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Diet and Dementia Worldwide: The Role of Meat Fat, Meat Protein, and Development Indicators

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Abstract

Background: Dementia incidence is rising globally, yet its determinants remain debated. While diet has been linked to cognitive health, distinguishing dietary effects from socioeconomic and demographic transitions is challenging. This study examined associations between meat protein and fat supply and dementia incidence worldwide, accounting for life expectancy, GDP per capita, urbanization, and genetic predisposition (I_{bs}). **Methods:** Ecological data from 204 "countries" were analyzed. Pearson and Spearman correlations assessed bivariate relationships. Stepwise regression identified independent predictors of dementia incidence (ln-transformed). Partial correlations tested unique effects of protein and fat after adjustment for confounders. Principal component analysis (PCA) explored latent structures. **Results:** Meat protein and fat supply correlated moderately with dementia incidence ($r \approx 0.65$, $p < 0.001$), but life expectancy showed the strongest association ($r = 0.82$, $p < 0.001$). Regression confirmed life expectancy as the dominant correlate ($\beta \approx 0.56$–0.82, $p < 0.001$). Meat fat supply remained an independent positive association ($\beta = 0.17$–0.23, $p \leq 0.01$; partial $r = 0.22$, $p = 0.004$), whereas protein effects were weaker and inconsistent, sometimes reversing to a negative association (partial $r = -0.15$, $p = 0.043$). PCA showed all variables loaded on a single "development–nutrition transition" factor explaining ~74% of variance. **Conclusions:** Dementia incidence is largely shaped by demographic aging, but dietary fat from meat shows a modest, independent association, whereas protein does not consistently relate to risk. Rising fat consumption linked to nutrition transitions may represent a modifiable global correlate of dementia.

Keywords: dementia incidence; dietary fat; meat protein; life expectancy; global analysis; nutrition transition

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1. Introduction

Dementia is a major global health concern, currently affecting over 55 million people with nearly 10 million new cases annually [1]. Its prevalence is projected to rise sharply, particularly in low- and middle-income countries undergoing rapid demographic transitions [2]. Despite extensive research, dementia's etiology remains multifactorial, influenced by genetic, biological, lifestyle, and socioeconomic factors [3,4]. Identifying population-level determinants is therefore essential for prevention and policy development.

Neuropathologically, dementia is characterized by progressive damage to the hippocampus, frontal cortex, amygdala, and white matter tracts, resulting in memory loss, impaired executive function, emotional dysregulation, and disrupted neural connectivity [5,6]. Key processes include oxidative stress, neuroinflammation, and protein aggregation, most notably the formation of β-amyloid plaques and hyperphosphorylated tau tangles, which disrupt neuronal communication and drive neurodegeneration [7–9].

Dietary factors may exacerbate these mechanisms. High intake of saturated fats contributes to oxidative stress, vascular dysfunction, and β-amyloid deposition, while meat-derived compounds add further risk [10,11]. Nutritional management and education interventions, particularly those improving dietary quality in aged care settings, have shown potential in mitigating diet-related cognitive decline [12,13]. Trimethylamine-N-oxide (TMAO), produced via gut microbial metabolism of red meat, has been associated with vascular dysfunction, systemic inflammation, and blood–brain barrier disruption [14–16]. Haem iron promotes oxidative stress, and advanced glycation end products (AGEs), formed during meat processing and cooking, trigger inflammation and enhance β-amyloid aggregation [17,18]. Collectively, these mechanisms provide biological plausibility for the relationship between meat consumption and dementia.

Clarifying the distinct roles of meat fat and protein is therefore critical. In this study, dementia was defined according to the Institute for Health Metrics and Evaluation (IHME) as "Alzheimer's disease and other dementias," encompassing Alzheimer's disease, vascular dementia, Lewy body dementia, frontotemporal dementia, and other subtypes, thus reflecting the total dementia burden.

Given these mechanisms, it is important to determine whether meat protein and fat contribute differently to dementia risk. While previous studies have primarily examined total meat intake [19], this ecological analysis distinguishes between meat fat and protein to clarify their independent associations with dementia incidence. By leveraging cross-national data and adjusting for socioeconomic and demographic factors, the study aims to provide novel insights into the dietary components most relevant to dementia prevention at the population level.

Diet has long been implicated in cognitive health [20]. Observational and experimental studies suggest that diets high in saturated fats and animal products increase dementia risk, whereas diets emphasizing plant-based foods, fish, and unsaturated fats appear protective [20–22]. However, most evidence comes from individual-level studies in high-income countries, which limits generalizability [23]. At the ecological level, diet–dementia associations are further complicated by broader structural factors such as economic development, life expectancy, and urbanization, all of which influence both food supply and dementia reporting [3,4].

Economic affluence and life expectancy are especially influential. As nations undergo nutrition and health transitions, populations live longer and consume more animal-sourced foods and processed fats [24,25]. These shifts parallel increasing burdens of non-communicable diseases, including dementia [26]. Higher GDP per capita often enhances diagnostic capacity, potentially inflating reported incidence. Life expectancy, meanwhile, strongly predicts dementia risk, given its exponential increase with age [27]. This collinearity complicates efforts to determine whether dietary supply independently contributes to dementia or simply reflects broader socioeconomic advancement.

Another relevant factor is the Index of Biological State (I_{bs}), which captures reduced natural selection in populations with lower mortality and fertility [28]. Populations with higher I_{bs} are thought to accumulate deleterious genetic variants that predispose to late-onset conditions such as dementia [3]. I_{bs}, alongside GDP and life expectancy, may therefore

confound observed associations between diet and dementia, highlighting the need for careful multivariable analyses.

Previous ecological studies investigating diet and dementia have yielded mixed findings [29]. Some report positive correlations between meat consumption and dementia prevalence [30], while others highlight dietary fat, particularly saturated fat [31,32], as a critical driver of cognitive decline. However, meat protein and fat supply are highly intercorrelated, rising together with economic growth and urbanization [24,33]. This overlap makes it difficult to identify which dietary component is the more relevant predictor of dementia [34,35]. Importantly, to date, no global study has systematically compared the relative roles of meat protein versus fat in predicting dementia incidence. This gap limits understanding of whether protein contributes independently to dementia risk, or whether dietary fat is the true dietary determinant embedded within broader nutrition transitions.

This study addresses these uncertainties by conducting a comprehensive ecological analysis across 204 countries and territories. We examine the associations of meat protein and fat supply with dementia incidence, while accounting for economic affluence, aging, urban living, and dementia genetic back accumulation. Using correlation analyses, regression models, partial correlations, and principal component analysis, we test whether meat protein and fat represent independent predictors of dementia, or whether their associations are better explained by socioeconomic and demographic transitions.

By explicitly comparing the predictive roles of protein and fat, this study offers a novel contribution to the dementia literature. Clarifying whether fat or protein is the stronger dietary component linked to dementia risk is critical, as the two often rise in tandem but may have very different biological implications [22]. Beyond diet, our findings also provide broader insights into how demographic aging, affluence, and nutrition transitions shape dementia burden worldwide, informing both prevention strategies and public health planning.

2. Materials and Methods

2.1. Data Collection and Selection

This population-level analysis used data from recognized international sources, including United Nations agencies and the Institute for Health Metrics and Evaluation (IHME). Dementia incidence rates (new cases per 100,000 individuals) were obtained from IHME's 2021 dataset [36]. A comprehensive list of 204 regions, consistent across variables, was sourced from the IHME. In this study, the term "country" refers to a geographic unit reporting separate health, demographic, and economic data, as defined by international agencies. The terms "country" and "population" are used interchangeably and do not necessarily denote political sovereignty [37].

The primary independent variables were meat protein supply and meat fat supply, measured in grams per capita per day (g/day/capita) for 2019–2021. Data were sourced from the FAOSTAT Food Balance Sheets [38], which reflect the average daily quantity of animal-based foods available for consumption. Included meats were beef, veal, buffalo, pork, mutton, lamb, goat, horse, poultry (chicken, goose, duck, turkey), rabbit, game, and offal [38].

The dependent variable, dementia incidence, was obtained from the Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease database [36]. IHME defines dementia as "Alzheimer's disease and other dementias", meaning the outcome represents all-cause dementia incidence, encompassing Alzheimer's disease, vascular dementia, Lewy body dementia, frontotemporal dementia, and other subtypes rather than being restricted to Alzheimer's disease alone.

Given dementia's multifactorial etiology, potential confounding variables were included:

- Economic status was measured by per capita GDP (PPP-adjusted, 2018), sourced from the World Bank. Higher GDP is associated with increased life expectancy, education, lifestyle-related risk factors (e.g., obesity, diabetes), and greater diagnostic capacity [39,40].
- Biological State Index (I_{bs}): a measure of genetic predisposition, ranging from 0 to 1, indicating the degree of accumulated deleterious variants due to relaxed natural selection. Higher I_{bs} values are linked to greater risk of late-onset disorders, including dementia [41].
- Life expectancy at birth (2018): used as a proxy for population aging, obtained from the World Bank [42]. As dementia risk rises steeply with age, life expectancy is a strong contextual factor.
- Urbanization (2018): defined as the percentage of the population living in urban areas, also from the World Bank [39]. Urbanization shapes lifestyle behaviors, including greater meat consumption [34,43], increased availability of processed foods [44], and reduced physical activity [45], and it may also facilitate earlier detection and reporting of dementia.

All variables were compiled in Microsoft Excel® 2016 and prepared for statistical analysis. Each country was treated as a unique data point. The number of countries included varied across analyses, depending on data availability from international sources.

2.2. Statistical Analyses

The analysis of the relationship between meat protein and meat fat supply and dementia incidence followed a structured, multi-step approach, guided by prior research [3,41,46–49]:

1. Initial Data Exploration: Scatterplots were generated using Microsoft Excel® 2016 to visually assess associations between meat protein and fat supply and dementia incidence. This step also identified potential outliers and ensured dataset integrity. Due to non-normal distributions, logarithmic transformation was applied to the six relevant variables for improving their homogeneity for the following bivariate and multiple variate analyses.
2. Bivariate Correlation Analysis: Pearson's and nonparametric (Spearman's rho) correlations were conducted to examine associations among six variables: meat protein supply, meat fat supply, dementia incidence, GDP per capita, I_{bs}, life expectancy, and urbanization.
3. Regional Correlation Analysis: Bivariate correlations were extended to subgroup analyses to capture variations across country classifications. Stratifications included:
    - World Bank income groups (low, lower-middle, upper-middle, high income), with Fisher's r-to-z transformation comparing high-income with low- and middle-income countries, reflecting WHO's emphasis on dementia burden in LMICs [1].
    - United Nations classification (developed vs. developing countries), also compared using Fisher's r-to-z [50].
    - WHO regions (Africa, Americas, Eastern Mediterranean, Europe, South-East Asia, Western Pacific) [51].
    - Cultural and economic groupings such as the Asia Cooperation Dialogue (ACD) [52], Asia-Pacific Economic Cooperation (APEC) [53], the Arab World [54], English-speaking countries (based on government data), Latin America [55], Latin America and the Caribbean (LAC) [55], Organisation for Eco-

nomic Co-operation and Development (OECD) [56], and Southern African Development Community (SADC) [57].

4. Principal Component Analysis (PCA): PCA was conducted separately for models including meat protein supply or meat fat supply, together with GDP, I_{bs}, life expectancy, and urbanization, to identify latent factor structures.
5. Partial Correlation Analysis: Pearson's partial correlations assessed the independent relationships of meat protein and dementia incidence after sequentially controlling for GDP, I_{bs}, life expectancy, and urbanization. Analyses were repeated for meat fat supply.
6. Multiple Linear Regression: Standard (enter) multiple regression was used to evaluate the predictive relationships between dementia incidence (dependent variable) and dietary plus confounding variables. This approach quantified the independent contributions of meat protein and meat fat after accounting for socioeconomic and demographic covariates. Stepwise regression was additionally applied to identify the most significant predictors, with models alternately including or excluding meat protein and fat.

Before multivariate analyses (partial correlations, PCA, regression), collinearity diagnostics confirmed acceptable thresholds (tolerance ≥ 0.10; VIF ≤ 10) [58]. For the protein model, tolerance ranged from 0.150 to 0.552 (VIF = 1.811–6.674), and for the fat model, 0.152–0.554 (VIF = 1.805–6.561), indicating no problematic multicollinearity.

All analyses were performed using SPSS version 31 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel® 2016. A significance level of 0.05 was applied, with additional reporting at 0.01 and 0.001 levels. Criteria for stepwise regression included probability of F to enter $\leq$0.05 and to remove $\geq$0.10.

3. Results

3.1. Descriptive Patterns and Scatterplots

Quadratic regression analyses revealed nonlinear associations between dementia incidence and both meat protein and fat supply (Figure 1). For protein, dementia incidence followed an inverted U-shaped curve ($y = -0.137\ x^2 + 10.662\ x - 28.331$), explaining 36% of the variance ($R^2 = 0.3595$), with peak incidence at ~38.9 g/capita/day (≈179 cases per 100,000). Meat fat showed a similar pattern ($y = -0.242\ x^2 + 11.142\ x - 10.685$), explaining 36.5% of variance ($R^2 = 0.3649$), with peak incidence at ~23.0 g/capita/day (≈118 cases per 100,000). Beyond these thresholds, higher supply was associated with declining dementia incidence.

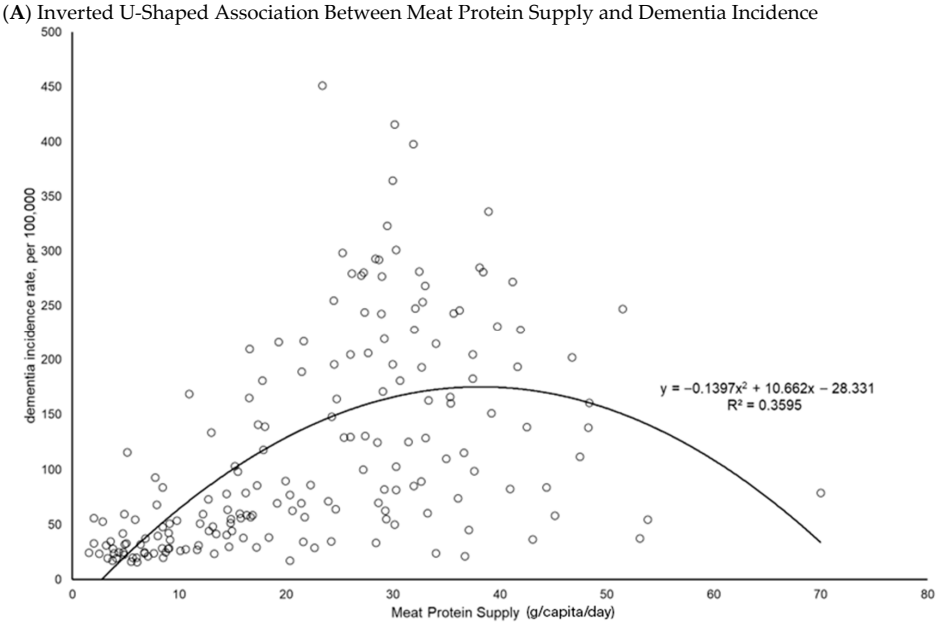
Data sources and variable definitions: Meat fat and meat protein supply, defined as the average g/capita/day over the period 2019–2021, was obtained from the Food and Agriculture Organization. The dementia incidence rate, representing new cases per 100,000 individuals in 2021, was sourced from the Institute for Health Metrics and Evaluation.

3.2. Correlations and Regression Results

3.2.1. Bivariate Correlations

Pearson's correlations demonstrated that both meat protein ($r = 0.648$, $p < 0.001$) and meat fat ($r = 0.645$, $p < 0.001$) were significantly correlated with dementia incidence (Table 1). However, dementia incidence correlated more strongly with development indicators: GDP PPP ($r = 0.775$, $p < 0.001$), I_{bs} ($r = 0.749$, $p < 0.001$), and especially life expectancy ($r = 0.823$, $p < 0.001$). Urbanization showed a weaker but significant relationship ($r = 0.512$, $p < 0.001$). Intercorrelations among predictors were high, with protein and fat almost perfectly correlated ($r = 0.974$, $p < 0.001$).

(**A**) Inverted U-Shaped Association Between Meat Protein Supply and Dementia Incidence



(**B**) Inverted U-Shaped Association Between Meat Fat Supply and Dementia Incidence

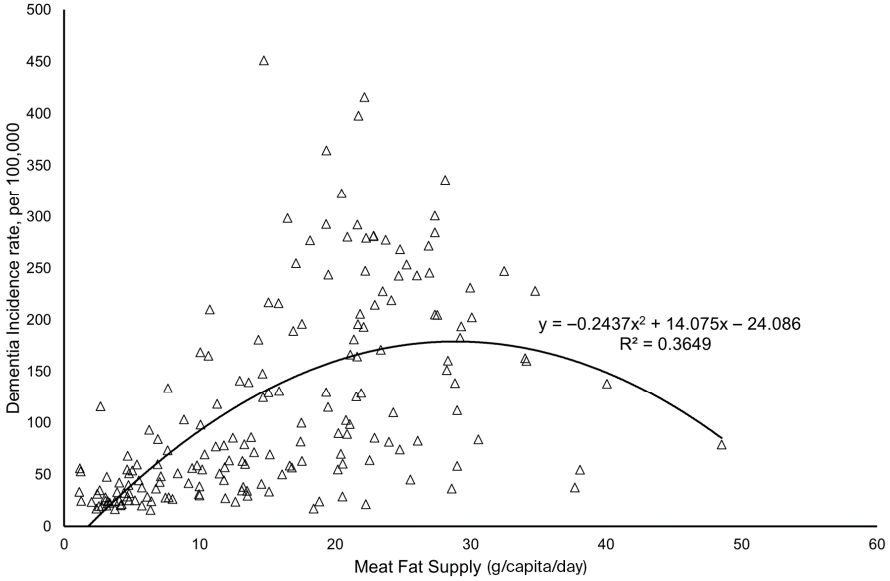


Figure 1. Inverted U-Shaped Associations Between Meat Protein and Fat Supply and Dementia Incidence.

Table 1. Pearson's r and Spearman's rho correlation matrix between all variables.

	Meat Protein	**Meat Fat**	**Dement Incidence**	**GDP PPP**	**I_{bs}**	**Life e(0)**	**Urbanization**
Meat Protein	1	0.648 ***	0.737 ***	0.673 ***	0.642 ***	0.515 ***	0.648 ***
Meat Fat	0.962 ***	1	0.645 ***	0.697 ***	0.625 ***	0.611 ***	0.502 ***
Dement Incidence	0.641 ***	0.666 ***	1	0.775 ***	0.749 ***	0.823 ***	0.512 ***
GDP PPP	0.732 ***	0.703 ***	0.777 ***	1	0.783 ***	0.854 ***	0.680 ***
I_{bs}	0.715 ***	0.708 ***	0.848 ***	0.895 ***	1	0.876 ***	0.494 ***
Life e(0)	0.648 ***	0.636 ***	0.829 ***	0.880 ***	0.930 ***	1	0.552 ***
Urbanization	0.549 ***	0.513 ***	0.525 ***	0.720 ***	0.630 ***	0.640 ***	1

Correlations were evaluated using Pearson's r (above the diagonal) and nonparametric methods (below the diagonal). *** $p < 0.001$ (2-tailed), with the number of countries ranging between 178 and 204. Data sources and variable definitions: Meat fat and protein supply (g/capita/day, 2019–2021) were obtained from the FAO. Dementia incidence (cases per 100,000, 2021) came from IHME. The Biological State Index [3] represented genetic predisposition, while GDP (PPP-adjusted), life expectancy, and urbanization (2018) were sourced from the World Bank.

Spearman's analyses yielded nearly identical results, confirming robustness (Table 1). The strongest associations with dementia were observed for life expectancy (ρ = 0.829), I_{bs} (ρ = 0.848), and GDP PPP (ρ = 0.777).

3.2.2. Regional and Subgroup Analyses

Associations varied markedly by development status. In developing and LMIC countries, meat supply and dementia incidence showed strong positive correlations (protein r ≈ 0.58–0.61; fat r ≈ 0.55–0.64; all $p < 0.001$, Table 2). In contrast, correlations were weak or absent in high-income and developed countries. Fisher's r-to-z confirmed stronger correlations in LMICs (z = 3.31–6.39, all $p < 0.001$).

Table 2. Bivariate Associations Between Meat Supply (Protein and Fat) and Dementia Incidence Across Global Country Groupings.

Country Groupings	Meat Protein → Dementia		Meat Fat → Dementia		
	Pearson's r	**Spearman's rho**	**Pearson's r**	**Spearman's rho**	**N**
Worldwide	0.648 ***	0.641 ***	0.645 ***	0.666 ***	184
United Nations common practice					
Developed countries	0.072	−0.043	−0.115	−0.156	45
Developing countries	0.576 ***	0.593 ***	0.552 ***	0.581 ***	139
Fisher r-to-z transformation: Developing vs. Developed	z = 3.31 ***	z = 4.11 ***	z = 4.17 ***	z = 4.65 ***	
World Bank income classifications					
Low Income (LI)	0.234	0.233	0.175	0.221	28
Lower Middle Income (LMI)	0.413 **	0.464 ***	0.375 **	0.467 ***	49
Upper Middle Income (UMI)	0.265 *	0.208	0.385 **	0.312 *	52
High Income (HI)	−0.139	−0.257 *	0.120	−0.016	55
Low- and middle-income (LMIC)	0.614 ***	0.659 ***	0.593 ***	0.635 ***	129
Fisher r-to-z transformation: LMIC vs. High income	z = 5.19 ***	z = 6.39 ***	z = 3.41 ***	z = 4.45 ***	
World Health Organization Regions					
African region	0.509 ***	0.453 **	0.438 **	0.411 **	45
American region	0.661 ***	0.568 ***	0.648 **	0.586 **	35
Eastern Mediterranean region	0.107	0.106	0.110	0.173	21
European region	0.550 ***	0.330 *	0.335 *	0.217	50
South-East Asian Region	0.221	0.200	0.355	0.394	10
Western Pacific Region	0.217	0.142	0.250	0.227	23
Countries grouped with various factors					
Asia Cooperation Dialogue (ACD)	0.070	−0.021	0.131	0.132	28
Asia-Pacific Economic Cooperation (APEC)	−0.069	−0.061	−0.053	−0.016	21
Arab World	0.722 ***	0.687 ***	0.743 ***	0.730 ***	23
English as official language (EOL)	0.724 ***	0.732 ***	0.697 ***	0.743 ***	52
Latin America (LA)	0.401	0.501 *	0.466 *	0.531 *	18
Latin America & the Caribbean (LAC)	0.631 ***	0.512 **	0.639 ***	0.550 ***	33
Organization for Economic Cooperation and Development (OECD)	−0.083	−0.231	−0.144	−0.297	37
Southern African Development Community (SADC)	0.632 **	0.624 **	0.486 *	0.397	16
Shanghai Cooperation Organization (SCO)	0.174	0.170	0.255	0.256	26

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Data sources and variable definitions: Meat fat and protein supply (g/capita/day, 2019–2021) were obtained from the FAO. Dementia incidence (cases per 100,000, 2021) came from IHME.

By WHO regions, associations were moderate in Africa (protein r = 0.51; fat r = 0.44) and the Americas (protein r = 0.66; fat r = 0.65), weaker in Europe, and non-significant in Eastern Mediterranean, South-East Asia, and Western Pacific. Group analyses showed particularly strong correlations in the Arab World and English-speaking countries ($r \approx 0.70–0.74$, $p < 0.001$, Table 2).

3.2.3. Partial Correlations

After adjusting for socioeconomic and demographic covariates, patterns diverged between protein and fat (Table 3).

Table 3. Partial correlations between meat supply (2019–21) and dementia incidence (2021) controlling for socioeconomic and demographic factors.

Model	Control Variables	Meat Protein (Partial r)	df	*p*-Value	Meat Fat (Partial r)	df	*p*-Value
1	GDP PPP	0.160	175	0.033	0.212	175	0.005
2	GDP PPP + I_{bs}	0.088	173	0.247	0.164	173	0.030
3	GDP PPP + I_{bs} + Life e(0)	0.159	172	0.037	0.217	172	0.004
4	GDP PPP + I_{bs} + Life e(0) + Urbanization	0.161	171	0.035	0.218	171	0.004

Note. df = degrees of freedom. All *p*-values are two-tailed. Data sources and variable definitions: Meat fat and protein supply (g/capita/day, 2019–2021) were obtained from the FAO. Dementia incidence (cases per 100,000, 2021) came from IHME. The Biological State Index [3] represented genetic predisposition, while GDP (PPP-adjusted), life expectancy, and urbanization (2018) were sourced from the World Bank. Included as the confounding factor.

Meat protein supply: The positive association weakened when controlling for GDP (r = 0.16, $p = 0.033$) and became non-significant when GDP and I_{bs} were both included (r = 0.09, $p = 0.247$). However, significance re-emerged when life expectancy and urbanization were added (r = 0.16, $p = 0.035$).

Meat fat supply: Associations remained consistently significant across all models. Controlling for GDP PPP alone (r = 0.21, $p = 0.005$), GDP PPP + I_{bs} (r = 0.16, $p = 0.030$), and GDP + I_{bs} + life expectancy (r = 0.22, $p = 0.004$) all retained significance. With all covariates included, fat supply remained a modest but robust correlate (r = 0.22, $p = 0.004$, Table 3).

3.2.4. Principal Component Analysis (PCA)

PCA extracted a single dominant component (eigenvalue > 1), explaining 75.2% of variance in the protein model and 74.0% in the fat model (Table 4). All variables showed strong communalities (0.526–0.893) and high loadings on the first component: meat protein (0.829), meat fat (0.796), GDP (0.944–0.945), I_{bs} (0.897–0.900), life expectancy (0.917–0.919), and urbanization (0.725–0.727) 0. These results indicate that dietary, demographic, and economic variables largely reflect a shared "development–nutrition transition" factor.

3.2.5. Regression Analyses

Multiple regression models confirmed that life expectancy was the dominant correlate of dementia incidence ($\beta \approx 0.52–0.56$, $p < 0.001$, Table 5). GDP retained a modest association ($\beta \approx 0.19–0.25$).

Table 4. Principal component analysis of meat protein and meat fat supply with socioeconomic and demographic variables.

Variable	Communalities (Meat Protein)	Communalities (Meat Fat)	Factor Loadings (Meat Protein)	Factor Loadings (Meat Fat)
Meat Protein	0.687	–	0.829	–
Meat Fat	–	0.634	–	0.796
GDP PPP	0.893	0.891	0.945	0.944
I_{bs}	0.810	0.805	0.900	0.897
Life e(0)	0.841	0.844	0.917	0.919
Urbanization	0.528	0.526	0.727	0.725
Eigenvalue (1st component)	3.76	3.70	–	–
% Variance explained	75.2%	74.0%	–	–

Note. Extraction method = Principal Component Analysis (no rotation). Only one component with eigenvalue > 1 was retained in each model. Data sources and variable definitions: Meat fat and protein supply (g/capita/day, 2019–2021) were obtained from the FAO. Dementia incidence (cases per 100,000, 2021) came from IHME. The Biological State Index [3] represented genetic predisposition, while GDP (PPP-adjusted), life expectancy, and urbanization (2018) were sourced from the World Bank.

Table 5. Multiple regression analyses showing associations of dementia incidence (2021) with socioeconomic, demographic, and dietary factors.

Predictor	Enter Method: Baseline (β)	Enter Method: Protein Model (β)	Enter Method: Fat Model (β)	Stepwise: Baseline (β)	Stepwise: Protein Model (β)	Stepwise: Fat Model (β)
GDP PPP	0.251 **	0.213 *	0.196	0.252 **	0.194 *	0.179 *
I_{bs}	0.102	0.037	0.039	–	–	–
Life e(0)	0.523 ***	0.530 ***	0.526 ***	0.820 *** 0.605 ***	0.821 *** 0.689 *** 0.562 ***	0.821 *** 0.683 *** 0.559 ***
Urbanization	−0.015	−0.026	−0.025	–	–	–
Meat Protein	–	0.138 *	–	–	0.205 *** 0.143 *	–
Meat Fat	–	–	0.172 **	–	–	0.226 *** 0.176 **
R^2 (Adjusted)	0.693 (0.686)	0.707 (0.699)	0.714 (0.706)	0.673 (0.671) 0.690 (0.687)	0.675 (0.673) 0.699 (0.696) 0.707 (0.702)	0.675 (0.673) 0.707 (0.703) 0.713 (0.708)
F-statistic	98.57 ***	82.67 ***	85.35 ***	–	–	–
N	180	177	177	180	177	177

Note. Standardized coefficients (β) are reported. Stepwise regression retained predictors sequentially; Enter regression included all variables simultaneously. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Data sources and variable definitions: Meat fat and protein supply (g/capita/day, 2019–2021) were obtained from the FAO. Dementia incidence (cases per 100,000, 2021) came from IHME. The Biological State Index [3] represented genetic predisposition, while GDP (PPP-adjusted), life expectancy, and urbanization (2018) were sourced from the World Bank.

When dietary factors were added:

- Meat protein displayed a weaker and less consistent association (β = 0.14, $p = 0.035$).
- Meat fat showed a stronger and more consistent independent association (β = 0.17, $p = 0.004$).

Stepwise regression supported these findings. Life expectancy consistently showed the strongest association (β ≈ 0.56–0.82, $p < 0.001$), followed by GDP PPP (β ≈ 0.18–0.25). Meat fat demonstrated a modest but consistent independent association (β = 0.18, $p < 0.01$), whereas protein effects were weaker and less stable.

4. Discussion

4.1. Interpretation of Findings

This ecological analysis explored global associations between dietary supply and dementia incidence while controlling for socioeconomic and demographic confounders. At the bivariate level, both meat protein and fat supply correlated strongly with dementia. However, multivariable models revealed a more nuanced picture: life expectancy was the dominant correlate, explaining most of the variance across countries. Importantly, meat fat retained a consistent positive association with dementia even after full adjustment, whereas the initial protein association weakened and, in some models, reversed. To the best of our knowledge, this is the first global study to compare meat protein and fat, highlighting dietary fat as the more relevant nutritional correlate in the context of development and nutrition transitions.

IHME data define dementia as "Alzheimer's disease and other dementias", meaning the outcome reflects the overall burden rather than subtype-specific risk. This distinction is critical, as dietary fat has been mechanistically linked to Alzheimer's disease through β-amyloid accumulation and neuroinflammation, while vascular dysfunction may underlie associations with vascular dementia [7,11]. Our findings therefore reflect broad dementia risk rather than pathways limited to a single subtype.

The persistence of fat associations is biologically plausible. High saturated fat intake promotes oxidative stress, neuroinflammation, and protein aggregation, damaging vulnerable regions such as the hippocampus, frontal cortex, amygdala, and white matter tracts [11,59]. By contrast, protein showed weaker and inconsistent associations, suggesting it is less directly involved in these processes and may even support resilience through metabolic and muscular health [60,61].

Beyond macronutrients, meat-derived compounds such as trimethylamine-N-oxide (TMAO), haem iron, and advanced glycation end products (AGEs) provide additional explanatory pathways [14,62]. These compounds disrupt vascular and neuronal integrity, amplify oxidative stress, and accelerate amyloid and tau pathology, reinforcing the plausibility of fat-related risk [16,63]. Although not measured directly here, these mechanisms complement our interpretation that dietary fat, more than protein, contributes to dementia burden globally [7,11].

4.2. Comparison with Previous Research

4.2.1. Meat Protein Versus Meat Fat: Clarifying Distinct Roles

Our findings emphasize that although both protein and fat appear correlated with dementia at a descriptive level, they behave very differently when confounders are introduced. Meat fat supply consistently remained a significant predictor, suggesting a direct and robust link with dementia incidence. This aligns with a large body of biological and clinical evidence: diets high in saturated fats increase β-amyloid accumulation, oxidative stress, vascular dysfunction, and neuroinflammation—all pathways central to dementia pathogenesis [21,22,64]. By contrast, unsaturated fats, especially polyunsaturated fatty acids, may offer neuroprotection [21,65]. Although our ecological dataset could not differentiate between fat types, the persistence of fat as an independent predictor highlights the need to address both the quality and quantity of dietary fat in dementia prevention [22,66].

In contrast, meat protein supply lost significance and even showed a weak negative association once fat and development factors were controlled. This reversal indicates that the initial positive association between protein and dementia was largely spurious, driven by collinearity with fat ($r \approx 0.97$) and with development indicators such as GDP and life expectancy [24,67]. Biologically, protein itself is not considered a direct risk factor for dementia. In fact, adequate protein supports muscle maintenance, immune function, and

resilience in aging populations. The weak negative signal observed here may reflect these potential protective effects, once disentangled from fat. Nevertheless, because protein and fat are so closely correlated at the population level, ecological analyses alone cannot fully separate their effects [34]. Future studies using individual-level data and distinguishing animal versus plant protein are needed.

4.2.2. Life Expectancy and Development Factors

While dietary fat emerged as an independent contributor, life expectancy was the strongest predictor of dementia incidence, consistent with evidence that aging is the principal risk factor [27,68]. Longer lifespans increase case counts both through age-related pathology and because populations live long enough to receive diagnoses [2]. Life expectancy correlated closely with GDP PPP, healthcare access, and urbanization [69]. Our PCA indicated that these variables cluster into a single latent factor reflecting socioeconomic–health advancement, explaining approximately 74% of the variance. Accordingly, countries with higher incidence not only live longer but also diagnose and report more accurately [70]. GDP made a modest contribution in regression models, acting both as a proxy for diagnostic capacity and as a driver of dietary transitions toward greater fat and animal-source food intake [67]. Importantly, partial correlations showed that fat supply remained significant after controlling for GDP PPP and life expectancy, suggesting that its effect is not merely a marker of affluence [22]. To our knowledge, few studies have contrasted meat fat with meat protein side-by-side at the global level; our approach therefore adds methodological and substantive novelty to this literature [29].

4.2.3. Multicollinearity and the Nutrition–Development Transition

The high intercorrelations among predictors underscore the challenge of isolating independent dietary effects in ecological analyses. Protein, fat, GDP PPP, life expectancy, and I_{bs} are all intertwined elements of a broader "development–nutrition transition." PCA confirmed that these clustered tightly within a single factor, illustrating how demographic, economic, and dietary changes co-occur as countries modernize [71]. Despite this clustering, fat supply continued to stand out as an independent predictor, reinforcing the likelihood of a genuine dietary effect rather than an artifact of development [22,64].

4.3. Future Directions

Future studies should employ longitudinal individual-level designs that differentiate fat subtypes and protein sources, and they should also explore genetic and biomarker pathways linking fat intake to dementia. Ecological analyses could be expanded to consider broader influences, such as obesity prevalence [49], cardiovascular risk [72], and education. In addition, developing interdisciplinary prevention strategies that combine nutrition, epidemiology, and health policy and tailoring them to countries at different stages of the nutrition transition will be crucial to inform effective and context-specific dementia prevention.

5. Conclusions

This global ecological analysis shows that although both meat protein and meat fat are correlated with dementia incidence, only meat fat remains an independent and consistent predictor after controlling for key socioeconomic and demographic variables. Life expectancy is the strongest correlate, reflecting the central role of population aging in influencing dementia incidence worldwide. However, the continued association between dietary fat from meat and dementia suggests that it may represent a modifiable risk factor linked to changing dietary patterns that accompany economic development.

By directly comparing the effects of meat protein and meat fat, this study provides new evidence that dietary fat, rather than protein, plays a more significant role in dementia risk at the population level. These findings highlight the importance of improving dietary quality and fat composition in dementia prevention strategies. Policymakers should consider incorporating the reduction of unhealthy fat intake, particularly saturated fat from animal sources, into broader public health and chronic disease prevention initiatives to lessen the neurological impact of global nutrition transitions.

6. Public Health and Policy Implications

These findings have important implications for dementia prevention. First, they reaffirm demographic aging as the principal driver of dementia, underscoring the need for health systems to prepare for a growing burden. Second, they identify dietary fat as a potentially modifiable risk factor, suggesting that nutrition interventions may complement existing strategies focused on cardiovascular and metabolic health.

Countries undergoing rapid nutrition transitions are particularly vulnerable. As life expectancy rises, populations adopt dietary patterns characterized by greater fat and animal-source food consumption, which can accelerate non-communicable disease burdens, including dementia. Policymakers should therefore integrate dementia prevention into broader chronic disease frameworks, emphasizing dietary quality alongside cardiovascular and metabolic risk reduction. Global dietary guidelines must also address the paradox of affluence: while higher GDP PPP and longevity improve health overall, they simultaneously foster dietary patterns that may elevate dementia risk. Balanced, cross-sectoral strategies are needed to mitigate these unintended harms of development.

7. Strengths and Limitations

This study's strengths include its wide global scope, covering 204 countries, and the application of multiple analytic approaches, including correlation, regression, partial correlation, and principal component analysis, to triangulate results. Most importantly, it provides the first direct ecological comparison of meat protein and fat in relation to dementia, clarifying which dietary component is more relevant.

Several limitations must also be acknowledged. First, dementia incidence was reported by IHME as an aggregate category (Alzheimer's disease and other dementias). As such, subtype-specific risks could not be assessed despite their distinct mechanisms. Future research using individual-level, clinically confirmed, or biomarker-based data is needed to clarify whether meat fat and protein differentially influence Alzheimer's disease, vascular dementia, or other subtypes. Second, regression models did not incorporate interaction terms or nonlinear specifications. While this maintained parsimony and minimized collinearity, it may have obscured threshold effects or context-specific variations. Future studies should test interaction terms (e.g., meat $\times$ income group) and nonlinear models.

Third, per capita meat supply was used as a proxy for consumption. Although food balance sheet data provide standardized global estimates, they do not capture individual intake, within-country disparities, or food waste, which may affect measurement accuracy. Additionally, residual confounding cannot be excluded. Despite adjusting for life expectancy, GDP per capita, urbanization, and genetic predisposition, factors such as education, physical activity, and healthcare access may also influence dementia incidence.

Finally, ecological analyses cannot establish causality and are vulnerable to ecological fallacy when applied to individuals. Supply data also obscure differences in fat type (saturated vs. unsaturated) and protein source (animal vs. plant). Dementia incidence estimates may vary in accuracy, with underreporting being likely in low-income settings.

High collinearity among predictors further complicates isolation of independent effects, though this was partly addressed with diagnostics and PCA.

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Data Availability Statement: Details of the data sources are outlined in Section 2. All datasets utilized in this study are freely accessible and downloadable from publicly available resources on United Nations (UN) agency websites. Since the data were sourced from open-access repositories, formal participant consent was not applicable. The use of these datasets aligns with the public use policies specified by the UN agencies, eliminating the need for additional permissions for academic research, as discussed in Section 2, with appropriate references.

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