

1 **Determinants of plant-based protein consumption: A global panel data**
2 **analysis with Driscoll and Kraay estimator**

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5 **ABSTRACT**

6 Promoting sustainable, healthy, and nutritious diets is essential for improving public health and
7 transitioning toward more sustainable food systems. A global shift from animal-based to plant-
8 based proteins is increasingly recognized as a key strategy in this regard. However, empirical
9 evidence on the main determinants of plant-based protein consumption at the global level
10 remains scarce. This study investigates the key factors associated with plant-based protein
11 consumption across 165 countries over the period 2001–2022, using a fixed-effects panel data
12 model with Driscoll–Kraay standard errors. The results indicate that income, population aging,
13 internet access, and globalization are positively associated with plant-based protein
14 consumption, while inflation and animal protein consumption show negative associations.
15 Heterogeneity analysis reveals that urbanization and income act as barriers to plant-based
16 consumption in high-income countries, whereas population growth has a negative association
17 in low- and middle-income countries. A series of robustness checks, including Winsorization,
18 lagged specifications, and quadratic and regional controls, confirm the stability of these
19 findings. These results highlight the context-dependent nature of dietary transitions and
20 underscore the need for targeted, income-specific policy approaches.

21 **Keywords:** DKSE method, Plant-based proteins, Panel data analysis, Income level
22 heterogeneity analysis, Sustainable consumption.

23
24 **INTRODUCTION**

25 Food systems, human health, and environmental sustainability are deeply interconnected
26 (James-Martin et al., 2022; Pecher et al., 2025). Since there is a significant synergy between
27 human and planetary health, food-based dietary guidelines have started to consider the
28 environmental sustainability of food choices (Springmann et al., 2020; Mago et al., 2024).
29 Promoting a more sustainable healthy and nutritious diet plays an important role in improving
30 human health (Varela et al., 2022; Al Masri and König, 2025) and is a vital step towards more

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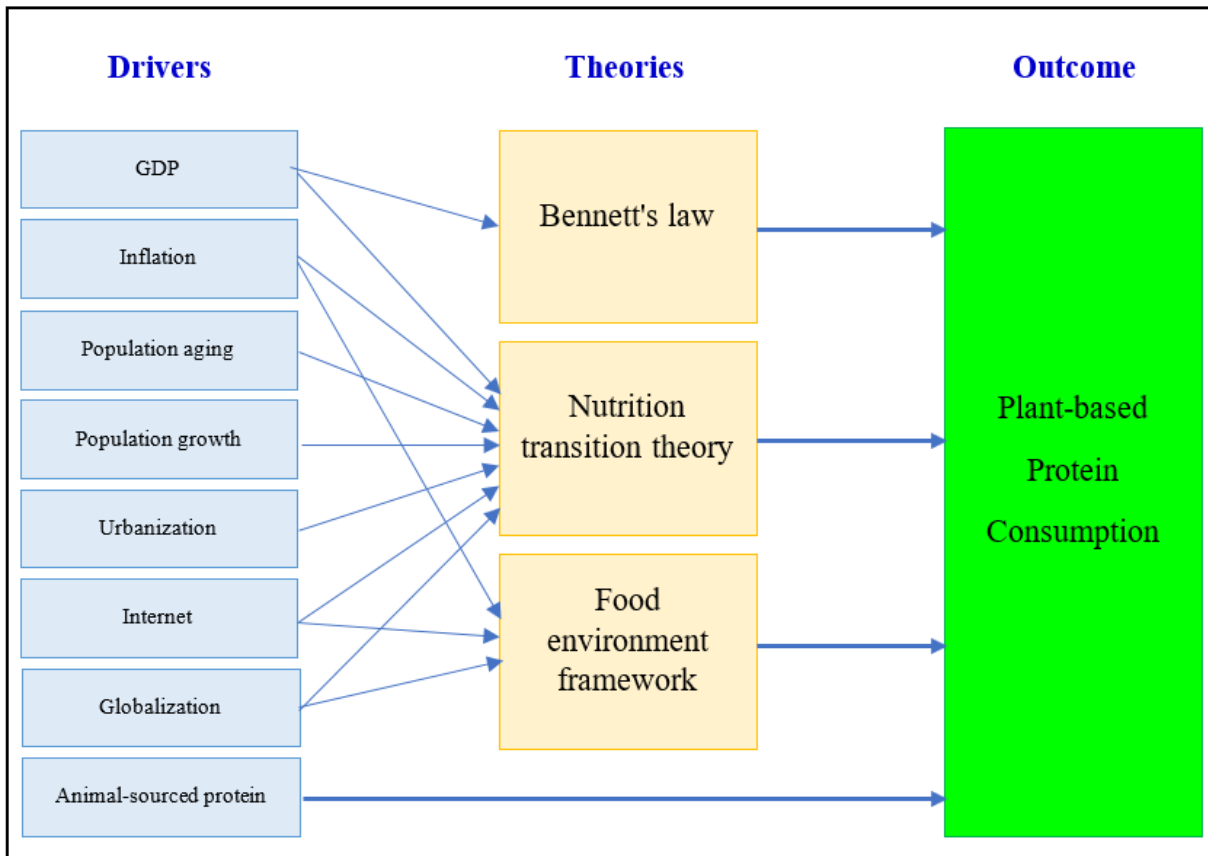
31 sustainable food systems (Springmann et al., 2020; Davies et al., 2025). Therefore, dietary
32 changes are necessary to reduce premature mortality from dietary risk, healthcare costs, and
33 environmental resource use (Tilman and Clark, 2014; Clark et al., 2022; Springmann et al.,
34 2025).

35 In the last decades, dietary patterns have shifted toward unhealthy diets that are high in calories,
36 heavily processed, and rich in animal-source foods particularly in high-income nations (Willett
37 et al., 2019; Springmann et al., 2025). Considering the increased awareness about the adverse
38 impacts of animal proteins consumption on public health and the environment, the plant-based
39 diet has increasingly attracted the attention of academics and policymakers. It is widely
40 accepted that shifting from animal-sourced to more plant-based proteins⁴ in people's diets is
41 needed to maintain public health and counter climate change (Van der Weele et al., 2019; Van
42 der Meer et al., 2025). The consumption of plant-based proteins provides several health
43 benefits such as reduced risks of cardiovascular disease, type 2 diabetes, and other metabolic
44 diseases (Jardine et al., 2021; Glenn et al., 2024). In addition, plant-based proteins are more
45 sustainable than animal proteins since their production is less polluting and energy consuming
46 (Drolet-Labelle et al., 2023; Sato and Oldroyd, 2026). Therefore, to enhance public health and
47 achieve sustainable development, decision-makers should prioritize the plant-based protein
48 consumption.

49 Hence, understanding the drivers of plant-based protein consumption is essential for designing
50 effective policies. While individual-level factors such as motivations and familiarity have been
51 widely studied, consumption patterns at the national level are also shaped by broader socio-
52 economic forces that operate through well-established mechanisms. Three theoretical
53 frameworks help explain these macro-level influences. First, the nutrition transition theory
54 (Popkin, 2006) argues that economic development, urbanization, and demographic change
55 drive systematic shifts away from plant-based staples toward animal-based and processed
56 foods. Second, Bennett's law (Bennett, 1941) posits that as income rises, the share of staples-
57 including plant-based proteins from cereals and legumes-in total caloric intake declines,
58 reflecting substitution toward higher-value foods. Third, the food environment framework
59 (HLPE, 2017) emphasizes that food availability, affordability, and accessibility—shaped by

⁴ Plant-based protein includes protein from cereals (e.g., wheat, rice, maize), legumes and pulses (e.g., soybeans, lentils, chickpeas, beans), nuts and seeds (e.g., almonds, walnuts, sunflower seeds), vegetables, fruits, roots and tubers, and vegetable oils.

60 inflation, digital infrastructure, and globalization—are key determinants of national dietary
 61 outcomes. Together, these frameworks suggest that country-level variables such as GDP per
 62 capita, food inflation, population aging, population growth, urbanization, animal-sourced
 63 proteins, internet access, and globalization influence plant-based protein consumption through
 64 income effects, substitution effects, and changes in the food environment. Figure 1 presents a
 65 conceptual diagram of these hypothesized relationships. These three frameworks collectively
 66 provide a solid theoretical foundation for selecting the macro-level determinants examined in
 67 this study and for hypothesizing their effects on plant-based protein consumption across
 68 countries and over time.



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 70 **Figure 1. Conceptual framework and logic diagram linking macro-level drivers to plant-**
 71 **based protein consumption.**

72
 73 The literature has focused on the main determinants of plant-based protein consumption at the
 74 individual level. Table 1 provides the summary of previous studies regarding the main
 75 determinants of plant-based proteins consumption. For instance, Vainio et al. (2016) showed
 76 that eating motivations play a crucial role in changing Finnish consumers’ diets towards plant-
 77 based proteins as a sustainable food consumption pattern. They found that the plant-based

78 consumers' motives relating to health and natural concerns were higher as compared beef
79 consumers. Clark and Bogdan (2019) revealed that animal/environmental ethics and personal
80 health have a significant influence on Canadians decision to consume plant-based proteins
81 instead of meat. However, availability and affordability are main barriers to future
82 consumption. Havermans et al. (2021) found that increasing awareness of the benefits and skills
83 to prepare a plant-based meal improve both familiarity and knowledge on plant-based food,
84 and hence contribute to increase its consumption in Netherlands. Varela et al. (2022) revealed
85 that although Norwegian and French consumers tend to eat less meat, their actual behavior was
86 often organized towards meat consumption. Ren et al. (2023) showed that Perceived value has
87 most significant effect on Chinese attitude, decision satisfaction, and purchase intention
88 towards insect protein food. Abebe et al. (2024) found that sustainability and ethical concerns
89 have positive effect on changing dietary patterns towards plant-based protein diets, while meat
90 attachment negatively influenced changes in dietary patterns. Rao et al. (2025) found that
91 increasing familiarity with plant-based meals and reducing food neo-phobia are important
92 determinants in Denmark and Australia as two of the world's highest meat-consuming
93 countries. Li et al. (2026) revealed that social image concern plays an important role in adopting
94 plant-based meat in Australian consumers. McRae et al. (2026) using two-level mixed effects
95 regression showed that Finnish consumers were more price elastic to animal-sourced proteins
96 than plant-based proteins, and consumers' income moderated price elasticity.
97 There is a limited studies at the global level. For instance, Kmeřková and řčasný (2025)
98 investigated the main determinants of animal-sourced proteins and showed a N-shaped
99 relationship between GDP and animal proteins consumption, particularly in Europea. They
100 found although increasing income can reduce the consumption of animal-sourced proteins,
101 their consumption would increase again at higher incomes.

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Table 1. Summary of previous studies in plant-based proteins consumption.

Authors (year)	Level of analysis	Country	Method	Key findings
Vainio et al. (2016)	Individual-level (cross-section)	Finland	Latent Class Analysis and ANOVA	Eating motivations play a crucial role in changing Finnish consumers' diets towards plant-based proteins.
Clark and Bogdan (2019)	Individual-level (cross-section)	Canada	Rank-based non-parametric Kruskal-Wallis H test	Animal/environmental ethics and personal health have a significant influence on Canadians decision to consume plant-based proteins instead of meat
Havermans et al. (2021)	Individual-level (cross-section)	Netherlands	Content analysis	Increasing awareness of the benefits and skills to prepare a plant-based meal improve both familiarity and knowledge on plant-based food, and hence contribute to increase its consumption
Varela et al. (2022)	Individual-level (cross-section)	France, Norway	Multifactor Analysis	Although Norwegian and French consumers tend to eat less meat, their actual behavior was often organized towards meat consumption.
Ren et al. (2023)	Individual-level (cross-section)	China	Structural Equation Modelling	Perceived value has most significant effect on Chinese attitude, decision satisfaction, and purchase intention towards insect protein food.
Azman et al. (2023)	Individual-level (cross-section)	Malaysia	Structural Equation Modelling	The results demonstrated that attitude, subjective norms, perceived behavioral control, environmental concern, and health consciousness influence Malaysian intention to purchase plant-based meat products.
Nakhonchaikul and Siriyota (2024)	Individual-level (cross-section)	Thailand	Structural Equation Modelling	The results indicated that attitudes, subjective norms, environmental concerns were affected positively influencing the adoption intention towards plant-based food products.
Abebe et al. (2024)	Individual-level (cross-section)	Canada	Structural Equation Modelling	sustainability and ethical concerns have positive effect on changing dietary patterns towards plant-based protein diets, while meat attachment negatively influenced changes in dietary patterns.
Rao et al. (2025)	Individual-level (cross-section)	Australia, Denmark	Linear regression models	Increasing familiarity with plant-based meals and reducing food neo-phobia are important determinants of plant-based consumption.
Kmeřková and Ščasný (2025)	Country-level (panel data)	200 countries	Fixed-effect	They found a N-shaped relationship between GDP and animal proteins consumption, meaning that animal proteins increase at higher incomes.
Li et al. (2026)	Individual-level (cross-section)	Australia	ANOVA	Social image concern plays an important role in adopting plant-based meat in Australian consumers.
McRae et al. (2026)	Individual-level (cross-section)	Finland, Canada	Two-level mixed-effects regression	Consumers were more price elastic to animal-sourced proteins than plant-based proteins. Socioeconomic status moderated both proteins.
This study (2026)	Country-level (panel data)	165 countries	Fixed-effect Driscoll-Kraay	Income, aging population, internet access, and globalization are positively affected the plant-based protein consumption, while inflation and animal protein consumption show negative associations. The effects vary by income level: income and urbanization have negative associations in high-income countries, while population growth is negatively associated in low- and middle-income ones.

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112 Despite the growing literature investigating the factors affecting plant-based food

113 consumption, two main gaps remain in previous empirical studies. First, prior research has

114 largely focused on individual-level determinants, whereas consumption patterns at the country
115 level are significantly shaped by macro-level socio-economic policies. Second, most existing
116 studies rely on cross-sectional data and therefore cannot capture changes in consumption
117 patterns over time. Therefore, the present study contributes to the literature in three distinct
118 ways. First, unlike recent work on global protein transitions that examines animal-sourced
119 proteins and the ratio of animal-to-plant protein (A:P) intake (Drewnowski and Hooker, 2025;
120 Kmeřková and Ščasný, 2025), we specifically focus on plant-based protein consumption as a
121 standalone outcome. This distinction is important because policies aimed at promoting plant-
122 based diets target plant protein intake directly, rather than the relative share of animal protein.
123 Second, we analyze income heterogeneity by classifying countries into low- and middle-
124 income and high-income groups according to the World Bank classification. This
125 disaggregation provides deeper insights into how national wealth moderates the effects of
126 macro-level drivers on consumer behavior toward healthy and sustainable food choices. Third,
127 by employing Driscoll-Kraay standard errors (DKSE), we ensure robust inference in the
128 presence of cross-sectional dependence and heteroskedasticity, which is a common concern in
129 macro-level panel data studies.

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131 METHODOLOGY AND DATA

132 Research model

133 To analyze the main determinants of plant-based proteins consumption, this study constructs
134 the research model in Equation (1):

$$135 \text{PBP}_{it} = \beta_0 + \beta_1 \text{GDP}_{it} + \beta_2 \text{INF}_{it} + \beta_3 \text{P65}_{it} + \beta_4 \text{POPG}_{it} + \beta_5 \text{URB}_{it} + \beta_6 \text{ANP}_{it} + \\ 136 \beta_7 \text{INT}_{it} + \beta_8 \text{GL}_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

137 where, i and t represent country ($i = 1, \dots, 165$) and time period ($t = 2001, \dots, 2022$),
138 respectively. β_0 denotes the constant term and β_1, \dots, β_8 are parameters to be estimated. μ_i and
139 ε_{it} show the country fixed-effect and error term, respectively. PBP is per capita consumption
140 of plant-based proteins. GDP is per capita gross domestic product. Previous research found that
141 income is an important economic factor influencing healthy food consumption and food
142 security (Dithmer and Abdulai, 2017; Abdullah et al., 2022; Garlock et al., 2022). Therefore,
143 it is expected that people's income can increase the consumption of plant-based proteins ($\beta_1 =$
144 $\frac{\partial \text{PBP}}{\partial \text{GDP}} > 0$). INF represents inflation. Empirical studies (e.g., Dithmer and Abdulai, 2017;
145 Subramaniam et al., 2020) showed that inflation plays an impeding role in food security.

146 Hence, it is expected that the plant-based foods consumption will decrease by increasing
147 inflation ($\beta_2 = \frac{\partial PBP}{\partial INF} < 0$). P65 denotes the share of the 65 and older population in a country.
148 Empirical research confirms that older people pay more attention to their health and are more
149 inclined to consume healthy foods. The study by Lee et al. (2024) revealed that China's food
150 security was significantly increased by population aging. Therefore, it is expected that the aging
151 population can increase the plant-based proteins consumption ($\beta_3 = \frac{\partial PBP}{\partial P65} > 0$). POPG is
152 population growth. The studies by Dithmer and Abdulai (2017) for 151 countries,
153 Subramaniam et al. (2020) for 51 developing countries, and Abdullah et al. (2022) for 35 Asian
154 countries revealed that population growth significantly reduces the food security. Hence, it is
155 expected that the consumption of plant-based proteins will decrease by population growth
156 ($\beta_4 = \frac{\partial PBP}{\partial POPG} < 0$). URB denotes urbanization. Previous research analyzed the influence of
157 urbanization on healthy food consumption and food security and showed mixed findings, such
158 as positive influence (Dithmer and Abdulai, 2017), and negative influence (Fusco et al., 2020).
159 Therefore, urbanization can decrease ($\beta_5 = \frac{\partial PBP}{\partial URB} < 0$) or increase ($\beta_5 = \frac{\partial PBP}{\partial URB} > 0$) the plant-
160 based proteins consumption. ANP is animal proteins consumption. Since animal and plant-
161 based proteins are substitutes, it is expected that increase in the consumption of animal proteins
162 will lead to a decrease in plant-based proteins consumption ($\beta_6 = \frac{\partial PBP}{\partial ANP} < 0$). INT denotes
163 internet access. The studies by Deng et al. (2024) in China, and Ayanwale and Kehinde (2025)
164 in Nigeria found that internet access significantly improves food security. Thus, it is expected
165 that greater internet access will increase plant-based protein consumption ($\beta_7 = \frac{\partial PBP}{\partial INT} > 0$).
166 GL is globalization. Theoretical and empirical research implied that globalization can increase
167 food security and healthy food consumption through increased interconnectedness among
168 nations (Dithmer and Abdulai, 2017); however, globalization can raise concerns regarding food
169 sovereignty (Rahman et al., 2025). Therefore, globalization can decrease ($\beta_8 = \frac{\partial PBP}{\partial GL} < 0$) or
170 increase ($\beta_8 = \frac{\partial PBP}{\partial GL} > 0$) the plant-based foods consumption.

171
172 **Estimation strategy**

173 The empirical model is built on four steps. First, we tested cross-section dependence using
174 Pesaran (2004) test. Second, we applied first- and second-generation unit root tests to check
175 the stationary study variables. We used first-generation unit root test namely Fisher Augmented

176 Dickey–Fuller (Fisher-ADF) in high-income countries sample because the cross-section
177 dependence has not been found in data. The second-generation unit root test, namely Cross-
178 section Augmented Dickey Fuller (CADF) is used to avoid the problem of cross-section
179 dependence in all countries and low- and middle-income countries samples.

180 In the third step, we employed the fixed-effect panel data model using the Driscoll-Kraay
181 Standard Errors (DKSE) approach (See Hoechle, 2007) to estimate the research model. Driscoll
182 and Kraay (1998) propose a nonparametric covariance matrix estimator that produces
183 heteroskedasticity- and autocorrelation- consistent standard errors that are robust to general
184 forms of spatial and temporal dependence. When $N > T$ and cross-section dependence is present,
185 the DKSE method is a suitable and powerful econometric approach to analyze the study's
186 objectives (Hoechle, 2007; Hussain et al., 2025). For these reasons, previous empirical studies
187 (e.g., Abban et al., 2025; Hussain et al., 2025; Wang et al., 2025) widely used DKSE method
188 to tackle the possible cross-section dependence, autocorrelation, and heteroscedasticity.
189 Fourth, we included an income heterogeneity analysis, providing detailed segmentation of
190 economies.

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192 **Data**

193 This study determines the plant-based proteins consumption for 165 countries from 2001 to
194 2022. The choice of time series length is determined by the availability of data on plant-based
195 protein consumption and independent variables. Table 2 presents the definition and source of
196 study variables. The data were obtained from several publicly available sources, including the
197 consumption plant-based and animal proteins data drawn from the Food and Agriculture
198 Organization (FAO, 2025), data on independent variables including GDP per capita, inflation,
199 population ages 65 and above, population growth, urban population, and internet access from
200 the World Bank's World Development Indicators (WDI) database (World Bank, 2025), and
201 data on globalization from the KOF Swiss Economic Institute (KOF Swiss Economic Institute,
202 2025). Table 3 shows the descriptive statistics of study variables for all countries and two sub-
203 samples of countries, comprising 113 low- and middle-income and 52 high-income.

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Table 2. Definition and source of study variables.

Variable	Definition	Unit	Source
PBP	Plant-based protein consumption	gr	FAO
GDP	Gross domestic product (Constant 2015 US\$)	\$	World Bank
INF	Consumer prices (annual %)	%	World Bank
P65	Population ages 65 and above (% of population)	%	World Bank
POPG	Population growth (annual %)	%	World Bank
URB	Urban population (% of population)	%	World Bank
ANP	Animal protein consumption	gr	FAO
INT	Individuals using the Internet (% of population)	%	World Bank
GL	Globalization	-	KOF Swiss Economic Institute

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Table 3. Descriptive statistics of study variables.

Variable	All countries				Low- and middle-income countries				High-income countries			
	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max	Mean	Std. dev.	Min	Max
LnPBP	3.76	0.21	3.08	4.41	3.78	0.22	3.12	4.41	3.72	0.17	3.08	4.22
LnGDP	8.54	1.40	5.53	11.63	7.79	0.93	5.53	9.55	10.17	0.65	8.26	11.63
LnINF	1.43	0.97	-4.11	6.32	1.61	1.00	-4.11	6.32	1.05	0.76	-2.57	3.57
LnP65	1.86	0.71	0.31	3.38	1.57	0.53	0.55	3.08	2.49	0.62	0.31	3.38
POPG	1.32	1.37	-7.62	14.23	1.57	1.28	-7.62	9.99	0.78	1.42	-3.86	14.23
LnURB	3.94	0.46	2.64	4.61	3.80	0.46	2.64	4.53	4.25	0.30	3.19	4.61
LnANP	3.44	0.69	1.33	4.74	3.15	0.62	1.33	4.61	4.09	0.22	3.38	4.74
LnINT	2.93	1.61	-8.15	4.61	2.41	1.66	-8.15	4.58	4.06	0.60	0.00	4.61
LnGL	4.06	0.25	3.22	4.50	3.95	0.20	3.22	4.40	4.30	0.16	3.71	4.50

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212 RESULTS AND DISCUSSION

213 In the first step, we tested cross section dependence and found there is a cross-section
 214 dependence in all countries sample and low- and middle-income countries sample. However,
 215 no dependence exists in high-income countries sample (Table 4). The results of unit root test
 216 are presented in Table 5 and showed the null hypothesis is rejected at 5 percent level and hence,
 217 **all study variables are stationary at level in three models.** The results of multicollinearity test
 218 using Variance Inflation Factors (VIF) are presented in Table 6. **The results revealed that the**
 219 **obtained values are less than 5, highlighting that there is no issue of multicollinearity (Pesaran,**
 220 **2015; Wooldridge, 2020; Baltagi, 2021).**

221

222 **Table 4.** The results of cross-section dependence using Pesaran (2004) test.

Variable	Model 1:	Model 2:	Model 3:
	All countries	Low- and middle-income countries	High-income countries
Cross-section dependence	10.806 (0.000)	9.791 (0.000)	-0.285 (0.775)

223 Source: research findings.

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229 **Table 5.** The results of unit-root tests using CADF and Fisher-ADF tests.

Variable	Model 1: All countries		Model 2: Low- and middle-income countries		Model 3: High-income countries	
	CADF test	Result	CADF test	Result	Fisher-ADF test	Result
LnPBP	-3.604***	I(0)	-2.866***	I(0)	-10.309***	I(0)
LnGDP	-15.409***	I(0)	-3.677***	I(0)	-7.680***	I(0)
LnINF	-8.583***	I(0)	-13.972***	I(0)	-8.778***	I(0)
LnP65	-6.883***	I(0)	-3.587***	I(0)	-5.653***	I(0)
POPG	-4.069***	I(0)	-3.914***	I(0)	-2.419***	I(0)
LnURB	-2.267***	I(0)	-2.182***	I(0)	-17.643***	I(0)
LnANP	-5.785***	I(0)	-4.144***	I(0)	-3.286***	I(0)
LnINT	-12.775***	I(0)	-6.227***	I(0)	-32.093***	I(0)
LnGL	-19.923***	I(0)	-9.024***	I(0)	-4.153***	I(0)
Residuals	-3.292***	I(0)	-3.842***	I(0)	-17.808***	I(0)

230 *** P < 0.01

231 Source: research findings.

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233 **Table 6.** The results of multicollinearity using Variance Inflation Factors (VIF) test.

Variable	Model 1:	Model 2:	Model 3:
	All countries	Low- and middle-income countries	High-income countries
LnGDP	5.90	3.83	2.44
LnINF	1.11	1.05	1.06
LnP65	5.48	4.51	3.50
POPG	2.54	2.98	2.40
LnURB	2.20	1.91	1.69
LnANP	4.99	3.32	2.16
LnINT	2.60	2.21	1.66
LnGL	3.77	2.49	2.23
Mean VIF	3.57	2.79	2.14

234 Source: research findings.

235 Table 7 presents the results of panel data model using the DKSE approach. According to the
 236 Hausman test, fixed effect method is more suitable for analyzing our model. The results show
 237 that economic growth has significantly positive effect on the consumption of plant-based
 238 proteins. A one percent increase in GDP per capita leads to increase people’s consumption by
 239 0.052 percent. This means people’s income plays an important role in eating healthy foods.
 240 This result is consistent to findings of previous research (Fusco et al., 2020; Garlock et al.,
 241 2022; Abdullah et al., 2022; Gahamanyi and Tchouassi, 2025), which showed that people’s
 242 income is a major driver of healthy food consumption and food security. In addition, we find
 243 that although income is the second strongest driver of plant-based protein consumption in the
 244 low- and middle-income nations, increasing income leads to a reduction in consumption in
 245 high-income nations. This may be because high-income nations usually adopt Western-style
 246 diets that are characterized by insufficient consumption of plant-based foods alongside
 247 excessive intake of animal products (Tuninetti et al., 2022; Sun et al., 2024). In the 2001-2005
 248 period, the high-income countries’ consumption ratio of animal proteins to plant-based proteins
 249 with an average per capita income of \$28945 was 1.44, which increased to 1.59 in the 2018-
 250 2022 period with an average income of \$34712. This pattern is consistent with the nutrition

251 transition framework, which posits that economic development initially shifts diets toward
 252 animal-based and processed foods. At higher income levels, however, increased health
 253 awareness and policy interventions may eventually reverse this trend—a stage not yet observed
 254 in our sample of high-income countries over the study period.

255 Our findings show that inflation has significantly negative effect on the plant-based proteins
 256 consumption. A one percent increase in inflation reduces the consumption by 0.005 percent.
 257 Inflation reduces people’s consumption through decreasing their purchasing power. This
 258 means rising costs of living by economic uncertainty plays an important role in changing
 259 people's diets towards a less healthy food. This finding is consistent to previous studies that
 260 revealed inflation significantly increases food insecurity (Dithmer and Abdulai, 2017;
 261 Ogunniyi et al., 2020; Abdi et al., 2024), and reduces healthy foods consumption (Çakır et al.,
 262 2018). Grunert et al. (2023) found that 81 percent of European’s consumers have changed food-
 263 related behavior due to rising prices. Although, as expected, there is a similar significant
 264 negative relationship between inflation and consumption in low- and middle-income
 265 economies, we find no significant influence in high-income ones. This suggests that inflation
 266 leads to the removal of healthier and nutritious foods, which are often more expensive and
 267 more flexible, from household tables, particularly in low- and middle-income nations.

268
 269 **Table 7.** The results of main determinants of plant-based proteins consumption using fixed
 270 effect panel data model with DKSE method.

Variable	All countries	Low- and middle-income countries	High-income countries
LnGDP	0.052*** (0.007)	0.105*** (0.011)	-0.104*** (0.022)
LnINF	-0.005* (0.003)	-0.005* (0.003)	-0.003 (0.004)
LnP65	0.076*** (0.017)	0.062*** (0.022)	0.076*** (0.026)
POPG	-0.004 (0.003)	-0.012* (0.007)	0.004 (0.003)
LnURB	-0.037 (0.032)	-0.010 (0.035)	-0.439*** (0.055)
LnANP	-0.041*** (0.012)	-0.055*** (0.009)	0.041 (0.060)
LnINT	0.015*** (0.004)	0.013** (0.005)	0.021*** (0.005)
LnGL	0.182*** (0.039)	0.122* (0.061)	0.401*** (0.092)
Constant	2.681*** (0.228)	2.584*** (0.306)	4.462*** (0.325)
F-statistics	533.06***	336.32***	78.60***
Chow test	117.29***	123.46***	74.16***
Hausman test	70.39***	42.55***	43.92***
Observation	3413	2339	1074

271 Driscoll-Kraay standard errors are presented in parenthesis. *** p < 0.01, ** p < 0.05, * p < 0.10.
 272 Source: Research findings.

273 This study finds that the effect of over-65 population is positive and significant on the plant-
274 based proteins consumption, meaning that older people tend to consume more plant-based
275 foods compared to younger people. One percent increase in aging population increases the
276 consumption by 0.076 percent. There are two possible reasons for these findings. First, younger
277 consumers were weakly influenced by foods' health-related attributes and were less involved
278 in health compared to older ones. Second, older people have a high moral obligation and there
279 is a responsibility among them to offer a nutritious and healthy meal to their families and
280 friends (Tomic et al., 2016). Our analysis shows similar findings in both income groups;
281 however, this effect is greater in high-income countries. The high proportion of older people
282 in most high-income countries has led governments to implement more public health programs
283 and policies to improve their health literacy, which has resulted in greater attention to various
284 aspects of healthy living, like healthy nutrition. This result is similar with previous studies (Lee
285 et al., 2024).

286 Our findings reveal that population growth has negative but insignificant effect on the
287 consumption of plant-based proteins. However, as expected, population growth significantly
288 reduces the consumption in low- and middle-income nations. **Population growth increases the**

289 **demand for food, which causes to decline healthy food consumption like plant-based proteins.**

290 The rapid population growth with low per capita incomes and inadequate food supply due to
291 underdeveloped agricultural sector structures are the main reasons to reduce healthy foods
292 consumption and increase food insecurity. Therefore, one of the most important governments'
293 challenges is to maintain the basic food needs for people. Consequently, the main effort of
294 governments in countries with high population growth is to provide sufficient and needed food
295 for their people, and as a result, paying attention to a healthy diet will be the next priority. Our
296 finding aligns with previous studies (Subramaniam et al., 2020; Abbas et al., 2025).

297 The findings show that urbanization has negative effect on plant-based proteins consumption,
298 but this effect is not significant. Similar result is observed for low- and middle-income
299 countries. Some empirical research (e.g., Mottaleb et al., 2022; Kamenya et al., 2022) found
300 no significant association between urbanization and food security in low- and middle-income
301 countries. However, we find urbanization significantly reduces the plant-based consumption in
302 high-income nations. The main reason is people's diet in these countries particularly urban
303 populations is based on animal-based proteins (Springmann et al., 2020; Sun et al., 2024).
304 Therefore, migration of rural populations to cities changes dietary and nutritional habits

305 towards Western diet (Zhang et al., 2025). Similarly, the study by Fusco et al. (2020) revealed
306 that urbanization growth significantly reduces food security in EU countries.

307 To examine whether the negative effect of urbanization on plant-based protein consumption in
308 high-income countries is driven by a few countries with exceptionally rapid urbanization, we
309 progressively excluded countries with urbanization growth exceeding 40% (5 countries) and
310 30% (11 countries) over the sample period. As reported in Table 8, the urbanization coefficient
311 remains negative and statistically significant at the 1% level across all specifications. Notably,
312 the magnitude of the coefficient increases consistently from -0.439 in the full sample to -0.529
313 after excluding the first group, and further to -0.930 after the second exclusion. This pattern
314 indicates that the negative association between urbanization and plant-based protein
315 consumption is not only robust but becomes stronger when high-growth countries are removed.
316 These results confirm that our main finding is not driven by a few exceptional cases, and that
317 in high-income countries with more gradual urbanization, the shift away from plant-based diets
318 toward animal-based protein sources is even more pronounced.

319 **Table 8.** The results of urbanization after excluding rapid-urbanization countries.

Model	Sample	Coef. (DKSE)
Base	52 high income countries	-0.439^{***} (0.055)
1	47 high income countries Excluding 5 countries with urbanization growth > 40%	-0.529^{***} (0.051)
2	41 high income countries Excluding 5 countries with urbanization growth > 30%	-0.930^{***} (0.120)

321 Driscoll-Kraay standard errors are presented in parenthesis. *** $p < 0.01$.

322 Source: Research findings.

323
324 This study shows that animal proteins consumption has negative and significant effect on plant-
325 based proteins consumption. A one percent increase in the consumption of animal proteins
326 reduces the plant-based consumption by 0.041 percent. The negative and significant coefficient
327 of animal protein consumption suggests a negative conditional correlation between animal and
328 plant protein intake, after controlling for other determinants. This pattern is consistent with a
329 substitution mechanism. This means animal proteins are substitutes of plant-based proteins and
330 are the main barrier of plant-based consumption. Our findings imply that the negative effect of
331 animal proteins is higher in low- and middle-income nations compared to all countries sample.
332 A one percent increase in animal proteins consumption significantly reduces the consumption
333 of plant-based foods by 0.055 percent. It is worth noting that in a number of low- and middle-
334 income countries, people who do not have high income control their food consumption. This
335 suggests that the reduction in animal protein consumption and the increase in plant-based food

336 consumption is not driven by health consciousness, and the main reason for the low
337 consumption of animal proteins in a large part of society is the reduced economic access to
338 animal proteins due to low income.

339 Our findings show that internet access play a significant role in increasing plant-based food
340 consumption. A one percent increase in internet users increase the plant-based consumption by
341 0.015 percent. Internet access contributes to increase people's awareness regarding the
342 nutritious foods and balanced diets. Nutritional knowledge plays an important role in shaping
343 eating habits and behaviours. On the other hand, internet access improves the physical and
344 economic access to healthy foods through direct connecting with farmers and buying from
345 online food stores. This result is consistent to previous findings (Deng et al., 2024; Ayanwale
346 and Kehinde, 2025), which revealed that internet access has significantly increased people's
347 dietary quality and food security. The results implied that internet access has a greater effect in
348 high-income nations compared to low- and middle-income ones. Developed internet
349 infrastructure in high-income countries play an important role in increasing the effect of the
350 internet on people in these societies.

351 Our findings demonstrate that globalization has a significantly positive influence on the plant-
352 based proteins consumption. A one percent increase in globalization increases people's
353 consumption by 0.182 percent, implying that globalization is a major driver of healthy and
354 nutritious foods. Increasing interdependence and integration among societies, cultures, and
355 economies of different nations lead to healthy diet and sustainable food systems. Additionally,
356 we find similar findings in both income-level countries; however, the effect of globalization is
357 greater in high-income nations. In this regard, Dithmer and Abdulai (2017) found that food
358 security was significantly increased by globalization at the global level. Abbas et al. (2025)
359 highlighted that globalization significantly mitigates the adverse impacts of population growth
360 and climate variability on Pakistan's food security.

361 **Robustness checks**

362 **To ensure the reliability of our main findings, we conducted a series of robustness checks**
363 **addressing potential concerns related to extreme observations, dynamic specification, reverse**
364 **causality, non-linearity, and regional heterogeneity. The results confirm that our main findings**
365 **remain consistent across all alternative specifications (Tables 9-14). We discuss each**
366 **robustness check in detail below.**

368 As an additional robustness check, we Winsorized the dependent variable at the 1st and 99th
 369 percentiles to assess whether extreme observations influence the results (Table 9). The re-
 370 estimated coefficients remained consistent with the baseline model in terms of both sign and
 371 statistical significance, further confirming the stability of our main findings.

372

373 **Table 9.** Robustness check after Winsorization of dependent variable (1st and 99th
 374 percentiles).

Variable	All countries	Low- and middle-income countries	High-income countries
LnGDP	0.050*** (0.008)	0.098*** (0.011)	-0.110*** (0.022)
LnINF	-0.005* (0.003)	-0.005* (0.003)	-0.003 (0.004)
LnP65	0.074*** (0.017)	0.064** (0.021)	0.077*** (0.027)
POPG	-0.004 (0.002)	-0.011 (0.007)	0.004 (0.003)
LnURB	-0.019 (0.034)	-0.009 (0.035)	-0.442*** (0.054)
LnANP	-0.036*** (0.011)	-0.055*** (0.009)	0.043 (0.059)
LnINT	0.014*** (0.004)	0.013** (0.005)	0.021*** (0.005)
LnGL	0.176*** (0.037)	0.131* (0.061)	0.404*** (0.092)
Constant	2.641*** (0.230)	2.592*** (0.308)	4.514*** (0.331)
F-statistics	706.21***	419.64***	84.92***

375 Driscoll-Kraay standard errors are presented in parenthesis. *** p < 0.01, ** p < 0.05, * p < 0.10.

376 Source: Research findings

377

378 To examine whether the negative effect of GDP per capita on plant-based protein consumption
 379 in high-income countries is driven by a few exceptionally wealthy countries, we Winsorized
 380 the GDP per capita variable at the 1st and 99th percentiles and re-estimated the model. As
 381 shown in Table 10, the coefficient remains negative (-0.110) and statistically significant at the
 382 1% level, which is very close to the original estimate. This confirms that our finding is not
 383 driven by a few extreme observations and that the negative association between income and
 384 plant-based protein consumption is a robust pattern across high-income countries.

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392 **Table 10.** Robustness check after Winsorization of GDP variable (1st and 99th percentiles).

Variable	All countries	Low- and middle-income countries	High-income countries
LnGDP	0.046*** (0.008)	0.098*** (0.011)	-0.110*** (0.022)
LnINF	-0.005* (0.003)	-0.005* (0.003)	-0.003 (0.004)
LnP65	0.078*** (0.017)	0.064** (0.021)	0.077*** (0.027)
POPG	-0.003 (0.002)	-0.011 (0.007)	0.004 (0.003)
LnURB	-0.036 (0.031)	-0.009 (0.035)	-0.442*** (0.054)
LnANP	-0.040*** (0.012)	-0.055*** (0.009)	0.043 (0.059)
LnINT	0.015*** (0.004)	0.013** (0.005)	0.021*** (0.005)
LnGL	0.187*** (0.039)	0.131* (0.061)	0.404*** (0.092)
Constant	2.700*** (0.039)	2.592*** (0.308)	4.514*** (0.331)
F-statistics	550.30***	419.64***	84.92***

393 Driscoll-Kraay standard errors are presented in parenthesis. *** p < 0.01, ** p < 0.05, * p < 0.10.

394 Source: Research findings.

395

396 To account for the dynamic nature of dietary patterns and reduce omitted variable bias, we
 397 included the one-period lag of the dependent variable as a regressor (Table 11). The main
 398 results remained largely unchanged in terms of sign and significance. This suggests that our
 399 findings are robust to controlling for past levels of plant-based protein consumption.

400

401 **Table 11.** Robustness check with lagged dependent variable.

Variable	Coefficient	DKSE	t	p-value
L.LnPBP	0.850	0.057	14.93	0.000
LnGDP	0.016	0.007	2.51	0.021
LnINF	-0.001	0.001	-0.87	0.396
LnP65	0.008	0.007	1.18	0.254
POPG	-0.002	0.001	-2.34	0.030
LnURB	-0.025	0.014	-1.84	0.080
LnANP	-0.016	0.004	-4.58	0.000
LnINT	0.003	0.001	3.49	0.002
LnGL	0.009	0.016	0.54	0.592
Constant	0.529	0.159	3.32	0.003
F-statistics		1007.29***		

402 *** p < 0.01

403 Source: Research findings.

404

405 To mitigate potential reverse causality concerns, we re-estimated the model using one-period
 406 lags of all independent variables (Table 12). The coefficients of the main variables of interest
 407 remained consistent with the baseline results. This provides further evidence that the direction
 408 of the estimated relationships is not driven by simultaneity.

409

410

411

Table 12. Robustness check with lagged independent variables.

Variable	Coefficient	DKSE	t	p-value
L.LnGDP	0.048	0.009	5.520	0.000
L.LnINF	-0.004	0.003	-1.350	0.193
L.LnP65	0.076	0.017	4.550	0.000
L.POPG	-0.004	0.003	-1.300	0.207
L.LnURB	-0.047	0.029	-1.640	0.117
L.LnANP	-0.042	0.009	-4.570	0.000
L.LnINT	0.015	0.004	3.860	0.001
L.LnGL	0.181	0.039	4.670	0.000
Constant	2.774	0.225	12.330	0.000
F-statistics			600.74***	

412 *** p < 0.01

413 Source: Research findings.

414

415 To test for a potential non-linear relationship between income and plant-based protein
 416 consumption, we added a quadratic term of GDP per capita to the model (Table 13). The
 417 coefficient of the squared term was negative and statistically significant, indicating an inverted
 418 U-shaped relationship. This suggests that at lower income levels, plant-based protein
 419 consumption increases with GDP, but after a certain threshold, further economic growth is
 420 associated with a decline. This finding aligns with the nutrition transition literature, where
 421 rising incomes initially improve dietary quality but later shift consumption toward more
 422 animal-based products.

423

424

Table 13. Robustness check with quadratic term of GDP.

Variable	Coefficient	DKSE	t	p-value
LnGDP	0.295	0.076	3.900	0.001
LnGDP ²	-0.015	0.004	-3.300	0.003
LnINF	-0.006	0.003	-2.020	0.056
LnP65	0.097	0.015	6.350	0.000
POPG	-0.003	0.002	-1.180	0.252
LnURB	-0.048	0.031	-1.560	0.134
LnANP	-0.040	0.011	-3.530	0.002
LnINT	0.012	0.004	2.960	0.008
LnGL	0.182	0.041	4.450	0.000
Constant	1.714	0.414	4.140	0.000
F-statistics			769.80***	

425 *** p < 0.01

426 Source: Research findings.

427

428 To control for unobserved regional heterogeneity, we included dummy variables for five
 429 continents, with Asia as the base category (Table 14). The coefficients for Europe, Africa,
 430 America, and Oceania were all negative and statistically significant. This indicates that,
 431 compared to Asia, all other regions have significantly lower levels of plant-based protein
 432 consumption, even after controlling for other determinants. This finding highlights the unique

433 dietary patterns in Asia, where plant-based proteins (e.g., soy, legumes) have historically
434 played a more central role in food culture.

435

436

Table 14. Robustness check with regional dummies.

Variable	Coefficient	DKSE	t	p-value
LnGDP	0.295	0.076	3.900	0.001
LnINF	-0.006	0.003	-2.020	0.056
LnP65	0.097	0.015	6.350	0.000
POPG	-0.003	0.002	-1.180	0.252
LnURB	-0.048	0.031	-1.560	0.134
LnANP	-0.040	0.011	-3.530	0.002
LnINT	0.012	0.004	2.960	0.008
LnGL	0.182	0.041	4.450	0.000
Europe	-0.314	0.047	-6.760	0.000
Africa	-0.105	0.037	-2.850	0.009
America	-0.413	0.030	-13.920	0.000
Oceania	-0.728	0.051	-14.190	0.000
Constant	1.714	0.414	4.140	0.000
F-statistics		769.80***		

437 *** p < 0.01

438 Source: Research findings

439

440 **CONCLUSIONS**

441 This study used cross-country panel data to analyze the main determinants of plant-based
442 proteins consumption across 165 countries during 2001–2022. Using a fixed effects panel
443 model with Driscoll–Kraay standard errors, which identifies within-country associations rather
444 than causal relationships, we report the following empirical findings. Income, population aging,
445 internet access, and globalization are positively associated with plant-based protein
446 consumption, while inflation and animal protein consumption show negative associations. The
447 income-level heterogeneity analysis suggests that population growth is negatively associated
448 with plant-based consumption in low- and middle-income countries, whereas in high-income
449 countries, income and urbanization show negative associations. Robustness checks including
450 Winsorization, lagged dependent variable, lagged regressors, a quadratic GDP term, and
451 regional dummies confirm the stability of these associations. Notably, an inverted U-shaped
452 relationship between income and plant-based consumption emerged, and Asian countries
453 exhibit significantly higher consumption compared to other continents.

454 Several limitations should be considered when interpreting these findings. First, the plant-based
455 protein indicators derived from FAO data rely on supply-side availability measures rather than
456 actual individual-level consumption, which may introduce measurement error. Second, despite
457 including a rich set of controls, potential endogeneity may arise from omitted variables such as
458 education levels, food prices, and cultural factors, as well as from reverse causality between

459 GDP, internet access, globalization, and dietary patterns. Third, the macro-level, cross-country
460 nature of the data limits our ability to capture within-country heterogeneity across regions,
461 income groups, or demographic segments. Therefore, the results should be interpreted as
462 associations rather than causal effects. With these caveats in mind, some broad policy
463 directions can be suggested. In low- and middle-income countries, where economic growth is
464 positively associated with plant-based consumption, policies that support income growth and
465 price stability may contribute to improved dietary quality. In high-income countries, where
466 income and urbanization show negative associations, public health strategies could focus on
467 raising awareness about the health and environmental benefits of plant-based diets, tailored to
468 local cultural contexts. Regarding internet access, although it is positively associated with
469 plant-based consumption, policymakers should be cautious about potential negative
470 externalities, such as increased exposure to unhealthy food marketing. Finally, the regional
471 differences suggest that culturally sensitive dietary interventions may be more effective than
472 one-size-fits-all approaches.

473

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