Ecological Study of the Impact of National Food Availability on the Epidemiology of National Cardiovascular Mortality

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Abstract: ***An ecological study investigates the relationship between national food supply and cardiovascular disease (CVD) mortality across high, upper-middle, and lower-middle-income countries. Using WHO and FAO data, the study applies linear and multivariate regression analyses to explore associations between dietary variables and CVD mortality. The findings reveal a significant positive association between animal food sources and CVD mortality, while vegetable food variables show no significant correlation. The study concludes that increasing animal food supply contributes to higher national CVD mortality, offering insights for public food policy adjustments***

Keywords: Cardiovascular disease, national food supply, public health nutrition, ecological study, dietary patterns

1. Introduction

Cardiovascular disease (CVD) is a non-communicable disease (NCD) that includes a spectrum of coronary, cerebrovascular, and peripheral vascular diseases.[1] CVD is considered a leading cause of death globally.[2] In 2008, CVD accounted for approximately 50% of NCD deaths and 30% of global overall mortality. CVD is considered one of the most important causes of disability, resulted in approximately 151 million Disability-Adjusted Life Years (DALYs) in 2008 [3] and represented 10.3% of the global disease burden in 1998.[4] Food represents an influential layer of social determinants of health that have an influential effect on CVD epidemiology.[5] A gap in knowledge about the relationship between cardiovascular mortality and food at the country level aiming to achieve a better understanding of the impact of food supply at the national level rather than to inform about harmful individual nutritional choices.

Research Question

Is there an association between the epidemiology of national CVD mortality and food availability?

Aims

To explore the effect of the national food supply policy on the epidemiology of CVD mortality.

Objectives

1) To review the available literature on CVD mortality and food production policy to identify the existing gap in knowledge.
2) To formulate recommendations for healthy public food supply policies.

Study Design: Ecological study using secondary data.

Study Setting and Population: The study setting was limited to high-, upper-middle-, and lower-middle-income countries. Firstly, it aims to eliminate the major effect of poverty in such a low-income context. Secondly, the role of poverty in high-income countries regarding population health is minor and depends on the magnitude of the population living in poverty.[7]

Sample Frame: High, upper, and lower-middle-income countries based on gross national income (GNI).[8]

Sample Size: it was calculated using the following equation: $n = [z^2\ p(1\text{-}p)/\ e^{\ 2}]$, where (n) is the sample size, (z) is a standard error at a particular type I error, (P) is the expected population proportion of a particular characteristic and (e) is the absolute error. The standard error was defined at 5% type I error ($P< 0.05$) to equal 1.96, while type II error was set at 10% (study power 90%).[6] Global CVD mortality is estimated at 31% of the total global deaths.[2] From the above-mentioned equation, the sample size was estimated to be 21 countries. 20% will be added to replace any missing values, making a sample size to be about 26 countries. Hence, each stratum will include a total number of 9 countries (Table 1).

Table 1: Selected countries

High-income countries	Upper-middle income countries	Lower-middle income countries
Australia	Albania	Angola
Brunei	Belarus	Cameroon
Darussalam	Chile	Djibouti
Hong Kong	Dominican Republic	Ghana
Japan	Jordan	India
New Zealand	Lithuania	Mauritania
Republic of Korea	Namibia	Pakistan
Sweden	Serbia	Sao Tome and Principe
United States of America	Tunisia	Syrian Arab Republic

Sampling Method: Stratified sampling was conducted among clusters of high, upper-middle, and lower-middle-income countries.[9] Countries were selected systematically by assigning a serial number to each country, which is already arranged alphabetically in each economic stratum.[10] Every third number was chosen until the required sample size was achieved.

Inclusion Criteria: High-, upper-middle-, and lower-middle-income countries with complete required secondary data.

Exclusion Criteria: Low-income countries and countries with missing data.

Data Collection: National CVD mortality was obtained from WHO data published in 2014 as the proportional mortality of national total deaths in both sexes over a period of 12 years from the year of 2000 [11] using the WHO standard population (an approach that builds the standard by comparing the average age structure of the different populations, using census, to that of the world over some time).[12] National food availability variables were collected using the FAO balance sheet published for the period between 2005 and 2009, [Appendix 1] covering the total food supply, protein supply quantity, and fat supply quantity for both animal and vegetable sources, in addition to the average dietary supply adequacy (Table 2).

Table 2: Food supply and unit of measurement

Factor	Unit of measurement
1. National CVD mortality	Proportion (%) of national CVD mortality from national total deaths [12]
2. Total vegetal food supply	kilocalories (Kcal)/capita/day
3. Total animal food supply	kcal/capita/day
4. Vegetal Protein supply quantity	Gram/capita/day
5. Animal Protein supply quantity	Gram/capita/day
6. Vegetal fat supply quantity	Gram/capita/day
7. Animal fat supply quantity	Gram/capita/day
8. Average dietary supply adequacy index	Proportion (%) of Dietary Energy Supply relative to the Average Dietary Energy Requirement in the country.

Analysis Approach: The average of all food availability variables was calculated between 2005 and 2009 using Excel program. All variables were analyzed in a continuous form of data. Using a histogram, the distribution of study variables was described in all included countries either in the form of mean and standard deviation or median and interquartile range with confidence intervals if data were normally or skewed, respectively. The skewed data were transformed using a suitable mathematical tool to obtain a normal distribution. The relationship between CVD mortality and independent food availability variables were examined subjectively using scatter plots and objectively using linear regression. All food availability variables associated significantly with CVD mortality were included and assessed by multivariate regression. [6]

Ethics: The study is dealing with an online published secondary data about non-sensitive public subjects.

Funding: Expenses for stationaries and internet connection were paid by the researcher.

Competing Interest: No competing interest.

2. Result

Descriptive analysis (Table 3, Table 4) [Appendix 2]

Dependent variable (CVD mortality)
National CVD mortality ranged from 63% in Belarus to 9% in Angola. The mean value of national CVD mortality in this study was 31.7% of national total deaths. The trend of national CVD mortality appears clearly when assessing this variable according to economic status. The highest mean value was reported in the upper-middle income group (44.11%), followed by the high-income group (31.86%), and finally by the lower-income group (15.57%). The range below the lower (first) quartile (19%) for national CVD mortality included Ghana, Djibouti, Mauritania, Cameroon, and Angola, all belong to the lower-middle income class. Most high-income countries were included in the lower and upper quartiles. Belarus, Albania, Serbia, Lithuania, and Tunisia, which are upper-middle-income countries were above the third quartile (41%).

Vegetable food supply
Most of the food availability variable data were normally distributed, except for vegetable protein supply and vegetable fat supply quantity variables. The mean value of the Total vegetable food supply was 2272.7 kilo-calorie/ capita per day. Vegetable protein and fat supply data showed a skewed distribution. The median value for vegetable protein supply was 40.9 grams/ capita per day, while the median value of vegetable fat supply was 45.9 grams/ capita/ day.

Animal food supply
The mean value of the Total animal food supply was 577.4 kilo-calorie/ capita/ day. The mean value of animal protein supply was 39.7 grams/capita per day, while the mean value of animal fat supply was 39.7 grams/capita/day.

Lower-middle-income countries lie below the lower quartile for total animal food supply (298.3 kilo-calorie/capita/day), animal protein supply (21.19 grams/capita/day), and animal fat supply (19.22 grams/capita/day).

In contrast, the high-income class was located above the upper quartile for total animal food supply (926.5 kilo-calorie/capita/day), animal protein supply (53.75 grams/ capita/ day) and animal fat supply (61.7 grams/ capita/ day).

Average dietary supply adequacy

The mean value of dietary supply adequacy (dietary energy supply to the average dietary energy) was 119.4% with a range between 98% in Namibia and 149% in the USA. USA, Lithuania, Tunisia, Jordan, the Republic of Korea, and New Zealand were found above the upper quartile (127.75%) while Namibia, Djibouti, Dominican Republic, Angola, India, and Cameroon were located in the range below the lower quartile of dietary supply adequacy (106.25%)

Table 3: Descriptive analysis of variables by countries

Country	National CVDs mortality from overall national mortality %	Total vegetable food supply K.calorie/ capita/day	Total animal food supply K.calori/ capita /day	Animal protein supply quantity Gram/ capita/ day	Vegetable protein supply quantity Gram/ capita/ day	Animal fat supply quantity Gram/ capita/ day	Vegetable fat supply quantity Gram/ capita/ day	Average dietary supply adequacy %
Belarus	63	2302.80	815.40	50.72	40.20	58.43	54.28	123.00
Albania	59	2023.80	860.60	49.77	48.06	58.82	33.31	117.00
Serbia	54	2092.00	622.00	35.98	42.85	44.31	37.59	109.00
Lithuania	54	2496.00	992.40	74.35	49.14	64.57	35.78	141.00
Tunisia	49	2930.00	348.60	25.15	67.07	21.26	67.05	137.00
Sweden	41	2073.00	1044.20	71.78	36.11	70.47	54.29	122.00
Dominican Republic	35	1974.20	394.40	27.67	26.87	26.99	55.03	102.00
Jordan	35	2732.60	384.20	27.70	53.54	25.68	66.69	137.00
Brunei Darussalam	34	2355.80	577.60	45.39	38.98	34.14	45.94	127.00
New Zealand	32	2163.80	1005.20	56.78	36.38	81.48	37.16	128.00
Australia	31	2167.60	1016.60	69.02	35.65	73.17	70.30	127.00
USA	31	2715.00	1034.80	73.67	40.37	70.81	92.02	149.00
Japan	29	2199.80	565.40	49.90	40.21	34.48	53.97	116.00
Chile	27	2229.40	704.80	43.54	42.11	53.42	32.25	122.00
India	26	2161.60	207.20	10.99	45.73	13.81	36.02	104.00
Republic of Korea	25	2639.00	511.00	41.63	49.00	35.83	56.46	128.00
Namibia	21	1834.20	336.60	24.17	38.46	22.74	29.41	98.00
Pakistan	19	1912.40	489.80	24.60	37.17	34.03	38.09	107.00
Ghana	18	2672.60	130.40	15.99	40.93	6.19	40.70	124.00
Djibouti	14	2120.40	260.00	18.21	42.20	17.18	48.72	100.00
Mauritania	12	2248.40	471.00	31.88	47.85	28.52	44.95	121.00
Cameroon	11	2256.80	139.40	12.76	51.29	8.58	43.65	106.00
Angola	9	1990.60	192.60	14.59	33.65	13.75	33.31	103.00
Hong Kong		2085.60	1157.00	80.48	34.43	83.14	52.84	
Sao Tome and Principle	-	2440.20	174.20	16.47	43.01	9.80	64.52	117.00
Mean (SD)	31.7% (15.6)	2272.7 (284.7)	577.4 (329.8)	39.7 (21.8)	-	39.7 (24.4)	-	119.4 (13.8)
Median (IQR)	-	-	-	-	40.9(36.8-48)	-	45.9 (36.6-55.7)	-

High-income countries Upper-middle income countries Lower-middle income countries

Inference analysis

Simple linear regression

National CVD mortality and total animal food supply (Figure 1)

A scatter plot of the data showed evidence of a weak positive relationship between national CVD mortality and the total animal food supply. This relationship was confirmed objectively by simple linear regression analysis, in which the association was evaluated to a relatively moderate degree (R= 0.58).[13] The model anticipated that the total animal food supply accounts for one-third (33.4%) of the total CVD mortality. An increase of one kilo-calorie/capita/day in total animal food supply is expected to result in a 2.9% rise in national CVD mortality.[14] This estimate of the regression coefficient value was significant (p=0.004) but with a wide 95% confidence interval ranging between 3.1 and 27.16, indicating a less precise estimate.[6] The F value of the test was 10.5, which is significant at a p-value of 0.04, indicating that the regression model has resulted in a better prediction of national CVD mortality than using the CVD mortality mean value alone and the possible probability of obtaining this result by chance is less than 5%.[15]

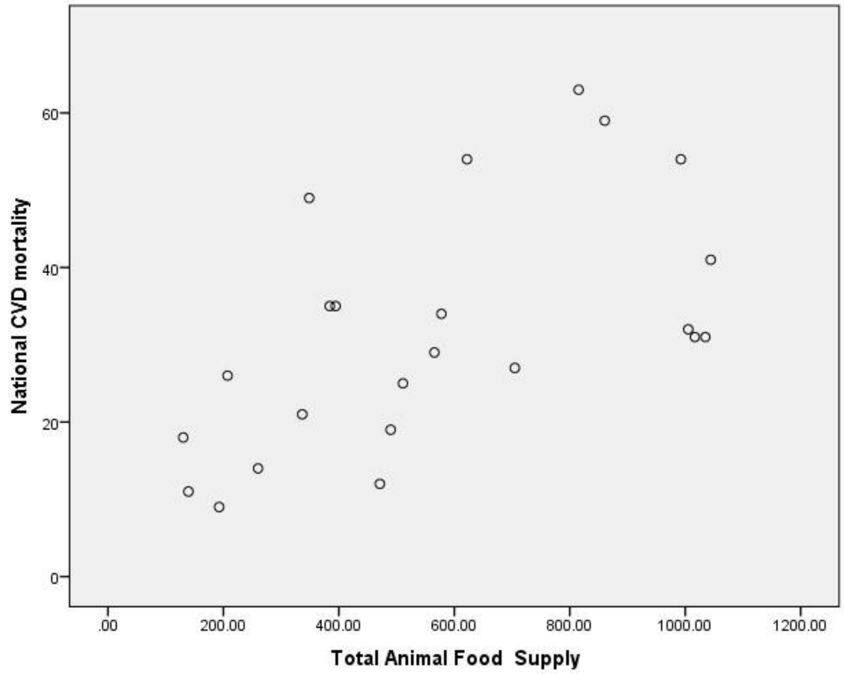

Figure 1: Scatter plot of national CVD mortality and total animal food supply.

National CVD mortality and animal protein supply quantity (Figure 2)

Evidence of a positive relationship between national CVD mortality and animal protein supply is shown in a scatter plot. The R-value of the simple linear regression model is 0.53. This result indicates a moderately positive association between the predictor and dependent variables. 28% of national CVD mortality was explained by the effect of animal protein supply quantity. The model expected that with every increase in animal protein supply quantity by one gram/ capita/day national CVD mortality will increase by 0.4%. The regression coefficient estimate of the two variables was significant (p=0.009) with a 95% confidence interval of 0.1 to 0.7%.[6] This narrow range points to a precise estimate of coefficient value.[13] The model also showed a better prediction of national CVD mortality than its mean, as the F value of the test was 8.16 as well as it was significant at a P-value of 0.009. [14]

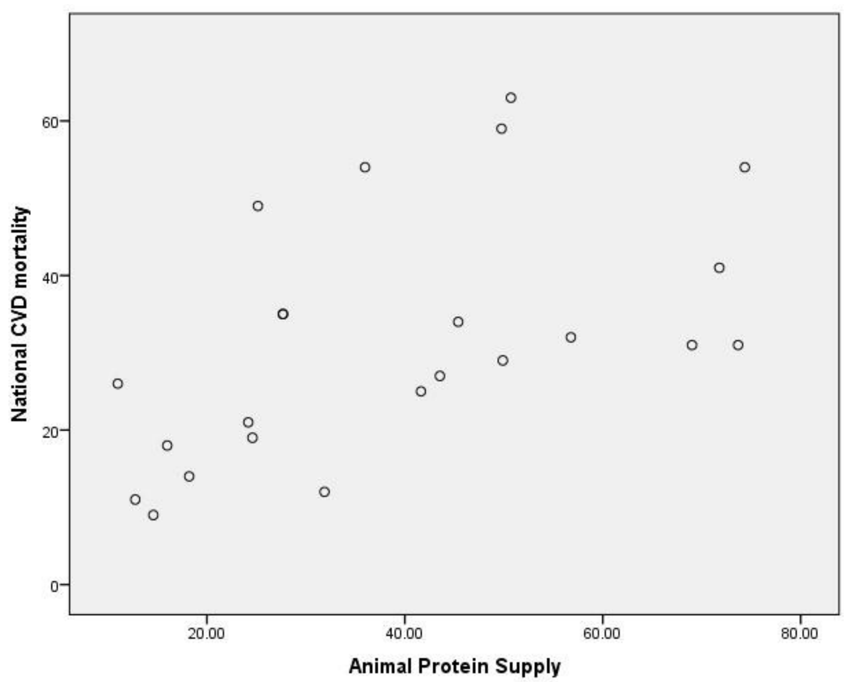

Figure 2: Scatter plot of national CVD mortality and animal protein supply quantity

National CVD mortality and animal fat supply quantity (Figure 3)

Subjectively, evidence of a positive association was found between national CVD mortality and animal fat supply in the scatter plot graph. This relationship was confirmed statistically using simple linear regression analysis as a moderate positive relationship, since the Pearson coefficient value (R) of the test was 0.547. The R-squared value of the test was 0.299, which means that animal fat supply quantity is responsible for 29.9% of all national CVD mortality. The model also anticipated significantly (p=0.007) that every increase in animal fat supply quantity by one gram/ capita/day would result in about a 0.4 % increase in national CVD mortality. The test makes investigators 95% sure that the true value of the regression coefficient lies between 0.11 and 0.63. The F value of the test was significant (p=0.007) and equal to 8.976. This means that the simple regression model is more powerful in predicting national CVD mortality than the mean value for the dependent variable.[15]

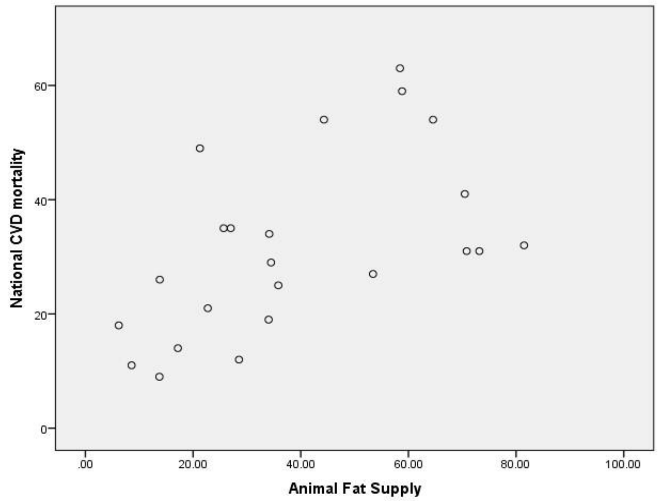

Figure 3: Scatter plot of national CVD mortality and animal fat supply quantity

Effect of vegetable food supply and dietary supply adequacy on National CVD Mortality

All of the total vegetable food supply quantity (Supplemental material 1), vegetable protein supply quantity (Supplemental material 2), vegetable fat supply quantity (Supplemental material 3), and average dietary supply adequacy (Supplemental material 4) showed an insignificant positive relationship with national CVD mortality because the 95% confidence interval of the regression coefficient included zero and the P value of the test was above 0.05.

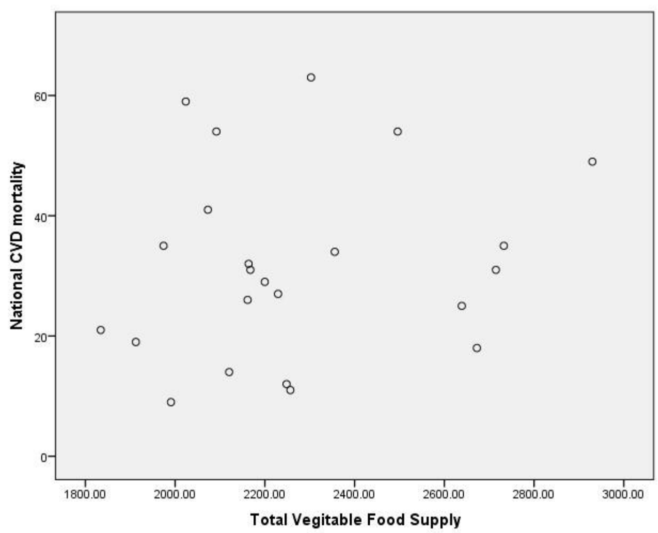

Figure 4: Scatter plot of national CVD mortality and total vegetable food supply

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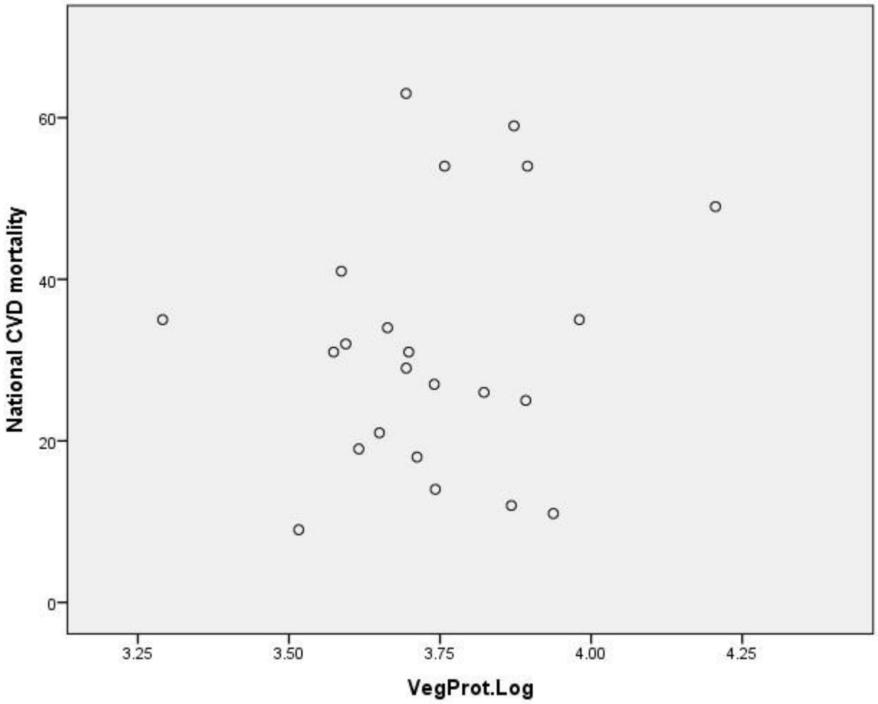


Figure 5: Scatter plot of national CVD mortality and vegetable protein supply quantity

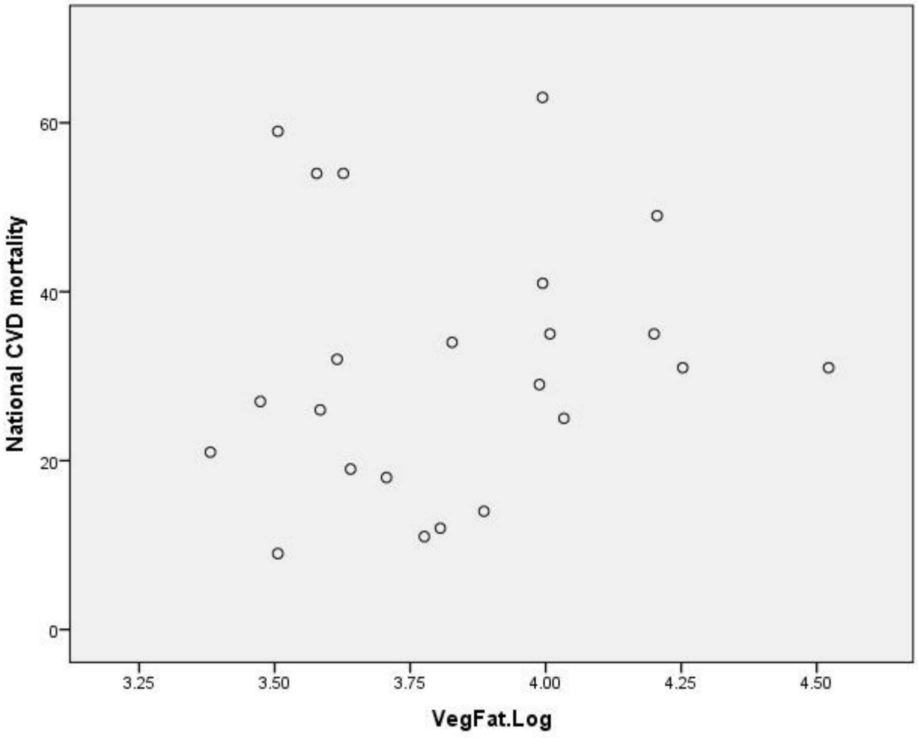


Figure 6: Scatter plot of national CVD mortality and vegetable fat supply quantity

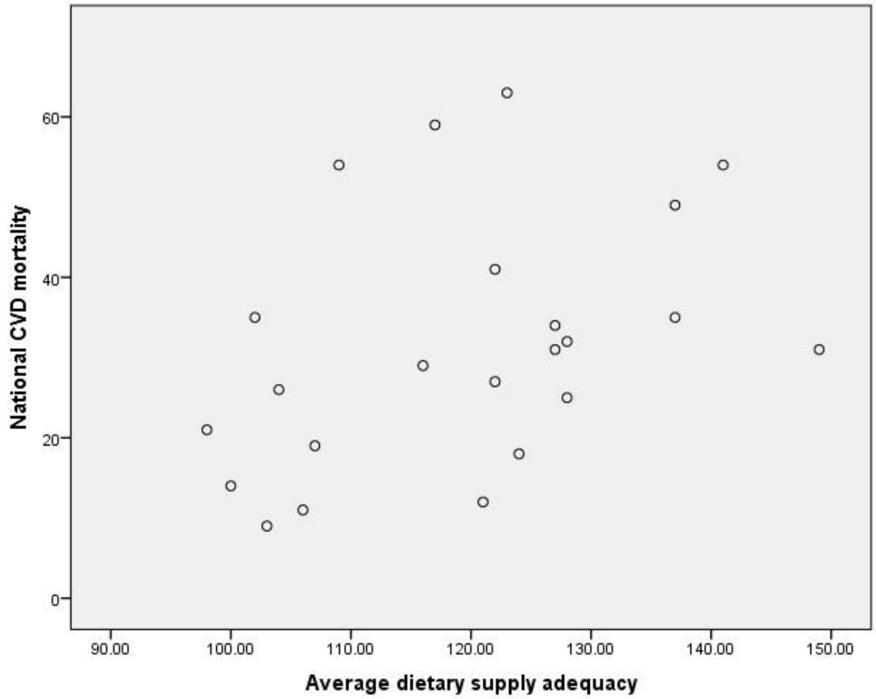


Figure 7: Scatter plot of national CVD mortality and average dietary supply adequacy

Multivariate regression analysis (Table 5) [Appendix 3]

Multivariate regression analysis included all food availability variables that were significant and influential on the national CVD mortality. The included variables were exclusive to animal sources, including total animal food supply, animal protein supply quantity, and animal fat supply quantity. The correlation coefficient of the regression model was 0.659; therefore, a relatively strong positive association was found between the national CVD mortality and all animal food availability variables.[14] The Squared R-value of the model was 0.435, which means that the model explained 44% of the whole national CVD mortality. However, 56% of national CVD mortality is explained by other factors. The model resulted in a significantly better national CVD mortality prediction than its mean value, as the F value of the test was 4.869 with a significant P value of 0.011. In this model, for every increase in total animal food supply by one kilo-calorie/capita/day, national CVD mortality will increase by 0.23% when all other variables in the test are fixed. Animal protein and fat supply quantity variables showed a negative relationship with national CVD mortality; however, they were no longer significant as the P value of the correlation coefficient for both of them was above 0.05 and the 95%confidence interval of the two variables included zero. [6]

Table 4 (A): Multivariate regression analysis- Model summary

Model	R value	Squared R value	F value	F value Significance
Multiple linear regression	0.659	0.435	4.869	0.011

Table 4 (B): Multivariate regression analysis- Correlation coefficient table

	Person correlation coefficient (B)	Standardized coefficient (Beta)	Significance	95% Confidence interval for B	
				Lower bound	Upper bound
(Constant)	13.59		0.03	1.19	25.99
Total animal food supply	0.23	4.54	0.049	0.001	0.46
Animal protein supply	-1.04	-1.36	0.13	-2.4	0.33
Animal fat supply	-1.84	-2.69	0.1	-4.04	0.36

3. Discussion

There is no systematic differences in the findings of the included peer-reviewed studies regarding the effect of animal food supply on CVD mortality. A population-based cohort study of 84,136 participants aged between 30 and 55 years over 26 years done in US showed a significant relationship between CVDs and red meat.[16] Abdominal and global obesity, as CVD risk factors, were positively associated with animal protein in another cohort study of 1152 participants during 14 monthly follow-up periods in Luxembourg.[17] Another population study showed that the European Common Agricultural Policy resulted in 9800 coronary heart disease deaths annually and an additional 3000 deaths due to stroke each year among European countries due to subsidizing dairy and meat production over vegetable sources of food.[18]

Countrywide Integrated Non-Communicable Disease Intervention denoted those changes in dietary habits for the North Karelia population in Finland towards less consumption of butter on bread from 90% in 1972 to less than 7% at the end of 1990s resulted in 73% decline in CVD.[19, 20] The magnitude of CVD mortality was related to the size of the fast-food supply in an ecological cross-sectional study performed in Ontario, Canada.[21] An Econometric-Epidemiologic Modelling study predicted a drop in national CVD mortality by 5% if the major source of saturated fat was reduced by 20% taxation.[22] No evidence of an ecological fallacy was found at an ecological level regarding the effect of the animal food supply on the national CVDs [23]. Similar findings have been reported in different populations, including Europe, [17, 18, 20] North America,[21, 16] and New Zealand.[22]

On the other hand, the research findings were inconsistent with other peer-reviewed studies that showed a protective effect of vegetable food on CVD. A community-based study explained the drop in national CVD mortality between 1990 and 2002 in Poland to the growing consumption of non-hydrogenated rapeseed and soybean oil.[24] In New Zealand, an Econometric-Epidemiologic Modelling study estimated that a 20% subsidy for vegetables and fruits is expected to reduce overall deaths, including CVD mortality, by 1.9% of the national annual all-cause mortality.[22] This protective effect of vegetables on CVD was also reported in several cohort studies including 40,653 volunteers with no CVD previously in 10.4 years mean follow-up period,[25] 9112 participants through 24 years follow-up,[26] 19,333 healthy participants at baseline of the study [27] and more than 100,000 participants in two large cohorts.[28] The same finding was reported in two case-control studies [29, 30] and a meta-analysis of 16 cohort studies.[31] This contradiction in the findings of the included peer-reviewed studies might result from the diverse characteristics of the different populations.

4. Strengths

The random error was reduced by increasing the number of included countries to 30% above the calculated sample size. [6] The random error was also reduced by increasing the measurements including an average of five annual measurements of different food availability variables [32] and a 3 years average dietary supply adequacy. [32] Selection bias was controlled by systematic stratified sampling to obtain a representative sample of the study population.[9] Limiting the study within high-income, upper-middle, and lower-middle-income country aiming to eliminate the major effects of poverty in terms of food insecurity and famines found in the low-income countries.[7] The involvement of the economic class of countries instead of involving certain populations provides an opportunity for wider generalizability and generating comparable evidence between different economic strata.

This study can be considered unique in studying the health impact of food at the ecological and macro-level.[34] It provides also a basis for producing public health comparative evidence at the macro level about such major health issue. [35, 34]

CVD mortality in all countries was measured as proportional mortality from total national deaths in both sexes, with age standardization over a period of 12 years.[11] Using census, this instrument used the WHO standard population approach which builds the standard by comparing the average age structure of the different populations to that of the world over time.[12] Moreover, the World Health Organization applied the Multinational Monitoring of Trends and Determinants in Cardiovascular Disease (MONICA) project in the estimation. The project is widely used by countries and involves different bodies, including the Council of Principal Investigators, a Steering Committee, a Management Center, a Data Center, Quality Control Centers, and Reference Centers for Optional Studies.[36, 37] This reflects that the included CVD mortality measurements were externally valid since different external quality controls were used in their assessment.[13]

The FAO balance sheet represents also a standardized tool for collecting information about the food supply available for consumption at an aggregated rather than individual level. Food supply was measured in grams or kilo-calories per capita per day [Appendix 1].[32] This helps to estimate national food supply at the individual level. This consistent technique results in repeatable measurements of different food supply variables [38] and a valid international comparison of food supply quantities and benchmarking generation. [39, 40]

5. Limitations

Animal and vegetable food differs in the form of carbohydrates, fats, and protein.[42] The vegetable protein supply variable failed to estimate the complete and incomplete forms of vegetable protein within and across countries.[41] Vegetable fat is also considered inconsistent in term of the nature and effects. Unlike saturated animal fat, vegetable fat includes unsaturated kind of fats, monounsaturated and polyunsaturated fats, which are considered healthy for the heart and blood vessels. It also includes saturated fat [43] and trans-fat, an industrially hydrogenated vegetable fat that are considered a cause of CVD.[44, 45] Despite the protective effect of vegetable food on CVD found in the above-mentioned peer-reviewed studies, the level of vegetable trans fats can determine the magnitude of the confounding effect of vegetable food supply on CVD mortality.[46] The ecological fallacy highlighted in the relationship between vegetable food supply and CVD mortality can be attributed to the heterogeneity of vegetable food variables rather than because of the chance.

Moreover, secondary data are prone to be incomplete or inaccurate and can vary among countries.[47] Death registers may fail to determine ill-defined mortalities or unattained deaths caused by CVD.[48] FAO Food Balance Sheet might not count all sources of food like wild animals or home and small farm [Appendix 1].[38] All these points can result in an artifact error and measurement inaccuracy. [6]

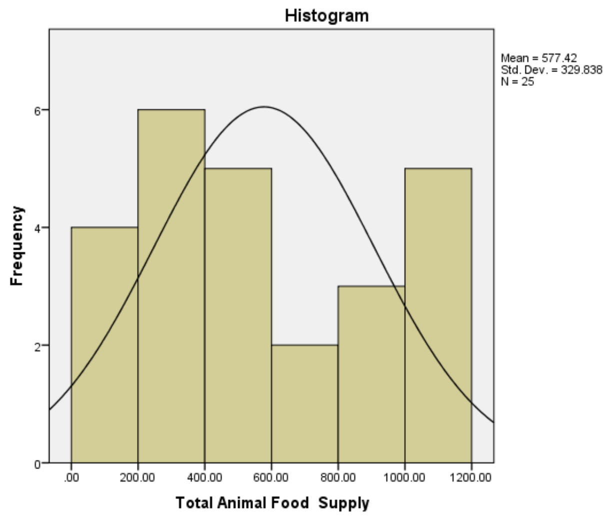
Article significance

The study provides evidence-based insights that can influence national food policies to mitigate cardiovascular mortality by promoting balanced dietary patterns

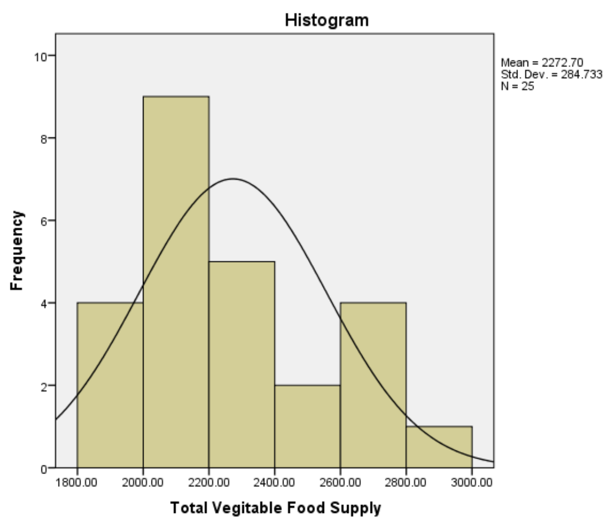
6. Conclusion

The study identifies significant associations between animal food supply and cardiovascular mortality, emphasizing the need for public policies that regulate animal-based food production and consumption. Future research should address the role of individual dietary patterns in complementing these macro-level insights

List of Supplemental Figures



Supplemental Figure 1: Distribution of Total Animal Food Supply data



Supplemental Figure 2: Distribution of Vegetable Animal Food Supply data

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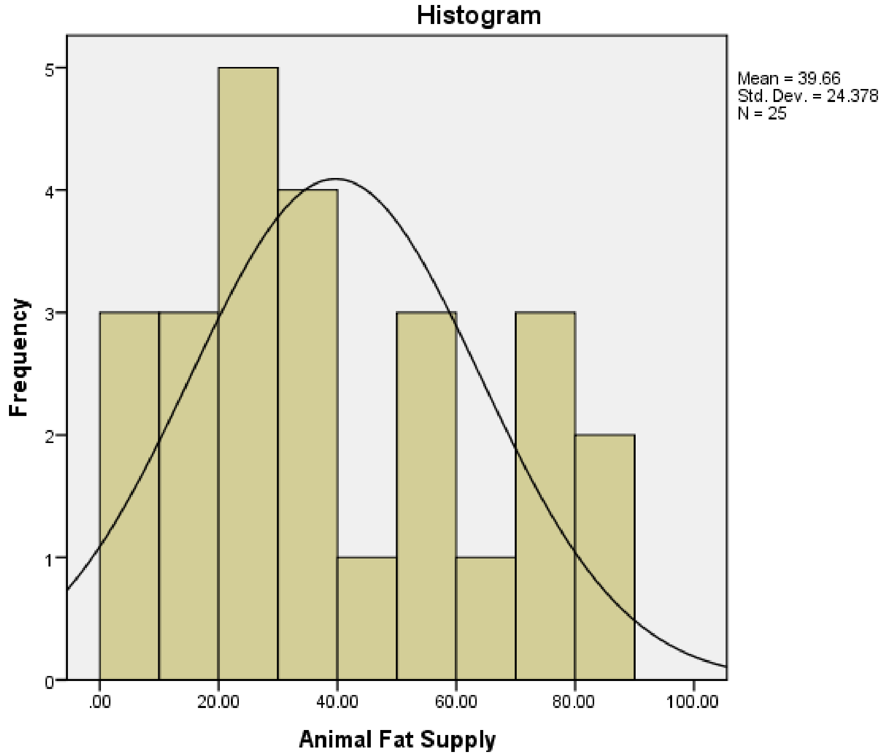
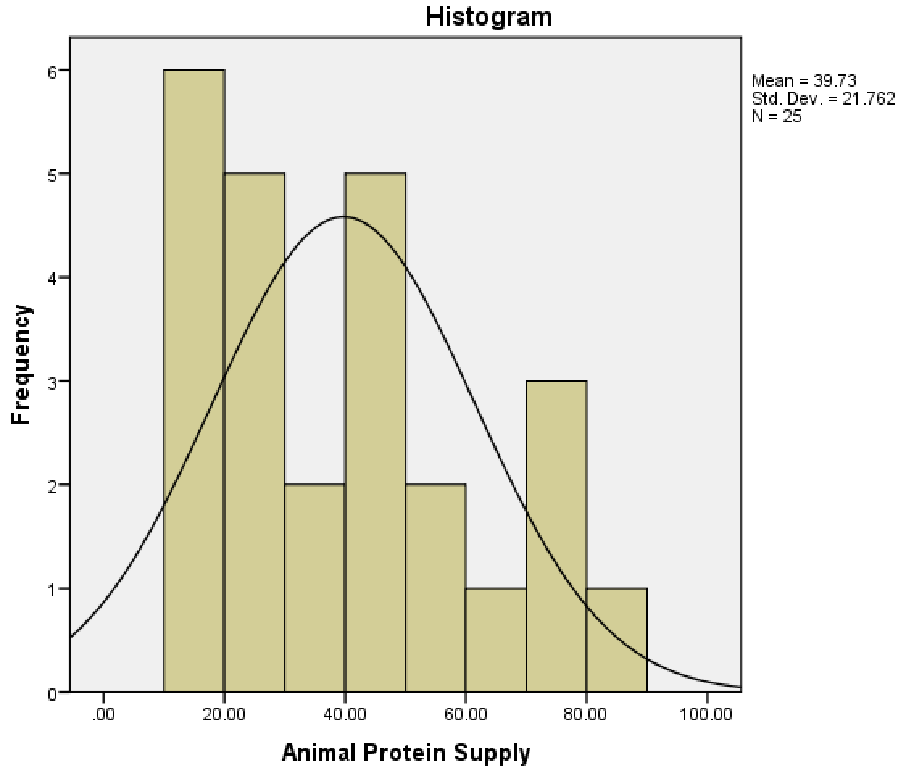
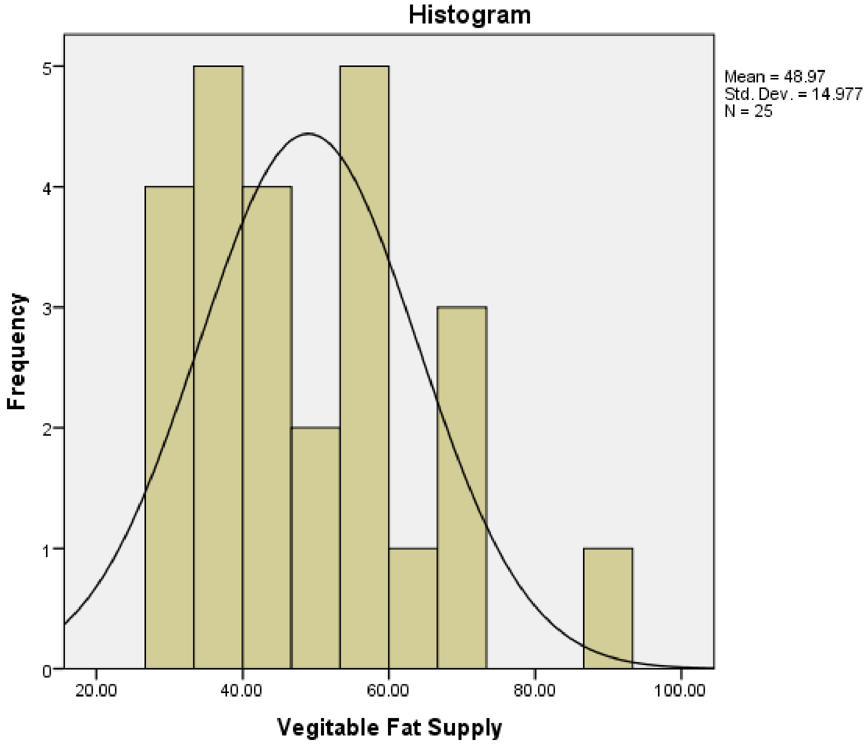


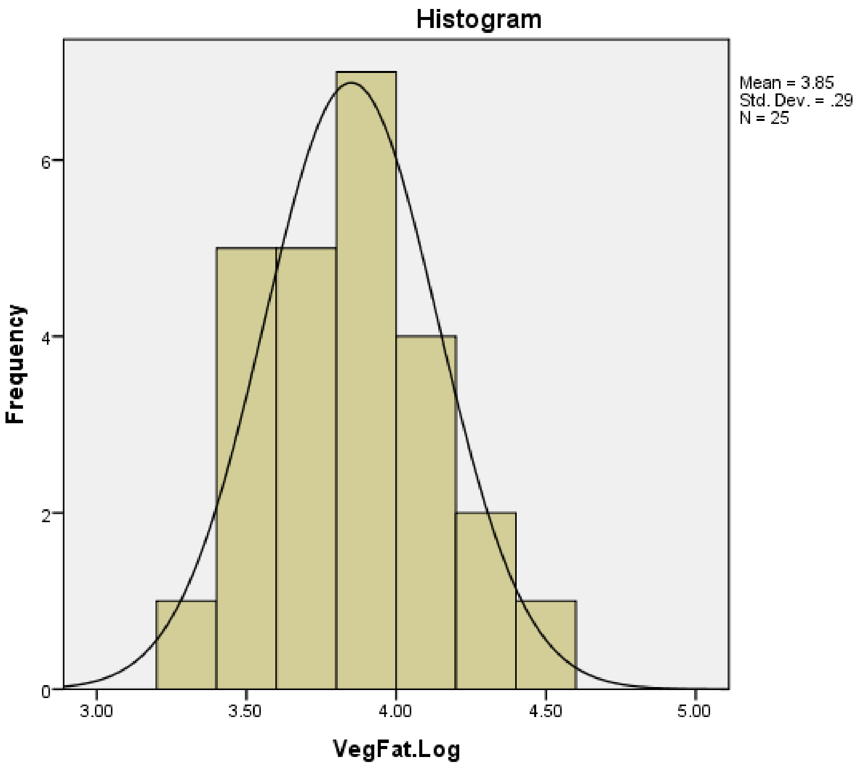
Supplemental Figure 3: Animal Fat Supply Distribution



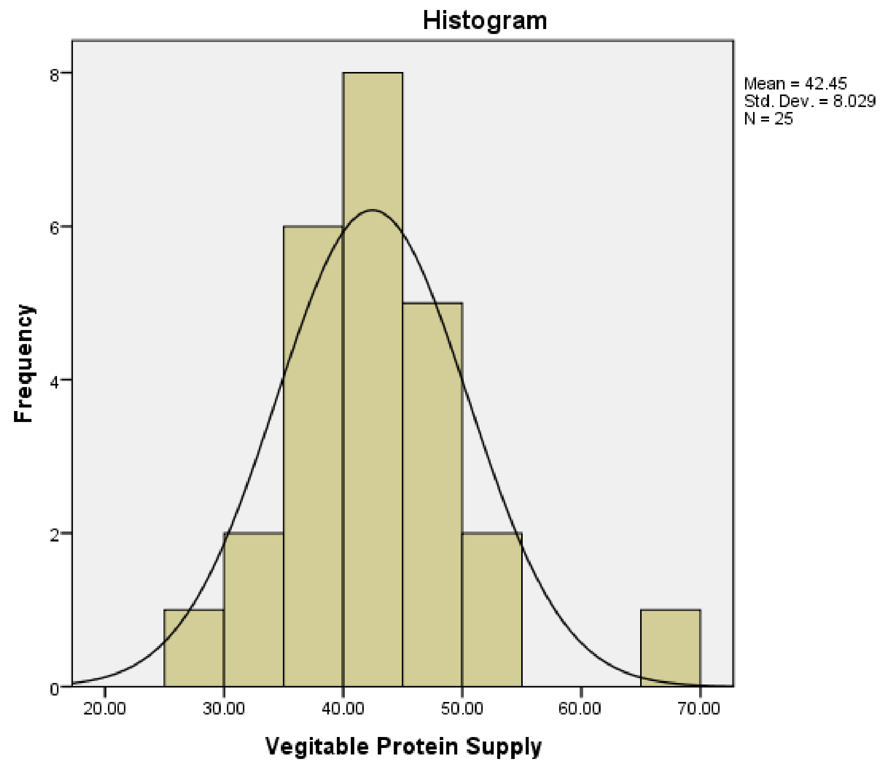
Supplemental Figure 4: Animal Protein Supply Distribution



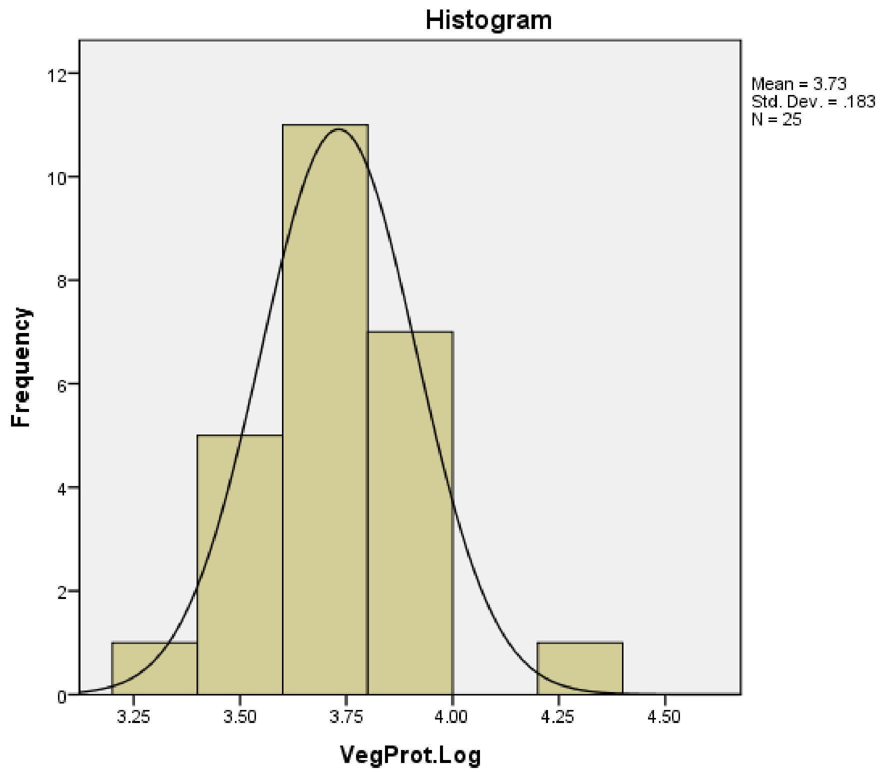
Supplemental Figure 5: Vegetable Fat Supply Distribution



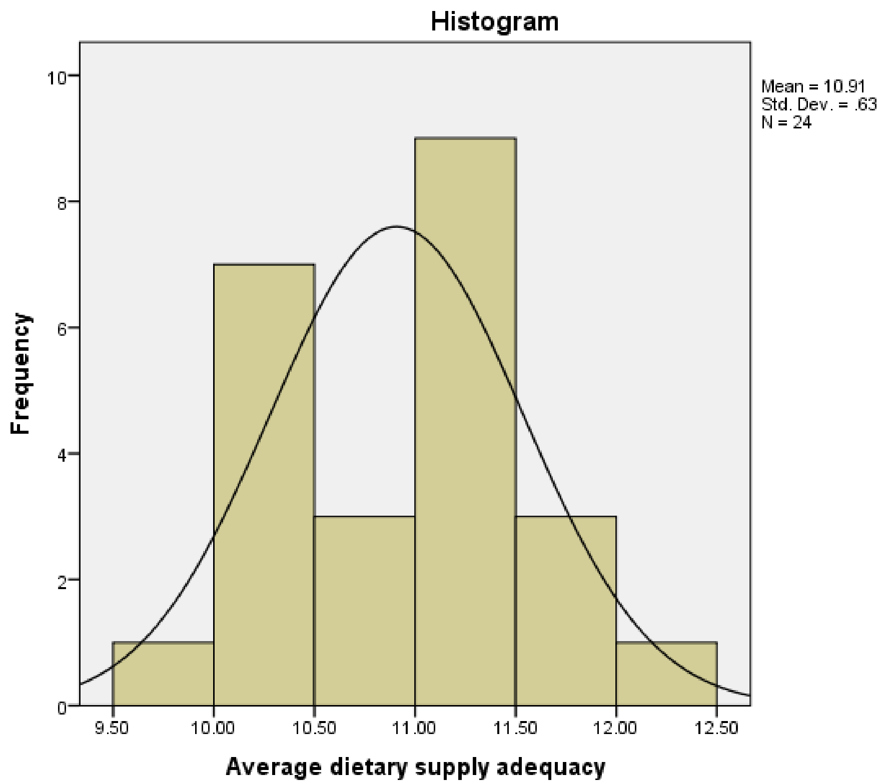
Supplemental Figure 6: Logarithm of Vegetable Fat Distribution



Supplemental Figure 7: Vegetable Protein Supply Distribution



Supplemental Figure 8: Logarithm of Vegetable Protein Distribution



Supplemental Figure 9: Average Dietary Supply Adequacy Distribution

Appendix I: FAO Food Balance Sheet

												Population (Thousand)			
Single items	Domestic Supply					Domestic Utilization						Per Capita Supply			
	1000 Metric tons											Total		Protein	Fat
	Prod.	Impo.	Stock Var.	Exp.	Total	Food	Food Manu	Feed	Seed	Waste	Oth. Uses	Kg/Yr	KCal/Day	Gr/Day	Gr/Day
Population															
Grand Total															
Vegetable Products															
Animal Products															

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