.16		0.18	
Middle size city [20000- 100000[ inhabt. (binary)	0.12		0.14		0.10		0.10	
Large city >=100000 inhabt. (binary)	0.30		0.36		0.26		0.27	
Paris' urban area (binary)	0.14		0.09		0.11		0.22	
Black's underreporting (binary)	0.17		0.21		0.16		0.13	
Black's overreporting (binary)	0.02		0.03		0.02		0.02	
<i>OBSERVATIONS</i>	<i>n=1,283;</i> <i>N=26,355,031</i>		<i>n=449;</i> <i>N=9,300,724</i>		<i>n=421;</i> <i>N=8,893,940</i>		<i>n=413;</i> <i>N=8,160,367</i>	

186 Notes: Means and standard errors are weighted using the survey recommendations to guarantee the representativeness of the

187 sample. *N* refers to the population size and *n* refers to the sample size. Lactating and pregnant women were excluded as well

188 as children (<18 yo) and the elderly (>65 yo).

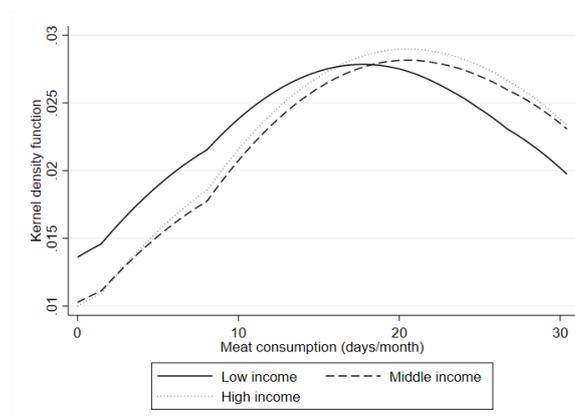
189 Source: INCA-3 (2014-2015).

190 **3. Results**

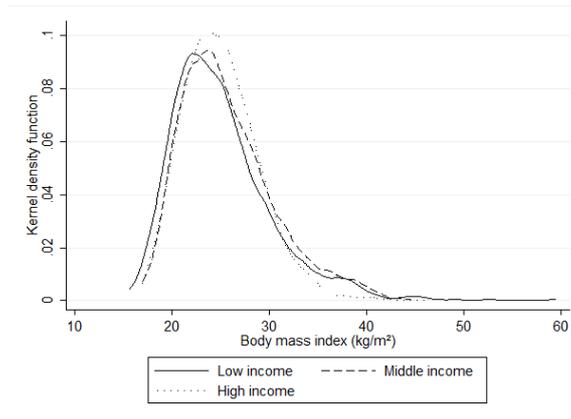
191 **3.1. BMI and raw associations with SES**

192 For each monthly household income group (low, middle, and high), Figure 1 displays the  
193 distributions of our main variables of interest, i.e., consumption of meat and adult BMI.  
194 Although the two variables are normally distributed, we detected income-based specificities. In  
195 terms of meat consumption, low-income households tended to report lower frequencies than  
196 middle- and high-income households, with a peak around 18 days/month for the former versus  
197 a peak around 21 days/month for the latter. The sample means reported in Table 1 are consistent  
198 with these values. In terms of BMI, Figure 1 suggests that, while underweight and normal-  
199 weight individuals are proportionally more represented among low-income households  
200 ( $BMI < 25 \text{kg/m}^2$ ), obese individuals are proportionally less represented among high-income  
201 households ( $BMI > 30 \text{kg/m}^2$ ). As suggested by the international literature, even if moderate  
202 excess weight seems to characterize richer individuals, the latter are also more frequently  
203 conscious than others about related comorbidities associated with extreme bodyweight, and  
204 thus are more likely to avoid extreme weight gain (16,17). Actually, average adult BMI is lower  
205 among high-income households than among poorer households (Table 1).

206 **Figure 1: Distribution of meat consumption and BMI across household income groups**



207



208

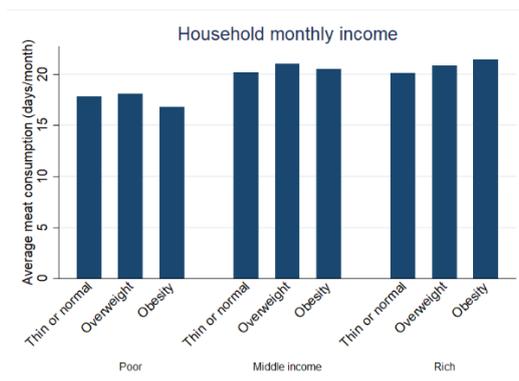
209 Notes: The Epanechnikov kernel density function was used. Lactating and pregnant women were excluded as well as children  
 210 (<18 yo) and the elderly (>65 yo).

211 Source: INCA-3 (2014-2015).

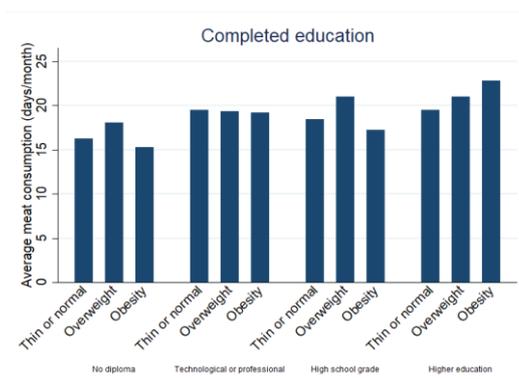
212 As expected, we found apparent raw associations between meat consumption, SES, and adult  
 213 BMI. As shown in Figure 2-a, middle and high income individuals consume meat  $2.3 \pm 0.75$   
 214 days/month more than low income households on average. Figure 2-a also shows that, while  
 215 obese individuals tended to report a lower monthly meat consumption than  
 216 underweight/normal-weight individuals) when the household income was low (1 day/month  
 217 less), the reverse was the case when the household income was high (the thinnest individuals  
 218 reported 2.4 days/month less in meat consumption compared to obese individuals). Likewise,  
 219 Figures 2-b and 2-c exhibit a positive association between adult BMI and meat consumption  
 220 among graded individuals and workers with a high occupation index, while negative or  
 221 nonlinear associations among individuals with lower levels of education and workers with a  
 222 low occupation index. In other words, one can assume that the “meat-BMI relationship” is  
 223 positive among upper social groups but negative among under-privileged social groups. The  
 224 following multivariate model aims to test the validity of this assumption, while controlling for  
 225 a large set of observed characteristics.

226 **Figure 2: Associations between meat consumption, SES and adult BMI**

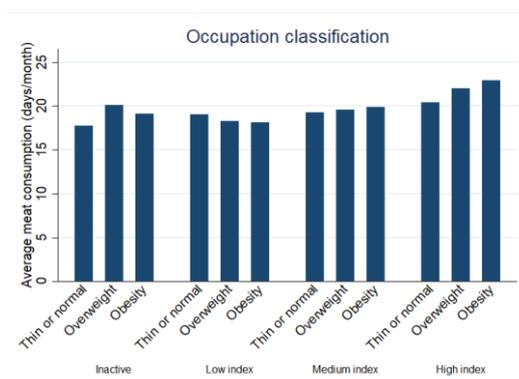
227



228



229



230 Notes: Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). The BMI-based  
 231 classification used is thin or normal (BMI<25kg/m<sup>2</sup>); overweight (25<=BMI<30kg/m<sup>2</sup>); obese (>=30kg/m<sup>2</sup>).

232 Source: INCA-3 (2014-2015).

### 233 3.2. Multivariate regressions

234 Table 2 shows OLS regressions based on Eq. 1 when household income groups are considered  
235 as an indicator of SES. Column 1 reports regressions for the whole adult sample (excluding  
236 pregnant and lactating women, children and the elderly) based on the classification of household  
237 income in three groups (i.e., low vs. medium vs. high). Then, to better explore the influence of  
238 poverty in the association between meat consumption and BMI (low vs. medium/high), we run  
239 an alternative model in Column 2 based on an income classification in two groups (low vs.  
240 medium/high). Finally, to investigate potential heterogeneity in the influence of poverty in the  
241 meat consumption-BMI relationship, Columns 3 and 4 report gender-specific regressions (male  
242 vs. female), Columns 5 and 6 report age-specific regressions (aged 18-44 vs. 45-64) and  
243 Columns 7 and 8 report living area-specific regressions (rural vs. urban).

244 Both models shown in Columns 1 and 2 fit relatively well. In Column 1 for instance, the  
245 explanatory variables capture 22% of individual variations in the BMI. Moreover, the fitted  
246 coefficient of control variables (below the dashed line) have the expected sign in accordance  
247 with the health economics literature on the determinants of BMI (e.g. Bonnefond and Clément,  
248 2014; Levasseur, 2015; Clément, 2017). While age, the sedentariness index, and family size are  
249 positively associated with BMI, the level of physical activity is inversely associated with BMI.

250 In Table 2, the fitted coefficients of interest ( $\beta_1$ ,  $\beta_2$  and  $\beta_3$ ) are reported above the dashed line.  
251 In Column 1 (based on the specification of household income in three groups),  $\beta_1$  in Column 1  
252 shows that among individuals who consume no meat, the BMI is significantly lower (3.1 kg/m<sup>2</sup>)  
253 among individuals belonging to the high-income group (>3 850 €/month) compared to that  
254 among individuals belonging to the low-income group (<1 750 €/month); no significant  
255 difference being observed between low and medium income groups. In addition, the interaction  
256 terms in Column 1 ( $\beta_3$ ) indicate that among high-income households, one extra day of meat

257 consumption is associated with a significantly higher individual BMI, 0.09 kg/m<sup>2</sup> on average,  
258 compared to low-income households.

259 In Column 2 (based on the specification of income in two groups),  $\beta_3$  consistently shows that  
260 among low-income households, one day less of meat consumption is associated with  
261 significantly higher individual BMI (0.07 kg/m<sup>2</sup>), compared to among richer individuals  
262 (combining medium and high incomes) for whom such a reduction is linked to a 0.04 kg/m<sup>2</sup>  
263 lower BMI ( $\beta_2$ ). Likewise, in alternative (unreported) estimates using ordinal values of  
264 household income as SES indicator (continuous income not being available in the INCA  
265 database), we find a positive and significant fitted coefficient for the interaction term  $\beta_3$   
266 (0.012±0.006), indicating that higher meat consumption among higher income groups tends to  
267 be associated with higher BMI.

268 When stratified according to gender, age group, and living area (Columns 3 to 8 in Table 2),  
269 the difference in the meat-BMI relationship between low and higher incomes (combining  
270 medium and high income) is particularly strong in male, younger (aged 18-44) and rural adults  
271 (living in villages with fewer than 2 000 inhabitants). These heterogeneous effects may be due  
272 to higher variations in meat consumption among men, young generations and rural inhabitants.

273

**Table 2: OLS regressions of adult BMI on income, meat consumption and covariates**

Dep. Var.= Body mass index (kg/m <sup>2</sup> )	WHOLE SAMPLE		MEN	WOMEN	AGED 18-44	AGED 45-64	RURAL AREAS	URBAN AREAS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Low income (binary)		2.104** (0.825)	2.495** (1.045)	1.290 (1.108)	2.635*** (0.959)	1.340 (1.079)	3.919*** (1.453)	1.260 (0.965)
Middle income (binary)	-1.188 (0.928)							
High income (binary)	-3.145*** (0.995)							
Meat consumption (days/month)	-0.032 (0.034)	0.044** (0.019)	0.054** (0.026)	0.031 (0.029)	0.088*** (0.033)	-0.010 (0.024)	0.072** (0.028)	0.023 (0.025)
LowInc.*MeatCons.		-0.074* (0.039)	-0.105** (0.050)	-0.040 (0.053)	-0.124*** (0.046)	-0.013 (0.052)	-0.157** (0.066)	-0.041 (0.044)
MiddleInc.*MeatCons.	0.057 (0.044)							
HighInc.*MeatCons.	0.089** (0.046)							
Male (binary)	0.526 (0.343)	0.407 (0.336)			0.050 (0.523)	0.991** (0.442)	0.667 (0.709)	0.265 (0.382)
Aged 45-64 (binary)	2.017*** (0.329)	1.996*** (0.339)	2.369*** (0.450)	1.425*** (0.519)			2.501*** (0.692)	1.905*** (0.381)
Daily smoking (binary)	-0.567 (0.377)	-0.485 (0.382)	-0.569 (0.480)	-0.476 (0.469)	-0.442 (0.531)	-0.589 (0.456)	-0.443 (0.654)	-0.478 (0.483)
Alcohol consumption index (0-to-90 score)	0.006 (0.011)	0.004 (0.011)	0.008 (0.012)	-0.038 (0.024)	0.029 (0.021)	-0.014 (0.013)	0.017 (0.024)	-0.001 (0.012)
Medium level of physical activity (binary)	-1.086*** (0.395)	-1.032** (0.398)	-0.243 (0.445)	-1.486*** (0.514)	-0.852 (0.521)	-1.912*** (0.501)	-0.545 (0.642)	-1.037** (0.453)
High level of physical activity (binary)	-2.009*** (0.450)	-1.939*** (0.449)	-0.992* (0.532)	-3.365*** (0.777)	-1.784*** (0.557)	-2.786*** (0.779)	-1.568 (1.042)	-1.835*** (0.494)
Medium level of sedentariness (binary)	0.289 (0.480)	0.223 (0.488)	-0.209 (0.596)	0.767 (0.646)	0.146 (0.629)	0.448 (0.665)	0.982 (0.642)	-0.216 (0.662)

High level of	1.100**	0.988**	0.690	1.436**	1.031*	0.983	0.949	0.867
sedentariness (binary)	(0.457)	(0.456)	(0.555)	(0.682)	(0.617)	(0.654)	(0.716)	(0.621)
Lunch at home	0.219	0.276	-0.750**	1.157**	-0.534	1.348***	0.613	0.160
(binary)	(0.310)	(0.313)	(0.351)	(0.471)	(0.420)	(0.381)	(0.539)	(0.393)
Number of adults per	0.809***	0.747***	0.326	0.828***	0.459	1.190***	0.872**	0.691**
household	(0.223)	(0.237)	(0.291)	(0.280)	(0.369)	(0.245)	(0.328)	(0.294)
Number of children	-0.000	-0.041	0.165	-0.425*	-0.041	-0.091	0.049	-0.068
per household	(0.182)	(0.175)	(0.185)	(0.218)	(0.221)	(0.201)	(0.249)	(0.218)
Season dummies	YES	YES	YES	YES	YES	YES	YES	YES
Urbanicity levels	YES	YES	YES	YES	YES	YES		YES
Region dummies	YES	YES	YES	YES	YES	YES	YES	YES
Black's misreporting	YES	YES	YES	YES	YES	YES	YES	YES
indexes								
Constant	24.067***	22.335***	22.063***	23.395***	23.359***	23.418***	19.631***	23.745***
	(1.295)	(1.255)	(1.723)	(2.290)	(2.518)	(1.408)	(2.116)	(1.577)
Observations	1,283	1,283	557	726	597	686	345	938
R-squared	0.222	0.211	0.226	0.279	0.171	0.281	0.247	0.220

275 Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample.

276 Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo).

277 Linearized standard errors are in parentheses. Levels of significance of fitted coefficients: \*\*\* p < 0.01, \*\* p < 0.05, \* p <

278 0.1.

279 Source: INCA-3 (2014-2015).

280 Figure 3-a plots the fitted marginal effects (at mean points) from the regression of Column 1  
281 (based on the whole sample). As shown in Fig. 3-a, the association between meat consumption  
282 and BMI tended to vary according to household income and was positive for the richest  
283 household ( $P < 0.05$ ), and tended to be inverse for the poorer ( $0.05 < P < 0.10$ ). This pattern is  
284 consistent with the findings shown in Columns 1 and 2 of Table 2. The fact that the middle  
285 income interaction is not significant in column 1 suggests that the high-income group dominates  
286 the interaction effect revealed in Column 2. As shown in Figures 3-b and 4-c, similar trends  
287 were observed when the level of completed education and the occupation classification were  
288 used as SES indicators, at least among male rural individuals (fitted coefficients are listed in  
289 Tables S1 and S2 in Supplementary Materials). However, only higher SES shows a (inverse)  
290 significant association between meat consumption and BMI, while in lower SES, BMI does not  
291 appear to be related to meat consumption when expressed as completed education or  
292 occupation. In alternative estimations, we replicated the same model as Eq. 1 but replaced the  
293 BMI dependent variable by a binary outcome indicator distinguishing overweight/obese status  
294 ( $>25 \text{ kg/m}^2$ ) from non-overweight status ( $<25 \text{ kg/m}^2$ ). Fitted marginal effects of these additional  
295 estimates are plotted in Figure 4. We found a positive and significant association between meat  
296 consumption and the probability of being classified as overweight in the richest, the most  
297 educated and the best positions in the international occupation classification, and that the  
298 associations tended ( $0.05 < P < 0.10$ ) to be inverted in the group with the lowest income (Figure  
299 4, Table S3). In addition, as a sensitivity check, we also replicated Eq. 1 by restricting the whole  
300 sample to likely normal respondents (based on Black's approach). Related fitted coefficients  
301 are plotted in Figure S.1 in Supplementary Materials. The results are similar and confirm the  
302 robustness of the main estimates. Finally, we tested subsample specific regressions of BMI on  
303 meat consumption and covariates for each group of SES (Table S.4 in Supplementary  
304 Materials). Results are consistent with our previous interacted models in terms of signs and  
305 magnitudes, although they are less significant. We find significant higher BMI for higher levels

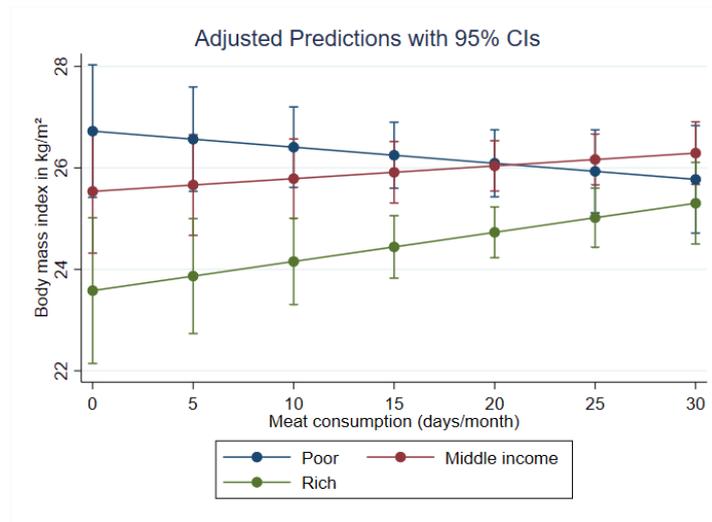
306 of meat consumption among the most privileged groups, while among lower SES groups, the  
307 association is not significantly different from 0. This secondary analysis suggests that the  
308 observed correlation between meat consumption and overweight is overall valid for individuals  
309 from privileged settings, but cannot be inferred in under-privileged populations.  
310

311

**Figure 3: Fitted BMI across socioeconomic groups**

312

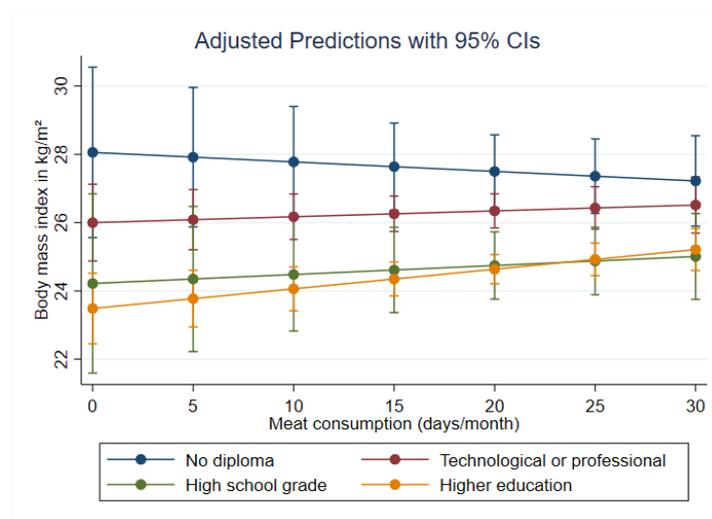
*a) Across household income*



313

314

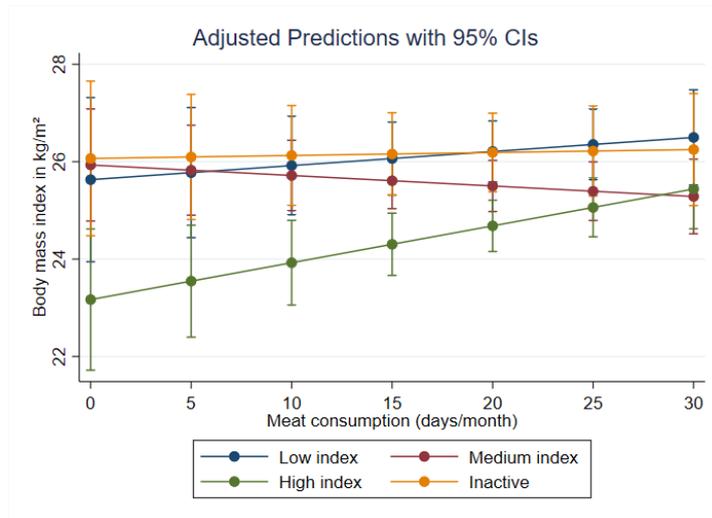
*b) Across education groups*



315

316

*c) Across occupation groups*



317

318 Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant

319 women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, lunch place, smoking,

320 alcohol consumption, physical activity, sedentariness, household size, number of children, season of survey, urbanicity, region, and Black's

321 index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level.

322

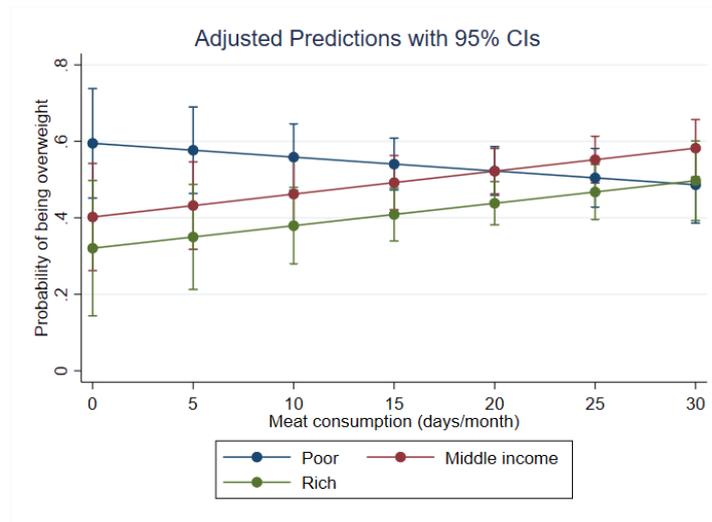
Source: INCA-3 (2014-2015).

323

**Figure 4: Fitted overweight risk (BMI $\geq$ 25kg/m<sup>2</sup>) across socioeconomic groups**

324

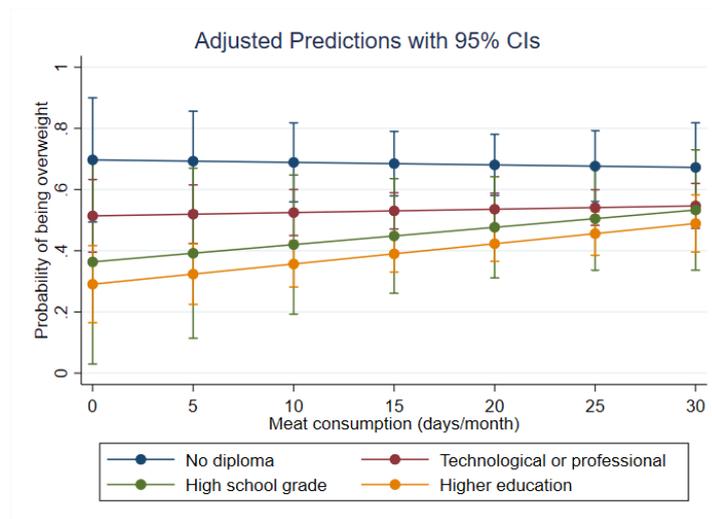
*a) Across household income*



325

326

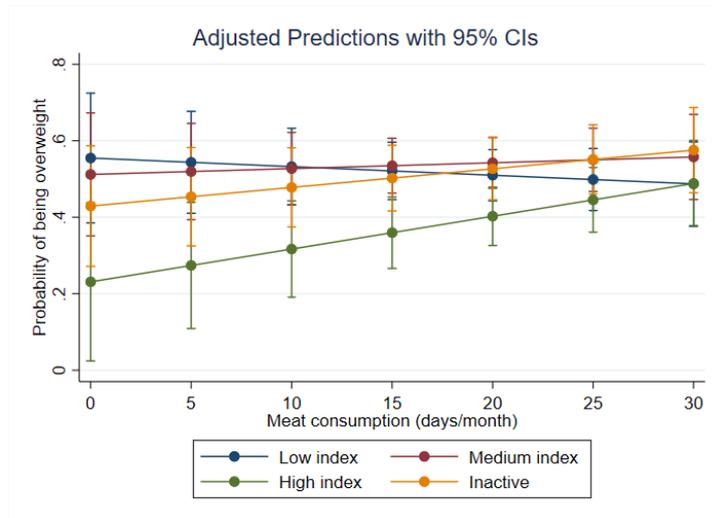
*b) Across education groups*



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*c) Across occupation groups*



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Notes: Estimates are weighted using the survey recommendations to insure the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, lunch place, smoking, alcohol consumption, physical activity, sedentariness, household size, number of children, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level.

Source: INCA-3 (2014-2015).

### 335 **3.3. Exploring consumption pathways**

336 Because meat is a marker of dietary patterns that may vary across social groups, our aim was  
337 to better understand the varying associations between meat consumption and BMI by further  
338 investigating the association between meat and foods/beverages that could be involved in  
339 weight control. Specifically, we focused on how meat consumption is correlated with high-fat  
340 and high-sugar products (ice cream and sorbet, cookies, salted snacks, chocolate, and soda),  
341 energy dense protein food such as dairy products (yogurt and cheese) and alternative sources  
342 of protein (soy-based products), for which we found income-based specific differences. In  
343 contrast, the consumption of other items (e.g., fish, carbohydrates, fruit and vegetables, or eggs)  
344 was positively associated with the frequency of meat consumption independently of the SES  
345 (i.e., the association was similar for both low income and higher income groups), and we  
346 therefore decided to not report on these items in this article.

347 As shown in Table 3, adults who do not consume any meat and have a low income (<1,750  
348 €/month) displayed higher ice cream and sorbet consumption (2 days/month higher) and lower  
349 consumption of alternative source of proteins such as soy-based food (1.2 days/month lower).  
350 Consistently, among low-income households, lower meat consumption was associated with  
351 higher consumption of ice cream and sorbet (+0.8 days/month when meat consumption  
352 decreases by 10 days/month). In contrast, among higher income groups (>1,751 €/month),  
353 lower meat consumption was associated with lower high-fat and high-sugar food and beverage  
354 items, as well as lower consumption of dairy products (cheese).

355

**Table 3: OLS regressions of diet items on income, meat consumption and covariates**

Dep. Var.= Body mass index (kg/m <sup>2</sup> )	High fat and sugar food & beverage					Dairy products		Alternative proteins
	Ice cream & sorbet	Cookies	Chocolate	Salted snacks	Soda	Yogurt	Cheese	Soy
Low income (binary)	1.991*** (0.693)	-0.621 (1.703)	-1.695 (1.656)	-0.350 (0.790)	0.701 (1.759)	-2.632 (2.081)	1.885 (1.895)	-1.223** (0.614)
Meat consumption (days/month)	0.061*** (0.016)	0.196*** (0.050)	0.180*** (0.058)	0.046** (0.019)	0.146** (0.067)	0.085 (0.066)	0.179*** (0.056)	0.006 (0.041)
LowInc. *MeatCons.	-0.075** (0.031)	0.027 (0.090)	-0.037 (0.086)	0.050 (0.051)	0.015 (0.089)	0.160* (0.096)	-0.054 (0.087)	0.014 (0.032)
Male (binary)	0.163 (0.225)	0.559 (0.863)	0.757 (0.939)	0.197 (0.381)	2.707*** (0.776)	-0.809 (0.939)	0.347 (0.822)	-0.586 (0.392)
Aged 45-64 (binary)	-0.810*** (0.249)	-2.857*** (0.755)	-1.154 (0.778)	-1.303*** (0.360)	-4.573*** (0.982)	0.714 (0.873)	2.953*** (0.853)	-0.090 (0.358)
Daily smoking (binary)	-0.463 (0.339)	-0.144 (0.875)	-1.963** (0.790)	0.033 (0.399)	3.384*** (0.995)	-1.352 (1.060)	-1.036 (0.901)	-0.322 (0.289)
Alcohol consumption index (0-to-90 score)	0.002 (0.013)	-0.064** (0.028)	0.020 (0.032)	0.086*** (0.015)	-0.017 (0.035)	-0.102*** (0.033)	0.119*** (0.028)	-0.016 (0.011)
Medium level of physical activity (binary)	0.503* (0.263)	2.003** (0.807)	1.030 (0.820)	0.714 (0.501)	-0.997 (0.855)	1.480 (0.914)	1.348 (0.900)	0.126 (0.308)

High level of physical activity (binary)	-0.171	0.514	0.955	0.241	-0.630	2.696**	1.194	1.502
	(0.291)	(1.216)	(1.290)	(0.508)	(1.250)	(1.200)	(1.350)	(1.045)
Medium level of sedentariness (binary)	0.697**	1.344	-1.637	1.242***	2.272***	-0.127	-2.068	-0.182
	(0.296)	(1.011)	(1.168)	(0.396)	(0.833)	(1.498)	(1.289)	(0.426)
High level of sedentariness (binary)	0.697**	0.382	-1.568	1.168***	3.886***	-1.069	-4.428***	-0.108
	(0.330)	(1.094)	(1.227)	(0.336)	(0.984)	(1.507)	(1.178)	(0.400)
Lunch at home (binary)	0.510**	-0.133	0.752	-0.114	2.311***	-1.884**	-1.054	0.311
	(0.240)	(0.737)	(0.851)	(0.451)	(0.797)	(0.832)	(0.910)	(0.505)
Number of adults per household	0.416	0.344	-0.599	0.143	1.447***	-0.347	0.019	-0.244**
	(0.271)	(0.534)	(0.460)	(0.226)	(0.488)	(0.696)	(0.693)	(0.123)
Number of children per household	0.099	0.304	-0.144	0.316	-0.946**	0.106	0.097	-0.393***
	(0.136)	(0.454)	(0.432)	(0.436)	(0.386)	(0.397)	(0.431)	(0.142)
Season dummies	YES	YES	YES	YES	YES	YES	YES	YES
Urbanicity levels	YES	YES	YES	YES	YES	YES	YES	YES
Region dummies	YES	YES	YES	YES	YES	YES	YES	YES
Black's misreporting indexes	YES	YES	YES	YES	YES	YES	YES	YES
Constant	-1.104	2.149	4.249*	-0.949	-3.019	18.109***	12.465***	0.757
	(1.240)	(2.117)	(2.413)	(1.145)	(3.324)	(3.918)	(3.204)	(1.325)
Observations	1,266	1,281	1,280	1,279	1,281	1,276	1,280	1,275
R-squared	0.101	0.150	0.108	0.219	0.219	0.085	0.138	0.105

Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Linearized standard errors are in parentheses. Level of significance of fitted coefficients: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1. Source: INCA-3 (2014-2015).

#### **4. Discussion**

The main result of this study shows that, while meat consumption is positively associated with BMI in upper SES classes, this relationship tends to be inversed in low SES classes. This difference is especially noticeable when based on household income. The BMI of the poorest who eat meat less often tended to be higher than the BMI of the poorest who eat meat more often, while BMI is lower among the richest individuals who eat meat less often than the BMI of the richest who eat meat more often. Another important finding of our study is that associations between meat consumption and unhealthy food consumptions (measured in frequency) differ depending on the SES status. For high income households, we consistently found that lower meat consumption was associated with lower consumption of unhealthy food items (lower consumption of high-fat and -sugar food and beverage), which may explain why lower meat consumption is negatively associated with BMI and risk of overweight in higher income groups. In contrast, the association between meat consumption and unhealthy food consumptions is much less consistent among lower income households.

To our knowledge, our study is the first to show that SES moderates the relationship between the level of meat consumption and BMI in a nationally representative sample. Although previous cross-sectional and longitudinal studies showed that a higher level of meat consumption was associated with a higher BMI (16,17,18,19), the influence of SES has rarely been investigated. Moreover, previous experimental studies were also limited because the experiments used the same diet for all participants, making it impossible to assess the impact of dietary socioeconomic context on health outcomes.

So far, our analysis does not elucidate why the association between BMI and frequency of meat consumption varies according to the SES, although we propose that this could be related to differences in the other components of the diet. Indeed, higher SES individuals are more successful at composing healthier diets than low SES individuals. Some studies showed the

importance to consider dietary quality to explain the effects of meat reduction on weight changes. For instance, cohort studies have reported that increased consumption of unhealthy plant-based foods was associated with greater weight gain (10), while another study of the same pooled cohorts found that weight gain associated with an increased meat consumption was lower in individuals who also reduced the glycemic load of their diets (23). However, we need to consider the parallels carefully because contrary to these studies reported intakes, our analysis was based on frequencies of consumption, not considering portion sizes. Furthermore, given the cross-sectional nature of our study, we cannot conclude that a reduction in the frequency of meat consumption precedes changes in diet according to SES, and analysis of longitudinal data would be needed in this regard.

In our analysis, we tested the interaction between SES and frequency of meat consumption using three SES markers: monthly income (low vs. medium vs. high, and low vs. medium/high), education level, and occupational status. Interestingly, monthly income was the most strongly associated with BMI levels in interaction with frequency of meat consumption. This is in line with what we know about the higher cost of a healthy diet (24,25), and suggests that the quality of the diet depends on the budget allocated to food. Unhealthy plant-based foods such as potatoes, candy or highly processed foods are generally cheaper than healthy plant-based foods such as fresh fruit, legumes, and vegetables, or protein sources such as fish and dairy products that can replace meat (26). In this regard, it is not surprising that individuals with a lower income, and therefore a lower food budget, are more likely to have low quality energy-dense diets when they consume less meat. On the other hand, higher meat intake has been also associated with higher diet cost in the general population. Therefore, studies of food purchase data are needed to clarify the relationship with the overall food budget, the proportion allocated to meat, and the overall quality of the diet.

The less robust findings for educational level and occupational status might be due to the fact that these markers are less directly representative of the individual SES – for instance, the “inactive” subpopulation includes both the unemployed, who tend to have lower than average SES, and the retired, who tend to have a higher than average SES. A multidimensional analysis of socio-economic attributes would allow a finer understanding of the link between SES, meat consumption and the BMI. This research strategy should be explored in further works.

Given the important, and growing, inequalities in our society, special attention needs to be paid to changes that could impact the health of all individuals. Dietary transition towards a more sustainable diet is one such change. While many studies have shown an association between reducing meat consumption and weight loss, our analysis nuances these results by showing that diets where meat is less frequently consumed are associated with a lower BMI only in individuals with a high or middle SES. To an even greater extent, the relationship tended to be inverted for low-income individuals. Based on our results, there is clearly a need to study the long-term health effects of dietary changes in populations with different SES in order to understand whether promoting a reduction in meat consumption could widen disparities in weight status, as well as in broader health outcomes.

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