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

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Abstract: There is a growing advocacy for reducing meat consumption in Western countries. However, healthier alternatives to meat may be more expensive, and populations with a low socioeconomic status (SES) may be more likely to replace meat by less healthy alternatives, which could reduce dietary quality and have negative effects on health outcomes such as weight gain. In the present study, we focused on the association between the body mass index (BMI), meat consumption and SES. We also studied the effect of interactions between meat consumption and SES on the consumption of food groups other than meat. We performed multivariate linear regressions based on a representative sample of the French adult population (n=1,300) collected in 2015. We found that among low-income households, one day less of meat consumption per month tended to be associated with a higher individual BMI (0.074 ± 0.039 kg/m²) in significant contrast with the inverse association found in richer households (combining medium- and high-income groups). This income-based difference in the meat-BMI relationship was particularly strong in male, younger (aged 18-44) and rural adults. This result is robust to alternative SES indicators: other income classifications, levels of completed education, and the occupation classification. Low-income and higher-income

households also had different eating habits associated with higher meat consumption: among low-income households, lower meat consumption was associated with higher consumption of ice cream and sorbet, while among higher income groups (>1 751 €/month), lower meat consumption was associated with lower consumption of high-fat and high-sugar food and beverage items, as well as cheese. 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. To understand whether promoting reduction in meat consumption could widen health inequalities, future works need to study the long-term effects of dietary changes on health as a function of SES.

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

Highlights:

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

1. Introduction

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

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

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

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

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

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

2. Methods

2.1. Data and sample

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

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

2.2. Model and variables

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

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

The dependent variable Y_i refers to the body mass indicator of an individual *i*, measured by the BMI. BMI is calculated by dividing the weight (in kg) by the square of height (in meters). In alternative estimations, we also use a binary dependent variable that takes the value 1 if an individual is classified as overweight or obese (i.e., a BMI higher than 25 kg/m²), 0 otherwise.

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

In order to explore the association between BMI and meat consumption according to SES, we also introduced an interaction term between the two factors of interest ($SES_i^j * Meat_i$). Thanks to this inclusion, β_1 estimates the association between SES and BMI, when meat consumption is equal to 0. In other words, this fitted parameter measures the extent to which SES influences BMI in individuals who consume no meat. β_2 estimates the association between meat consumption and BMI, when the SES indicator is equal to 0 (i.e., for the reference group *j=0*, which is low income, no educational qualification, or low occupation index). β_3 is the fitted trend of the association between meat consumption and each category *j* of SES (excluding the reference group). Then, β_0 is the constant (i.e., the BMI fitted value considering that all independent variables are equal to 0), ε_i is fitted residuals (i.e., unexplained variations in the BMI), and β_4 refers to the fitted parameters of the control variables X_i.

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

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

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

In Eq. 2, the right side of the equation (independent variables) is fundamentally the same as Eq. 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.

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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/m²)	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	
OBSERVATIONS	*n=1,283; N=26,355,031*		*n=449; N=9,300,724*		*n=421; N=8,893,940*		*n=413; N=8,160,367*	

Notes: Means and standard errors are weighted using the survey recommendations to guarantee the representativeness of the sample. *N* refers to the population size and *n* refers to the sample size. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo).

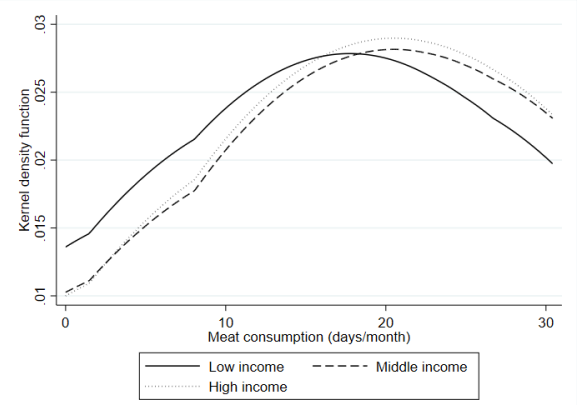
Source: INCA-3 (2014-2015).

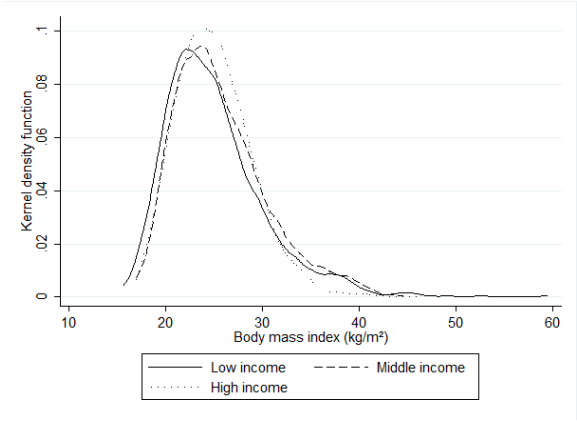
3. Results

3.1. BMI and raw associations with SES

For each monthly household income group (low, middle, and high), Figure 1 displays the distributions of our main variables of interest, i.e., consumption of meat and adult BMI. Although the two variables are normally distributed, we detected income-based specificities. In terms of meat consumption, low-income households tended to report lower frequencies than middle- and high-income households, with a peak around 18 days/month for the former versus a peak around 21 days/month for the latter. The sample means reported in Table 1 are consistent with these values. In terms of BMI, Figure 1 suggests that, while underweight and normal-weight individuals are proportionally more represented among low-income households (BMI<25kg/m²), obese individuals are proportionally less represented among high-income households (BMI>30kg/m²). As suggested by the international literature, even if moderate excess weight seems to characterize richer individuals, the latter are also more frequently conscious than others about related comorbidities associated with extreme bodyweight, and thus are more likely to avoid extreme weight gain (16,17). Actually, average adult BMI is lower among high-income households than among poorer households (Table 1).

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



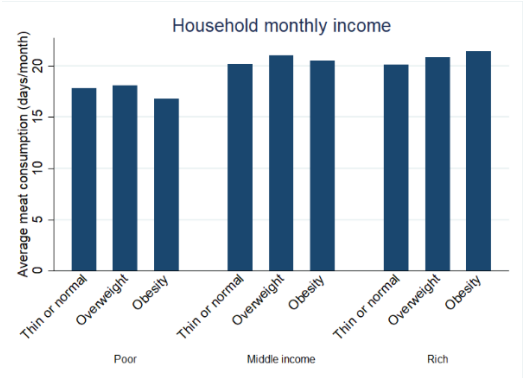


Notes: The Epanechnikov kernel density function was used. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo).

Source: INCA-3 (2014-2015).

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

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



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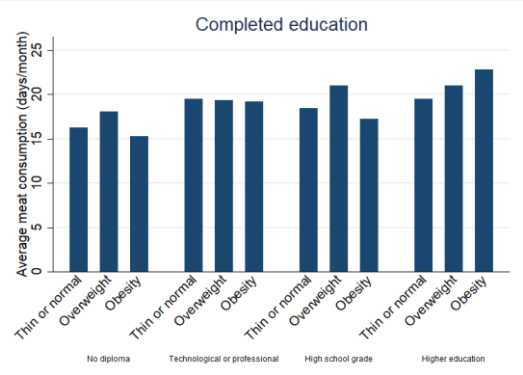

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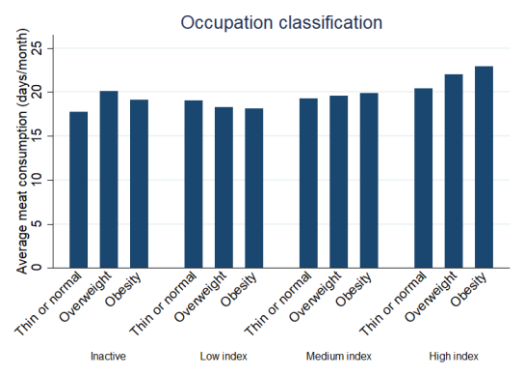

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230 Notes: Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). The BMI-based
231 classification used is thin or normal (BMI<25kg/m²); overweight (25<=BMI<30kg/m²); obese (>=30kg/m²).
232 Source: INCA-3 (2014-2015).

3.2. Multivariate regressions

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

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

In Table 2, the fitted coefficients of interest (β_1, β_2 and β_3) are reported above the dashed line. In Column 1 (based on the specification of household income in three groups), β_1 in Column 1 shows that among individuals who consume no meat, the BMI is significantly lower (3.1 kg/m²) among individuals belonging to the high-income group (>3 850 €/month) compared to that among individuals belonging to the low-income group (<1 750 €/month); no significant difference being observed between low and medium income groups. In addition, the interaction terms in Column 1 (β_3) indicate that among high-income households, one extra day of meat

consumption is associated with a significantly higher individual BMI, 0.09 kg/m² on average, compared to low-income households.

In Column 2 (based on the specification of income in two groups), β_3 consistently shows that among low-income households, one day less of meat consumption is associated with significantly higher individual BMI (0.07 kg/m²), compared to among richer individuals (combining medium and high incomes) for whom such a reduction is linked to a 0.04 kg/m² lower BMI (β_2). Likewise, in alternative (unreported) estimates using ordinal values of household income as SES indicator (continuous income not being available in the INCA database), we find a positive and significant fitted coefficient for the interaction term β_3 (0.012±0.006), indicating that higher meat consumption among higher income groups tends to be associated with higher BMI.

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

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

Dep. Var.= Body mass index (kg/m²)	**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**	2.495**	1.290	2.635***	1.340	3.919***	1.260
		(0.825)	(1.045)	(1.108)	(0.959)	(1.079)	(1.453)	(0.965)
Middle income	-1.188							
(binary)	(0.928)							
High income (binary)	-3.145***							
	(0.995)							
Meat consumption	-0.032	0.044**	0.054**	0.031	0.088***	-0.010	0.072**	0.023
(days/month)	(0.034)	(0.019)	(0.026)	(0.029)	(0.033)	(0.024)	(0.028)	(0.025)
LowInc.*MeatCons.		-0.074*	-0.105**	-0.040	-0.124***	-0.013	-0.157**	-0.041
		(0.039)	(0.050)	(0.053)	(0.046)	(0.052)	(0.066)	(0.044)
MiddleInc.*MeatCons.	0.057							
	(0.044)							
HighInc.*MeatCons.	0.089**							
	(0.046)							
Male (binary)	0.526	0.407			0.050	0.991**	0.667	0.265
	(0.343)	(0.336)			(0.523)	(0.442)	(0.709)	(0.382)
Aged 45-64 (binary)	2.017***	1.996***	2.369***	1.425***			2.501***	1.905***
	(0.329)	(0.339)	(0.450)	(0.519)			(0.692)	(0.381)
Daily smoking	-0.567	-0.485	-0.569	-0.476	-0.442	-0.589	-0.443	-0.478
(binary)	(0.377)	(0.382)	(0.480)	(0.469)	(0.531)	(0.456)	(0.654)	(0.483)
Alcohol consumption	0.006	0.004	0.008	-0.038	0.029	-0.014	0.017	-0.001
index (0-to-90 score)	(0.011)	(0.011)	(0.012)	(0.024)	(0.021)	(0.013)	(0.024)	(0.012)
Medium level of	-1.086***	-1.032**	-0.243	-1.486***	-0.852	-1.912***	-0.545	-1.037**
physical activity	(0.395)	(0.398)	(0.445)	(0.514)	(0.521)	(0.501)	(0.642)	(0.453)
(binary)								
High level of physical	-2.009***	-1.939***	-0.992*	-3.365***	-1.784***	-2.786***	-1.568	-1.835***
activity (binary)	(0.450)	(0.449)	(0.532)	(0.777)	(0.557)	(0.779)	(1.042)	(0.494)
Medium level of	0.289	0.223	-0.209	0.767	0.146	0.448	0.982	-0.216
sedentariness (binary)	(0.480)	(0.488)	(0.596)	(0.646)	(0.629)	(0.665)	(0.642)	(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

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. Levels of significance of fitted coefficients: *** p < 0.01, ** p < 0.05, * p < 0.1.

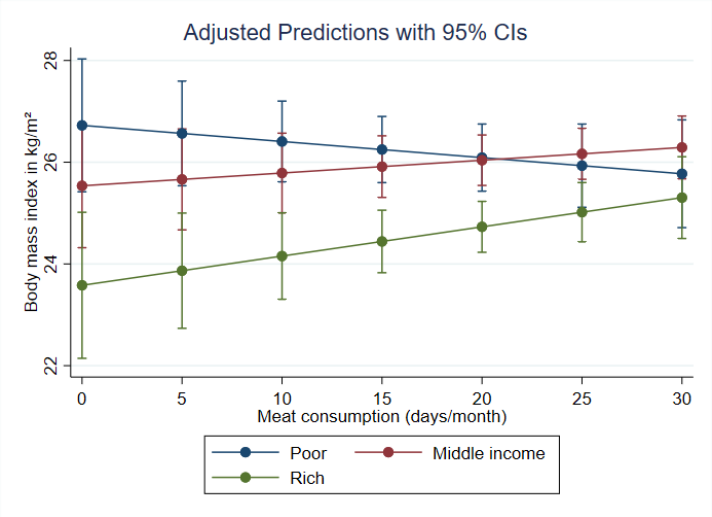
Source: INCA-3 (2014-2015).

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

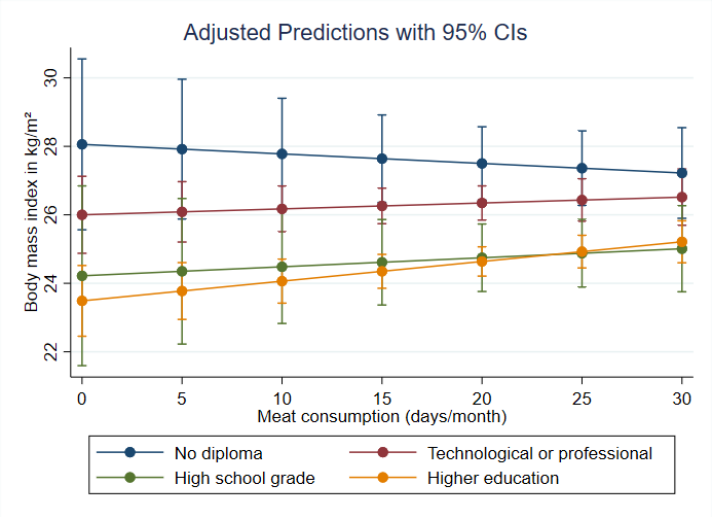
306 of meat consumption among the most privileged groups, while among lower SES groups, the
307 association is not significantly different from 0. This secondary analysis suggests that the
308 observed correlation between meat consumption and overweight is overall valid for individuals
309 from privileged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

Figure 3: Fitted BMI across socioeconomic groups

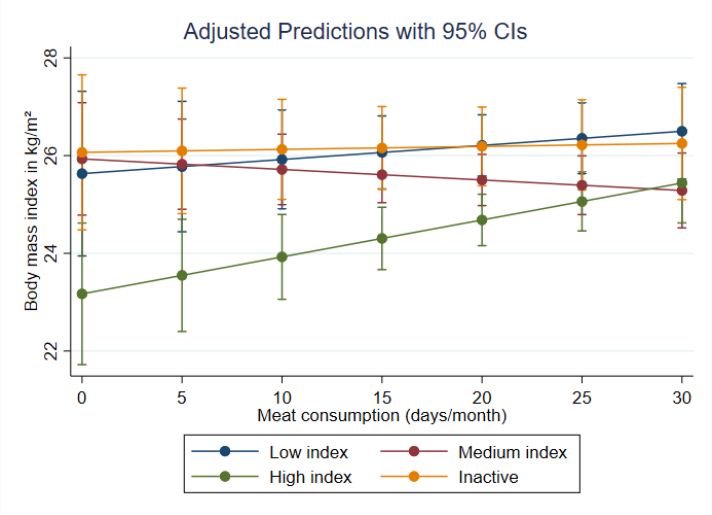
a) Across household income



b) Across education groups



c) Across occupation groups

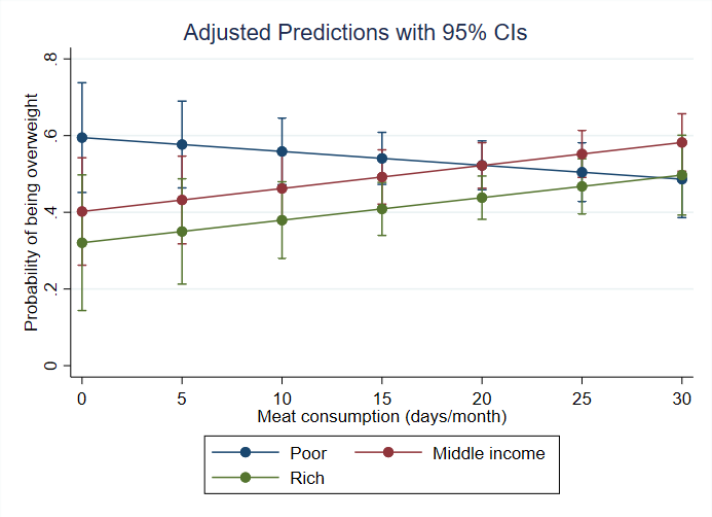


Notes: Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (<18 yo) and the elderly (>65 yo). Estimates are adjusted by age, gender, lunch place, smoking, alcohol consumption, physical 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.

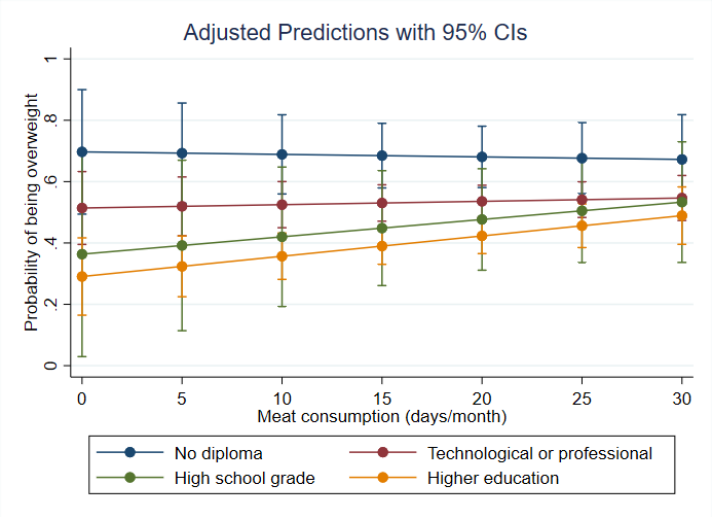
Source: INCA-3 (2014-2015).

Figure 4: Fitted overweight risk (BMI>=25kg/m²) across socioeconomic groups

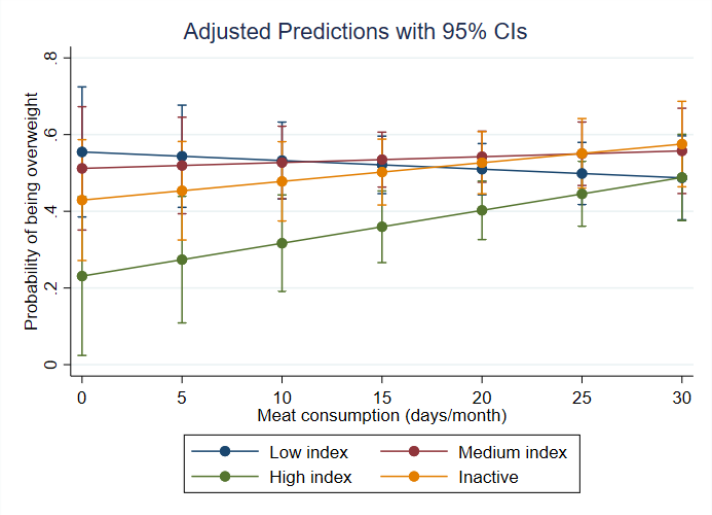
a) Across household income



b) Across education groups



c) Across occupation groups



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).

3.3. Exploring consumption pathways

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

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

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

Dep. Var.= Body mass index (kg/m²)	**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***	-0.621	-1.695	-0.350	0.701	-2.632	1.885	-1.223**
	(0.693)	(1.703)	(1.656)	(0.790)	(1.759)	(2.081)	(1.895)	(0.614)
Meat consumption (days/month)	0.061***	0.196***	0.180***	0.046**	0.146**	0.085	0.179***	0.006
	(0.016)	(0.050)	(0.058)	(0.019)	(0.067)	(0.066)	(0.056)	(0.041)
LowInc.*MeatCons.	-0.075**	0.027	-0.037	0.050	0.015	0.160*	-0.054	0.014
	(0.031)	(0.090)	(0.086)	(0.051)	(0.089)	(0.096)	(0.087)	(0.032)
Male (binary)	0.163	0.559	0.757	0.197	2.707***	-0.809	0.347	-0.586
	(0.225)	(0.863)	(0.939)	(0.381)	(0.776)	(0.939)	(0.822)	(0.392)
Aged 45-64 (binary)	-0.810***	-2.857***	-1.154	-1.303***	-4.573***	0.714	2.953***	-0.090
	(0.249)	(0.755)	(0.778)	(0.360)	(0.982)	(0.873)	(0.853)	(0.358)
Daily smoking (binary)	-0.463	-0.144	-1.963**	0.033	3.384***	-1.352	-1.036	-0.322
	(0.339)	(0.875)	(0.790)	(0.399)	(0.995)	(1.060)	(0.901)	(0.289)
Alcohol consumption index (0-to-90 score)	0.002	-0.064**	0.020	0.086***	-0.017	-0.102***	0.119***	-0.016
	(0.013)	(0.028)	(0.032)	(0.015)	(0.035)	(0.033)	(0.028)	(0.011)
Medium level of physical activity (binary)	0.503*	2.003**	1.030	0.714	-0.997	1.480	1.348	0.126
	(0.263)	(0.807)	(0.820)	(0.501)	(0.855)	(0.914)	(0.900)	(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 inversed 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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