

Relationship between food polyamines and gross domestic product in association with longevity in Asian countries

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ABSTRACT

The relationship between gross domestic product (GDP) and dietary profile, with a focus on polyamine intake, was investigated in 35 Asian countries. Data on food supply, GDP, and health condition were collected from databases of the United Nations, the International Monetary Fund, and the World Health Organization, respectively. The amount of polyamine intake from food was estimated using polyamine concentrations listed in published sources. The amounts of putrescine, spermidine, spermine, and total polyamines in 1000 kcal of food in Asian countries were 39.07 ± 17.98 , 33.74 ± 14.35 , 14.05 ± 6.60 and 86.85 ± 33.96 $\mu\text{mol}/1000$ kcal, respectively. Putrescine, spermidine, and spermine constituted 44, 39, and 17% of total polyamine, respectively. Vegetables contributed the largest amount of both putrescine and spermidine and the second largest amount of spermine (45.5%, 62.2% and 27.2% of total putrescine, spermidine, and spermine, respectively). Meat was the richest source of spermine and contributed the greatest amount (50%) of this polyamine. We showed a significant positive association between GDP and the amount of polyamine per 1000 kcal of food. Lifespan was associated with both GDP and the amount of polyamine per energy quotient of food. As several basic research studies have shown that polyamines help prolong longevity, it follows that polyamines may have a role in determining the lifespan of humans.

Keywords: Polyamine; GDP; Longevity; Cardiovascular Diseases; Food

1. INTRODUCTION

The polyamines putrescine, spermidine, and spermine, not only play an essential role in the proliferation and differentiation of mammalian cells but also have important physiological roles on cellular function. In addition, very recent studies have shown that exogenous polyamine suppresses the progression of age-associated pathologies and increases the life span of cells and several living organisms including mice [1,2]. On the other hand, there is evidence that increased polyamine concentrations are associated with several deteriorations in health [3-6].

Food is one of the important sources of body polyamines which are absorbed by the intestinal lumen and then distributed to all organs and tissues [7]. In fact, differences in polyamine intake have been shown to influence blood polyamine concentration in both mice and humans [8]. As most foods originate from plants or animals, almost all foods contain polyamines, but in widely varying concentrations [9-12]. It is therefore very important to delineate the factors that may influence polyamine intake.

Socioeconomic status is closely associated with favorable health status and prolonged lifespan [13-18]. Gross domestic product (GDP) is one of the representative indicators of socioeconomic status of countries, and we have shown using an open database that individuals living in European and Western countries with a high GDP prefer foods containing abundant polyamines compared to individuals living in countries with a lower GDP [19]. This study aimed to examine the relationship between the amount of food polyamine and GDP in Asian countries. In addition, as polyamines have been shown to have several roles on health status in experimental models, we also examined the relationship between health status and polyamine intake in association

with GDP.

2. METHODS AND MATERIALS

2.1. Database

Data on food supply in 2002 were obtained from the online database of the Statistics Division of the Food and Agriculture Organization of the United Nations (FAOSTAT). The target populations were 35 Asian countries that included Bangladesh, Brunei Darussalam, Cambodia, China, Democratic People's Republic of Korea, Fiji, India, Indonesia, Islamic Republic of Iran, Japan, Jordan, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Republic of Korea, Samoa, Saudi Arabia, Solomon Islands, Sri Lanka, Syrian Arab Republic, Thailand, Timor-Leste, United Arab Emirates, Vanuatu, Viet Nam, and Yemen. The concentrations of spermine, spermidine, and putrescine in foods were obtained from published reports of concentrations measured in Japanese foods [9,10]. When these reports did not show the polyamine content of certain foods, we used additional data obtained from European studies [11,12] (**Table 1**). All the food items were categorized

Table 1. Polyamine contents in Asian foods (nmol/g or nmol/mL)[†]

Food items	Putrescine	Spermidine	Spermine
<i>Cereals</i>			
Barley	17	16	20
Maize	576	144	8
Millet	19	63	48
Oats	41	133	148
Rice (milled equivalent)	8	7.5	1.5
Rye	41	133	148
Sorghum	14	12	0
Wheat	19	29.5	0.5
Other cereals	31.7	90	23.7
<i>Vegetables</i>			
Cassava	0	0	0
Cloves	0	0	0
Onions	29.5	86.5	4.5
Potatoes	89	68	15.5
Pulses ¹	26	144	74
Roots & tuber dry equiv ²	118	109.3	19.8
Sweet potatoes	29	25.2	16.5

Tomatoes	146.3	22.5	2.5
Vegetables ³	113.5	170.2	17.4
Yams	73	89.5	2
Aquatic plants	118	109.3	19.8
<i>Fruits</i>			
Apples	10	14	0.5
Bananas	160	50	1.5
Grapefruit	436	19.5	1.5
Grapes	106	87	0
Lemons, limes	390.5	19	4.5
Oranges, mandarins	432	15.5	0
Pineapples	46	30	0
Citrus, other ⁴	460.2	26.5	0
Fruits, other ⁵	74.5	55.4	4
<i>Beans and Nuts</i>			
Beans ⁶	147	644.8	299.7
Groundnuts ⁷	18	110	88
Peas ⁸	367	341	32
Sesame seed	29	126	22
Soybean	297	909	235.5
Sunflower seed	34	383	89
Tree nuts ⁹	104.5	108.9	111.6
<i>Seafoods</i>			
Cephalopods ¹⁰	3.3	9.3	93.3
Crustaceans ¹¹	26.5	0	0
Fish ¹²	27.2	37.1	53.1
Fish, oil	0	0	0
Molluscs ¹³	19.7	143.5	383.5
Aquatic animals and others ¹⁴	26.3	55.1	87.2
<i>Meat</i>			
Bovine meat	18.5	17.5	149
Mutton & goat meat	8.2	39.7	131.3
Pig meat	4.5	9.5	165
Poultry meat ¹⁵	13.3	48.5	3.5
Meat, other	11.5	26.7	194.2
Offal, edible ¹⁶	63.8	188	825.8
<i>Dairy products</i>			
Butter, ghee, whey & milk	0	0	0
Cheese	0	15	3.5
Cream	0.3	0	0

	6.5	2.5	2.5
Eggs	6.5	2.5	2.5
<i>Vegetable oil and animal fat</i>			
Vegetable oil	0	0	0
Animal fat	0	0	0
<i>Sugar & Sweeteners</i>			
Sugar & Sweeteners	3	0	0
<i>Beverages and stimulants</i>			
Beer	153.3	1	0
Wine	49	1.5	0
Tea leaf	49.5	96.3	72.8
Coffee	0	0	0
Other beverages ¹⁷	0	0	0
Pepper	621	80	45
Pimento & Spices	0	0	0

† The average content of spermine, spermidine, and putrescine in each food item expressed as nmol/g or nmol/mL was calculated using data for foods available in Japan reported by K. Nishimura, *et al.*, (Decrease in polyamines with aging and their ingestion from food and drink. *J Biochem* 2006; 139: 81-90) and N. Nishibori, *et al.*, (Amounts of polyamines in foods in Japan and intake by Japanese. *Food Chem* 2007; 100: 433-872). ¹Field pies; ²Burdock root and lotus root; ³Asparagus, bean sprouts, beet, beetroot, broccoli, Brussel sprouts, butterbur, cabbage, carrot, cauliflower, celery, Chinese cabbage, green cabbage, red cabbage, chervil, chicory, cucumber, eggplant, escarole, green leek, leek, lettuce, mushrooms, parsley, pumpkin, spinach, radish, salsify, sorrel, watercress; ⁴Oranges, mandarins, and tangerines; ⁵Pear, strawberry, persimmon, fig, pomegranate, peach, blueberry, melon, watermelon, cherry, prune, durian, papaya, dragon fruit, kiwifruit, mango, and avocado; ⁶Adzuki bean, cow pea, and soybean; ⁷Peanut; ⁸Green peas; ⁹Almond, cashew, and pistachio nuts; ¹⁰Squid and octopus; ¹¹Shrimp and crab; ¹²Horse mackerel, Japanese needlefish, mackerel, salmon, sardine, tuna, conger, angler, sweetfish, alfonsino, saury, shark, scabbard fish, yellowtail, swordfish, bonito, codfish, eel, and whitefish; ¹³Oyster, white scallop, coral scallop, and clam; ¹⁴Fish and shellfish; ¹⁵Chicken and duck; ¹⁶Beef liver, beef intestine, pork liver, chicken liver, chicken gizzard, and chicken heart; ¹⁷Soft drink and cocoa.

the following 12 groups for further analyses; including 1) Cereals, 2) Vegetables and starchy roots, 3) Fruits, 4) Beans, 5) Seafoods, 6) Meat, 7) Dairy products, 8) Eggs, 9) Vegetable oil and animal fat, 11) Sugar and sweeteners, and 12) Beverages and stimulants. As the data on food supply from the WHO does not necessarily indicate the absolute amount consumed by each nation, and in order to ascertain the features of dietary patterns, we used a relative measure of the amount of various foods, such as food consumption per energy quotient. GDP per capita in 2002 was obtained from the International Monetary Fund (IMF), and age-standardized mortality rates (per 100,000 population) due to cardiovascular diseases

(CVD) and cancer in 2002 and life expectancy at birth in 2006 were derived from the World Health Organization Statistical Information System (WHOSIS).

2.2. Statistics

The data were analyzed using the statistical package SPSS for Windows (SPSS Inc., *Chicago, IL, USA*). Pearson's correlation coefficients were calculated to examine the association between the relative amount of polyamine in foods, GDP per capita, and life expectancy. A *P*-value < 0.05 was considered statistically significant.

3. RESULTS

3.1. Polyamine Contents in Asian Foods

The average content of the three polyamines, putrescine, spermidine, and spermine in each food item is shown in **Table 1**. Polyamine content ranged widely among the foods, with several foods having increased polyamine concentrations. The highest putrescine levels were found in maize, citrus fruits, grapefruit, peas, soybeans, and other beans. Spermidine concentrations were high in soybeans, other beans, and vegetables, while spermine concentrations were high in edible offal, molluscs, meats, soybeans, and other beans. Generally, foods of plant origin tended to have higher contents of spermidine compared to spermine, whereas foods of animal origin had the opposite composition. The levels of all polyamines were very low or undetectable in vegetable oil, animal fat, sugar and sweeteners, eggs, and dairy products including butter, cream, whey, cow milk and infant milk formulas.

3.2. Daily Amounts per capita and Amounts per 1000 kcal of Polyamines

Table 2 shows the daily amounts per capita and **Table 3** shows the daily amounts per 1000 kcal of the three polyamines in Asian countries. The average estimated daily intake of putrescine, spermidine, spermine, and total polyamines in Asian countries were 106 μ mol, 91 μ mol, 38 μ mol and 235 μ mol, respectively. Putrescine, spermidine, and spermine accounted for 44%, 39%, and 17% of total polyamine intake, respectively. The amounts of putrescine, spermidine, spermine, and the sum of the three polyamines per 1000 kcal energy were 39, 34, 14, and 87 μ mol/day.

3.3. Sources of Polyamines

The proportions of the three polyamines provided by each food group are shown in **Figure 1**. Overall, vegetables provided the largest amount of putrescine and sper-

Table 2. The daily amounts of polyamines in each food group.

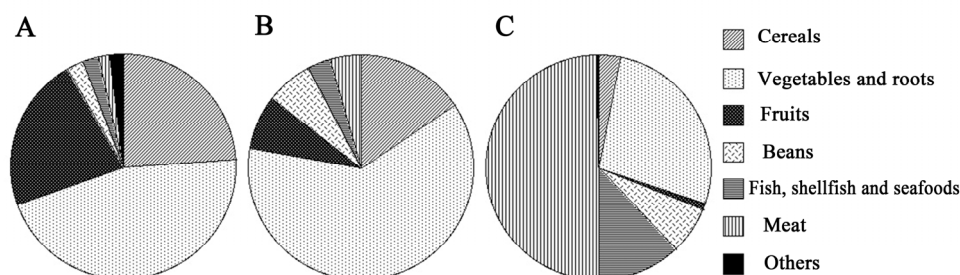
c	Amount (g/day)	Putrescine ($\mu\text{mol/day}$)	Spermidine ($\mu\text{mol/day}$)	Spermine ($\mu\text{mol/day}$)
Cereals	417.4 \pm 101.2	26.04 \pm 35.19	12.28 \pm 8.63	0.92 \pm 1.17
Vegetables and roots	497.6 \pm 290.0	48.40 \pm 30.81	59.70 \pm 35.20	8.68 \pm 4.90
Fruits	172.0 \pm 116.3	23.85 \pm 19.19	6.72 \pm 5.06	0.32 \pm 0.25
Beans	28.6 \pm 30.9	2.24 \pm 2.87	6.03 \pm 9.24	2.33 \pm 3.14
Seafoods	75.4 \pm 97.4	1.86 \pm 2.60	2.80 \pm 3.65	4.64 \pm 5.80
Meat	89.7 \pm 67.5	1.30 \pm 1.09	3.64 \pm 3.34	21.34 \pm 16.73
Dairy products	138.8 \pm 136.5	0	0.04 \pm 0.09	0.01 \pm 0.02
Eggs	14.2 \pm 13.8	0.09 \pm 0.09	0.04 \pm 0.03	0.01 \pm 0.01
Vegetable oil	21.7 \pm 14.3	0	0	0
Animal fat	5.1 \pm 6.5	0	0	0
Sugar and sweeteners	63.2 \pm 36.1	0.19 \pm 0.11	0	0
Beverages and stimulants	34.6 \pm 42.1	1.87 \pm 2.84	0.11 \pm 0.17	0.04 \pm 0.01
Total	1558.2 \pm 480.9	105.85 \pm 52.48	91.36 \pm 41.61	38.29 \pm 19.61

Per-capita daily availability of amount of food and the amount of putrescine, spermidine, and spermine from each food group are expressed as the mean \pm standard deviation (SD). Values < 0.001 are expressed as 0.

Table 3. The daily amounts per 1000 kcal of polyamines in each food group.

Food groups	Amount (g/1000kcal)	Putrescine ($\mu\text{mol}/1000\text{kcal}$)	Spermidine ($\mu\text{mol}/1000\text{kcal}$)	Spermine ($\mu\text{mol}/1000\text{kcal}$)
Cereals	158.7 \pm 41.4	9.99 \pm 13.26	4.64 \pm 3.25	0.35 \pm 0.42
Vegetables and roots	183.3 \pm 104.3	17.68 \pm 10.49	21.89 \pm 12.01	3.22 \pm 1.82
Fruits	62.7 \pm 38.2	8.59 \pm 6.24	2.46 \pm 1.73	0.12 \pm 0.09
Beans	10.2 \pm 10.4	0.84 \pm 1.17	2.32 \pm 3.93	0.89 \pm 1.35
Seafoods	28.2 \pm 36.8	0.70 \pm 0.98	1.04 \pm 1.37	1.72 \pm 2.14
Meat	32.7 \pm 24.9	0.47 \pm 0.42	1.32 \pm 1.26	7.74 \pm 6.07
Dairy products	50.4 \pm 47.7	0.0 \pm 0.0	0.01 \pm 0.03	0.003 \pm 0.007
Eggs	5.1 \pm 4.8	0.03 \pm 0.03	0.01 \pm 0.01	0.003 \pm 0.002
Vegetable oil	7.9 \pm 4.7	0	0	0
Animal fat	1.8 \pm 2.3	0	0	0
Sugar and sweeteners	23.2 \pm 12.5	0.07 \pm 0.04	0	0
Beverages and stimulants	12.6 \pm 14.6	0.69 \pm 1.01	0.04 \pm 0.06	0.01 \pm 0.03
Total	576.8 \pm 128.7	39.07 \pm 17.98	33.74 \pm 14.35	14.05 \pm 6.60

Per-capita availability of the amount of food and the amount of putrescine, spermidine, and spermine per person are listed by food category. The daily amounts per 1000 kcal are expressed as the mean \pm SD. Values < 0.001 are expressed as 0

**Figure 1.** The contribution of each food group to the amount of putrescine (A), spermidine (B) and spermine (C).

midine, and also provided the second largest amount of spermine (45.5% of putrescine, 62.2% of spermidine, and 27.2% of spermine). Other important sources of putrescine were cereals and fruits, which provided 24.0% and 22.3% of total putrescine, respectively. Cereals, fruits, and beans supplied 15.5%, 7.7%, and 6.6% of total spermidine, respectively. Animal meats were the biggest source of spermine, and provided 50% of total spermine.

3.4. Associations between the Amounts of Putrescine, Spermidine, and Spermine per Total Energy and GDP per capita

The GDPs of the Democratic People's Republic of Korea and Timor-Leste could not be obtained. These two countries were therefore excluded from the analyses which subsequently included 33 countries. The GDP data were transformed to natural logarithms to approximate a normal distribution. Pearson's correlation coefficients were calculated to investigate the relationship between polyamine amount per food energy (1000 kcal) and GDP. As shown in **Table 4**, GDP per capita correlated positively with all three polyamines, with different levels of correlation being observed. Although the correlation coefficients between GDP and spermidine and putrescine per energy quotient were < 0.4 with p values < 0.05 , spermine per energy quotient showed a strong positive correlation with GDP.

3.5. Correlation among the Amount of Polyamine, GDP, and Health Status

GDP was associated positively with life expectancy ($r = 0.890$, $p < 0.001$) and negatively with mortality due to cardiovascular diseases ($r = -0.640$, $p < 0.001$). Life expectancy was associated negatively with CVD mortality ($r = -0.674$, $p < 0.001$). Although no significance associations were found, the correlation coefficients between CVD mortality and spermine/energy, spermidine/energy, putrescine/energy, spermine plus spermidine/energy, and total amount of all three polyamines/energy all had negative values ($r = -0.276$, -0.057 , -0.035 , -0.154 , and -0.103 , respectively). No significant association was found between life expectancy and cancer mortality. As shown in **Table 4**, GDP and life expectancy were associated positively with the total amount of food polyamine per energy, with various levels of correlation being observed.

4. DISCUSSION

Reference to our previous report on European foods [19] showed that although there were many similarities in the

Table 4. Correlation between polyamine/energy and GDP and life expectancy.

	GDP		Life expectancies	
	r	P	r	P
Putrescine / energy	0.366	0.036	0.232	0.181
Spermidine / energy	0.386	0.026	0.308	0.072
Sermine / energy	0.607	<0.001	0.585	< 0.001
Spermine plus spermidine / energy	0.532	0.001	0.453	0.006
Polyamine / energy	0.480	0.004	0.367	0.030

The correlation between each polyamine / energy and GDP (natural logarithm) was examined in 33 countries, as the GDP of the Democratic People's Republic of Korea and Timor-Leste could not be obtained. r indicates the correlation coefficient of the linear regression between polyamine/energy and GDP or life expectancy.

proportions of supplied foods, there were striking differences in the higher amounts of dairy products and animal-derived products consumed in European countries, whereas consumption of cereals was higher in Asian countries. Similarly, polyamine concentrations in Japanese foods [9,10] were similar to those in European foods [11,12], whereas in some foods, especially cheese, the concentrations were markedly different. These variations in polyamine content could be explained by the effects of food processing and storage changes, and one of the weaknesses of the present study was the inability to comprehend these changes. However, the estimated daily amount of food polyamines in Asian countries was similar to those contained in a previous report on Japanese foods [9] in which the daily amount of supplied putrescine, spermidine, and spermine per person were 113, 82, and 39 μmol , respectively. In that study, putrescine, spermidine, and spermine accounted for 45%, 37% and 18% of total daily polyamine supply in Japanese diets, respectively. The daily amount of polyamine availability from foods in Asian countries was considerably lower than that reported in European countries, especially countries with a higher GDP (350-500 $\mu\text{mol/day/person}$) [20,21]. However, the proportions of each of the three polyamines relative to total polyamines were similar to those in European countries [20,21]. The lower amount of total polyamine availability appeared to be due to the lower amount of total food supply in Asian countries, as the amounts of spermine and spermidine per food energy in Asian countries were higher than those in European countries, while the sum of the total amount of the three polyamines per energy was similar to European and Western countries with a lower GDP [19].

The results of the present study using databases for Asian countries were relatively similar to those reported in earlier studies in European and Western countries in which socio-economic status showed a close positive association with longevity and a close negative associa-

tion with CVD mortality [13-18]. The results of the present study also indicated that reducing the incidence of CVD is very important for improving health status and prolonging lifespan, even in Asian countries. Studies using personal databases have shown decreases in CVD incidence and increases in life span are often associated with socioeconomic status [13-18]. Although the factors affecting health condition according to socioeconomic status are not fully understood, the present study showed that the amount of polyamine in foods was associated closely with GDP per capita. A very interesting finding in our study was that the amount of food polyamine per energy quotient was associated not only positively with GDP but also negatively with CVD incidence. As the current study was an ecological investigation, it would therefore be expected there were potential confounding factors in these associations. However, recent basic research studies have shown that increased polyamine intake prolongs the longevity of some small organisms and rodents [1,2], and therefore increased polyamine intake may theoretically help maintain vascular health by increasing the amount of arginine available for nitric oxide (NO) synthesis [22-25]. These findings and those of the present study suggest a possible role of food polyamines on human health.

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