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Major correlates of male height: A study of 105 countries

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ABSTRACT

The purpose of this study is to explore the main correlates of male height in 105 countries in Europe & overseas, Asia, North Africa and Oceania. Actual data on male height are compared with the average consumption of 28 protein sources (FAOSTAT, 1993–2009) and seven socioeconomic indicators (according to the World Bank, the CIA World Factbook and the United Nations). This comparison identified three fundamental types of diets based on rice, wheat and milk, respectively. The consumption of rice dominates in tropical Asia, where it is accompanied by very low total protein and energy intake, and one of the shortest statures in the world (~162–168 cm). Wheat prevails in Muslim countries in North Africa and the Near East, which is where we also observe the highest plant protein consumption in the world and moderately tall statures that do not exceed 174 cm. In taller nations, the intake of protein and energy no longer fundamentally rises, but the consumption of plant proteins markedly decreases at the expense of animal proteins, especially those from dairy. Their highest consumption rates can be found in Northern and Central Europe, with the global peak of male height in the Netherlands (184 cm). In general, when only the complete data from 72 countries were considered, the consumption of protein from the five most correlated foods ($r = 0.85$) and the human development index ($r = 0.84$) are most strongly associated with tall statures. A notable finding is the low consumption of the most correlated proteins in Muslim oil superpowers and highly developed countries of East Asia, which could explain their lagging behind Europe in terms of physical stature.

1. Introduction

In our previous study (Grasgruber et al., 2014), we identified nutrition and genetics as the strongest correlates of height among contemporary young men from 42 European and three overseas countries (Australia, New Zealand and the USA). Out of all the socioeconomic factors that were examined, only children's mortality approached the significance of nutrition and genetics, which points to the importance of a disease-free environment. Improved nutrition and better healthcare are direct consequences of improving living standards that accompanied the process of the industrial revolution (Hatton, 2013).

In the present study, we aim to extend this research to North Africa, Asia and Oceania. These regions include mostly developing countries, but Muslim oil superpowers (Bahrain, Brunei, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates/UAE) and some developed countries of East Asia (Japan, Singapore, South Korea, Taiwan) currently belong to the wealthiest in the world, with the gross domestic product (GDP) per capita higher than 30,000 USD (World Bank, 2013), not to mention the semi-independent territory of Hong Kong. Interestingly, male height in some of these regions (Arab countries of North Africa and the Near East) was once similar or even higher than in Europe, but after the 1880s it started to lag

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behind considerably (Stegl and Baten, 2009). On the other hand, wealthy nations of East Asia are still known for their surprisingly small stature, despite very high values of the GDP per capita (Baten and Blum, 2014). Therefore, it would be important to identify the main factors that currently distinguish these regions from Europe.

As we did similarly in our previous study, we plan to explore the correlation of factors such as nutrition, healthcare and national wealth with the height of contemporary young men. Genetic factors (frequencies of Y haplogroups) are included as well, but in a supplementary function, because no Y haplogroup is shared in appreciable frequencies across the whole area of Europe, North Africa, Asia and Oceania.

2. Methods

2.1. Collection of anthropometric data

The selected regions of North Africa, Asia and Oceania encompass 63 countries (including three semi-independent territories–American Samoa, French Polynesia, Hong Kong), for which data on body height were researched. In Oceania, only more populous countries with a population size exceeding 50,000 inhabitants were considered, because statistics were not available for small island nations. Preferably, we searched for anthropometric data on young, mature men aged 18–30 years (but ideally 20–25 years) from the time after the year 2000. Only surveys that incorporated at least 50 individuals were used, but whenever possible, nationwide surveys with more than 200 individuals were preferred. The only samples with fewer than 100 individuals were from Guam ($n = 59$) and Algeria ($n = 55$)[1]. By far the most representative data (regular measurements of recruits) were available from Israel, but paradoxically, they were the most problematic due to the inclusion of young immigrants, who were not born and raised in Israel[2].

The majority of surveys included in our study are nationwide health surveys incorporating all social groups. Some other surveys had certain limitations. Six of them (from Bhutan, Laos, Libya, Oman, the Maldives and Syria) incorporate an urban population from a single city. The sample from Libya consists of patients visiting a hospital in Derna. Three surveys (from Saudi Arabia, the United Arab Emirates and the Federative States of Micronesia) come from a specific region of the country. The sample from North Korea includes refugees. In the case of Afghanistan, Kyrgyzstan, Pakistan, Tajikistan and Turkmenistan, the male height was estimated, based on highly representative studies of local women. The height in Kazakhstan (175.6 cm) was computed from the data of Facchini et al. (2007). (See Appendix: Methods for a more detailed discussion.)

Due to the scarcity of information from some countries, certain compromises needed to be made. This especially concerns the STEPS surveys (Noncommunicable Disease Risk Factor Surveys) performed by the World Health Organization (WHO), which rarely include people younger than 25 years and routinely start with the age category of 25–34 years. Nevertheless, it is unlikely that the inclusion of older subjects would markedly distort our results, because the pace of the secular trend in the majority of the examined countries is very slow or almost non-existent.

Besides that, some means of male height from our previous study were updated. This update relates to Bosnia and Herzegovina, Bulgaria, the Czech Republic, Georgia, Moldova and Ukraine (see Appendix: Methods and Appendix Table 1). Recent anthropometric data were even obtained from Armenia, but they did not seem to be sufficiently representative. Nevertheless, they indirectly supported the accuracy of our male estimate based on DHS 2005 (171.9 cm)[3].

Altogether, information on body height was collected from 61 out of 63 targeted countries (Table 1). Only data from Macau and New Caledonia were missing[4]. Our list also includes the Maori, but considering that they make up a minority in New Zealand, this sample was not useable.

2.2. Collection of nutritional and sociodemographic data

The information about the average daily protein consumption (in grams) was computed from FAOSTAT.org[5]. The statistics on the gross domestic product (GDP) per capita (by purchasing power parity/PPP, in current international USD), health expenditure per capita (by PPP, in constant 2005 international USD), urbanization (% of urban population), children's mortality under 5 years (per 1000 live births) and total fertility rate (births per woman) were taken from the World Bank[6], and the Gini index of social inequality from the CIA World Factbook[7]. In addition, we included the human development index (HDI) that is regularly calculated by the United Nations[8]. Since 2010, the HDI has been computed

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[1] Large samples of young men from Algeria, Morocco and Tunisia were recently measured within the epidemiological survey ETHNA, but the authors were reluctant to share the data.

[2] A large sample of 2.1 million Israeli men born between 1950 and 1993 included only 5.7% men born in Israel, but 53.1% of the men came from Africa or Asia (Meydan et al., 2013).

[3] According to "Tables for evaluation of physical development of 16–25 years old boys and girls in the Republic of Armenia (guidance for medical doctors)" published in 2010 (A. Tadevosyan—pers. communication), the average height in the age category 21–25 years was 176.1 cm in men ($n = 157$) and 162.9 cm in women ($n = 210$). However, the average height of Armenian women aged 20–24 years in DHS 2005 was only 159.2 cm ($n = 1066$). This strongly suggests that we are dealing with the data of university students, which was also indicated by other surveys provided by A. Tadevosyan that examined students from elite educational institutions. More importantly, the male/female ratio in the above mentioned survey was 1.081, which agrees with the ratio 1.08 that was used in our previous study for the estimation of male height in Armenia.

[4] The most recent sample from New Caledonia that we were able to find came from 1991. A sample of 495 men aged 30–32 years reached 171.0 cm (A. Cournil—pers. communication).

[5] FAOSTAT, http://faostat3.fao.org/download/FB/CC/E.

[6] The World Bank, http://data.worldbank.org/topic. Statistical data of GDP per capita from Taiwan (Republic of China) were specially requested from the World Bank.

[7] The CIA Factbook, https://www.cia.gov/library/publications/the-world-factbook/fields/2172.html.

[8] Human development statistical annex (2011), http://www.undp.org/content/dam/undp/library/corporate/HDR/2011%20Global%20HDR/English/HDR_2011_EN_Tables.pdf

Table 1
Male height in North Africa, Asia and Oceania.

Country/region	*n*	Age	Date	Height	Source
France: French Polynesia	232	18–24	2010	178.6	French Polynesia STEPS 2010
Tonga	229	18–20	2008	176.7	Swinburn et al. (2011) (pers. communication)
USA: American Samoa[a]	272	25–34	2004	175.9	American Samoa: STEPS 2004
Maori (New Zealand)		19–30	2008–09	175.9	New Zealand Adult Nutrition Survey 2008–09
Kazakhstan	∼200	18	2002–04	175.6 (m)	Estimate (based on Facchini et al., 2007)
Lebanon	343	20–30	2009	175.5 ± 6.6	Naja et al. (2011) (pers. communication)
Algeria[b]	55	18	2010–11	174.6 ± 6.6	Musaiger et al. (2012) (pers. communication)
Israel (Israeli-born only)	1845	20–25	2010	174.5	IDF (R. Kayouf—pers. communication)
South Korea	*ns*	20	2005	174.3	Moon (2011)
Tunisia[c]	456	18–20	2005	174.2 ± 7.4	Aounallah-Skhiri et al. (2008) (B. Maire—pers. comm.)
Fiji	289	18	2007–08	174.1	Swinburn et al. (2011) (P. Kremer—pers. comm.)
Samoa	186	24–30	2010	173.9 ± 5.2	Hawley et al. (2014) (S. McGarvey—pers. comm.)
United Arab Emirates (Dubai)	164	17–19	2009–11	173.5 ± 7.5	Al-Hazzaa et al. (2011) (pers. comm.)
Palestine (incl. Gaza)	197	17–19	2013	173.5 ± 7.0	PMS survey (2013) (A. Aburub—pers. comm.)
Iran	*ns*	21–25	2001–05	173.4	Haghdoost et al. (2008)
Libya (Derna; northeast)	108	18–30	2014	172.9 ± 7.0	T. Elhisadi (pers. communication)
Bahrain	146	17–19	2009–11	172.5 ± 10.5	Al-Hazzaa et al. (2011) (pers. comm.)
Taiwan[d]	199	18–30	2003–08	172.3	A weighted mean of 2 samples
China	3853	19	2010	172.1	China: General Administration of Sport
Kuwait	111	20–24	2006	172.1	Kuwait STEPS 2006
Japan	1512	20–24	2006	172.1 ± 5.7	Japan: Official Statistics
Qatar[e]	713	18–44	2012	171.7	Qatar STEPS 2012
China: Hong-Kong	468	18	2005–06	171.7 ± 5.5	So et al. (2008)
Morocco	3005	18–24	2011	171.7	K. El Rhazi—pers. communication
Singapore	*ns*	21–25	2010	171.5	Ministry of Health (pers. communication)
Kyrgyzstan		20–24	2012	171.3	Estimate (based on Kyrgyzstan DHS 2012)
Uzbekistan	602	20–25	2002	171.1 ± 5.6	Uzbekistan DHS 2002 (pers. comm.)
Syria (Aleppo)	229	18–25	2004	171.0 ± 7.3	Fouad et al. (2006) (pers. comm.)
Turkmenistan		20–24	2000	170.9	Estimate (based on Turkmenistan DHS 2000)
Jordan	181	18–29	2009–10	170.9 ± 7.0	Y. S. Khader–pers. communication
Iraq	603	25–34	2006	170.9	Iraq STEPS 2006
Egypt	845	20–24	2008	170.3	El-Zanaty and Way (2009)
Tajikistan		20–24	2012	170.1	Estimate (based on Tajikistan DHS 2012)
Saudi Arabia (Al Ula + Taif)	646	20–30	2005–07	169.9 ± 7.5	Taha et al. (2009)
Fed. St. of Micronesia (Chuuk)	174	25–34	2006	169.9	FSM (Chuuk): STEPS 2006
Kiribati	163	25–34	2004	169.8	Kiribati STEPS 2004
Guam	59	18–30	2011–12	169.8 ± 8.6	Y. C. Paulino—pers. communication
Oman (Muscat City)	224	17–19	2009–11	169.6 ± 7.8	Al-Hazzaa et al. (2011) (pers. comm.)
Mongolia[f]	400	15–24	2009	168.2	Mongolia STEPS 2009
Afghanistan		18–29	2010	167.9	Estimate (based on Afghanistan MICS4 2010)
Vanuatu	698	25–34	2011	167.8	Vanuatu STEPS 2011
Pakistan		20–24	2012–13	167.8	Estimate (based on Pakistan DHS 2012–13)
Thailand	855	20–30	2009	167.6	Aekplakorn et al., 2014 (pers. communication)
Malaysia	823	18–19	2006	167.5	Malaysia NHMS 2006 (C.C. Kee—pers. comm.)
Solomon Islands	263	25–34	2005	167.4	Solomon Islands STEPS 2005
Brunei	473	20–25	2009–11	166.9 ± 6.0	Z. Bin Kamis—pers. communication
Maldives (Malé)[f]	244	15–24	2011	166.1	Maldives STEPS 2011
North Korea (refugees)	520	20–27	2000–07	165.6 ± 5.8	Pak et al. (2011)
Sri Lanka	312	18–29	2005–06	165.6 ± 7.1	Ranasinghe et al. (2011)
India	21,394	20–29	2005–06	165.2 ± 6.9	Mamidi et al. (2011)
Vietnam	*ns*	22–26	2009	164.4	Vietnam: General nutrition survey 2009–10
Marshall Islands	177	25–34	2002	164.1	Marshall Islands STEPS 2002
Indonesia	1275	20–25	2007–08	163.9	Sohn (2015) (pers. communication)
Myanmar/Burma	619	25–34	2009	163.9	Myanmar STEPS 2009
Bhutan (Thimphu City)	255	25–34	2007	163.8	Bhutan STEPS 2007
Philippines	*ns*	20–29	2011	163.8	FNRI 2011 (G. Gironella–pers. comm.)
Laos (Vientiane City)	370	25–34	2008	163.6	Laos STEPS 2008
Yemen	374	20–25	2005–06	163.1 ± 10.4	Yemen—Household Budget Survey Project (2013)
Papua New Guinea	334	25–34	2008–09	163.1	PNG STEPS 2008–09 (P. van Maaren—pers. comm.)
Nepal[f]	286	15–29	2012–13	163.0	Nepal STEPS 2012–13
Bangladesh	1172	25–34	2010	162.7	Bangladesh STEPS 2010
Cambodia	526	25–34	2010	162.4	Cambodia STEPS 2010
Timor-Leste	713	20–29	2003	161.6 ± 5.5	Timor-Leste DHS 2003 (M. Dibley—pers. comm.)

Notes: A complete list of references is included in the Appendix.
ns = nationwide survey. The precise number of measured subjects is unknown.

[a] A smaller, but somewhat more actual sample of young men aged 18–30 years (*n* = 94), measured in 2002–2003, reached 175.6 cm (Keighley et al., 2006; S. McGarvey—pers. communication).

[b] A sample of Algerian farmers coming mainly from the region of Oued Souf, northeastern Algeria (age below 25 years, *n* = 143) measured by Mokdad (2002) reached 175.7 cm. Farmers made up ca. 23% of the Algerian population of that time.

[c] The true average height was 173.4 cm, but the authors recommended to use a mean corrected for the socioeconomic characteristics of the sample.

[d] A weighted mean of two samples: (1) Huang and Malina (2010): 172.4 cm (age 18 years, *n* = 100) measured in 2003; (2) Taiwanese Ministry of Health (personal communication): Nutrition and Health Survey in Taiwan from 2005 to 2008: 172.2 cm (age 19–30 years, *n* = 99).

[e] This value concerns 18–44 year olds, but it is higher than the height of 18-year old boys (170.8 cm; *n* = 258) in Bener and Kamal (2005), measured in 2003–2004.

[f] The youngest age category included 15–24 year olds, which must undoubtedly underestimate the actual height of young adult men, but the mean was still higher than in 25–34 year olds.

from the statistics of life expectancy, mean and expected years of schooling, and the GDP per capita by PPP.

To obtain the most precise results, we extended the period, for which the average values of nutritional and sociodemographic data were calculated (from 2000 up to 1993), but this required the elimination of Montenegro from the European sample, because many key data from Montenegro would be missing. A further historical extension (before 1993) was not possible, because many statistics from the disintegrated countries of the former Communist bloc have been available only since 1993. The information on the GDP and health expenditure has been complete since 1995.

The average daily protein consumption, children's mortality, total fertility and urbanization were therefore computed for the period 1993–2009 and the GDP and health expenditure for 1995–2009. The data of the Gini index were computed as averages of all the available values from 1990 to 2013. Considering that the historical HDI data were often incomplete, only the HDI values from 2011 were used. This limitation should not pose a problem, because HDI values largely summarize the societal development in the near past. Furthermore, the use of the HDI from 2011 enabled a mutual comparison with the newly introduced 'inequality-adjusted HDI' (IHDI), which takes the demographic variance in the HDI indicators into account.

Altogether, information was collected on male height from 106 countries (including Montenegro), on urbanization from 105 countries, on total fertility from 102 countries, on children's mortality from 101 countries, on the HDI from 100 countries, on health expenditure from 97 countries, on the GDP from 96 countries, on protein consumption from 93 countries, but on the Gini index only from 80 countries. All the data were available for 72 countries.

2.3. Collection of genetic data

For the genetic comparison, we use frequencies of Y haplogroups (male lineages)[9]. Y haplogroups usually show a more refined geographical pattern than mtDNA haplogroups (female lineages), because males rarely leave their 'clan' (Rosser et al., 2000). This is also evident from the fact that the distribution of Y haplogroups correlates with certain language groups[10]. Therefore, it is more likely that Y haplogroups will be associated with the prevalence of certain physical traits, because they mostly evolved within separate patrilocal communities. As shown by the results of our previous study, typical European Y haplogroups correlate quite strongly both with male height and with the prevalence of lactose tolerance. The relationship between the combined frequency of Y haplogroups I-M170 & R1b-U106 and male height in 34 countries reached $r = 0.75$ ($p < 0.001$). It is true that a recent study by Robinson et al. (2015) attributed only 24% of the height differences among 14 European countries to genetic differences, but this percentage may be underestimated, because this study apparently used very low height values of the whole male population and it did not include any samples from the Western Balkans.

In the present study, two major regions with a relatively high frequency of particular Y haplogroups are examined. In North Africa and the Near East (including Turkey and the Caucasian republics), six major Y haplogroups were selected: E1b1b1a1-M78 (E1b-M78), E1b1b1b1a-M81 (E1b-M81), G-M201, J1-M267, J2-M172 and R1a-M420. Data on the frequency of these Y haplogroups were available from 21 countries (Appendix Table 2a). Only representative information on Bahrain and Israel was missing. In South, Southeast & East Asia and Oceania, four Y haplogroups were selected: O1-MSY2.2, O2-P31, O2a-PK4 and O3-M122 (Appendix Table 2b). Data from this region are still quite scarce and often confined to specific areas or tribal groups; hence information from 8 out of 35 targeted countries was missing.

Data on the phenotypic prevalence of lactose tolerance are taken from three main sources: the Global Lactase Persistence Association Database, Ingram et al. (2009) and Flatz and Rotthauwe (1977). Only studies incorporating ≥50 individuals were used, which limited the number of countries to 20 (see Appendix Table 3). When combined with the countries examined in our previous study, the prevalence of lactose tolerance was available for 47 countries.

2.4. Statistical analyses

Statistical analyses were conducted by the software Statistica 12. A standard comparison via Pearson linear correlations was performed between male height and all the data that were available (Tables 2 and 3a–3b). Because complete information was not available for all the countries, the number of countries differed from variable to variable. To make the results comparable, we undertook an additional, separate analysis with only 72 countries, for which all the information was available (Table 3b and Appendix Table 4). These 72 countries were also subsequently used in a multiple regression. The drawback of this limited sample was the complete absence of Oceania and many Muslim countries. Therefore, an additional regression analysis with 83 countries (without the Gini index) was performed, but as we will show below, there were only small differences in the results. More sophisticated statistical procedures such as the use of instrumental variables were also considered, but we failed to find a variable that would be useful for such models.

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[9] Y haplogroups are defined by a specific mutation—SNP (single nucleotide polymorphism)—on the male chromosome Y, which is passed from father to son. In 2002, the Y Chromosome Consortium introduced a unified nomenclature, which currently distinguishes 20 major Y haplogroups designated with letters from A to T. The last big revision of this system was conducted in 2008. (See Karafet et al., 2008) A combination of letters with numerals defines various sub-branches (e.g. R1b1a2). With regard to the discoveries of new SNPs and the incessantly changing haplogroup trees, a combination of the existing nomenclature with the specific mutation (e.g. R1b1a2-M269) prevents possible confusion.

[10] In Western Eurasia, a clear geographical relationship can be found between N-M231 and Uralic languages (Mirabal et al., 2009), J1-M267 and Semitic languages (Chiaroni et al., 2010), R1a-Z93 and Indo-Iranian languages (Underhill et al., 2015), or between certain Y-haplogroups and local language families in the Caucasus (Balanovsky et al., 2011). A similar situation emerges in East Asia, where the frequency of O1a-M119 is apparently tied with Austronesian and Tai-Kadai languages, O2a1-M95 to Austroasiatic languages, O3-M122 to Hmong-Mien and Chinese-Tibetan languages (Van Driem, 2011), and O2b-M176 to Koreans and Japanese (Kim et al., 2011).

Table 2
Correlations between male height and socioeconomic variables, depending on the number of examined countries (*n*).

	Individual correlations					All variables combined				
	n	Mean	SD	*r*	*p*	*n*	Mean	SD	*r*	*p*
Europe										
Human Development Index (2011)	44	0.83	0.08	**0.57**	**0.000**	43	0.83	0.08	**0.60**	**0.000**
GDP 1995–2009	44	19,328	11,394	**0.44**	**0.003**	43	19,602	11,382	**0.48**	**0.001**
Health exp. 1995–2009	44	1,630	1,265	**0.41**	**0.006**	43	1,654	1,269	**0.44**	**0.003**
Urbanization 1993–2009	44	68.0	13.2	**0.34**	**0.023**	43	68.4	13.1	**0.38**	**0.012**
Total fertility 1993–2009	43	1.6	0.3	−0.26	0.09	43	1.6	0.3	−0.26	0.09
Gini index 1990–2013	44	31.8	5.4	**−0.36**	**0.017**	43	31.8	5.4	**−0.37**	**0.015**
Children's mortality 1993–2009	44	13.2	12.3	**−0.63**	**0.000**	43	13.2	12.5	**−0.64**	**0.000**
Asia, Oceania, North Africa										
Human Development Index (2011)	56	0.66	0.13	**0.67**	**0.000**	32	**0.65**	**0.13**	**0.74**	**0.000**
Urbanization 1993–2009	61	51.9	26.4	**0.55**	**0.000**	32	**45.5**	**23.4**	**0.73**	**0.000**
Health exp. 1995–2009	53	416	519	**0.40**	**0.003**	32	**331**	**509**	**0.48**	**0.006**
GDP 1995–2009	52	14,820	21,555	**0.28**	**0.041**	32	**7,896**	**9,615**	**0.47**	**0.006**
Gini index 1990–2013	36	38.7	6.0	−0.04	0.80	32	38.6	5.6	−0.13	0.49
Total fertility 1993–2009	59	3.3	1.3	**−0.31**	**0.017**	32	**3.0**	**1.1**	**−0.53**	**0.002**
Children's mortality 1993–2009	57	45.3	32.0	**−0.59**	**0.000**	32	**51.5**	**32.4**	**−0.57**	**0.001**
Total sample										
Human Development Index (2011)	100	0.73	0.13	**0.80**	**0.000**	75	0.75	0.13	**0.85**	**0.000**
Health exp. 1995–2009	97	966	1,110	**0.60**	**0.000**	75	58.6	21.4	**0.74**	**0.000**
Urbanization 1993–2009	105	58.6	23.2	**0.58**	**0.000**	75	1,090	1,207	**0.62**	**0.000**
GDP 1995–2009	96	16,886	17,700	**0.30**	**0.003**	75	14,607	12,092	**0.62**	**0.000**
Gini index 1990–2013	80	34.9	6.6	**−0.51**	**0.000**	75	34.7	6.4	**−0.54**	**0.000**
Total fertility 1993–2009	102	2.6	1.3	**−0.64**	**0.000**	75	2.2	1.0	**−0.75**	**0.000**
Children's mortality 1993–2009	101	31.3	29.9	**−0.73**	**0.000**	75	29.5	29.9	**−0.78**	**0.000**

Note: Statistically significant correlations ($p < 0.05$) are in bold.

3. Results

3.1. Distribution of male height

The data collected from 61 countries/regions are summarized in Table 1 and the geographical comparison of all 106 countries is displayed in Fig. 1. The range of values is very wide, from 161.6 cm in Timor-Leste up to 183.8 cm in the Netherlands (22.2 cm). Very tall statures above 180 cm are typical only of Europe, especially the areas with the highest frequency of Y-haplogroups I-M170, R1b-U106 and R1a-M420[11], and the highest quality of nutrition. The lowest values (below 165 cm) can be found in Yemen and Southeast Asia (Timor-Leste, Cambodia, Bangladesh etc.). Highly developed countries in East Asia (Japan, Singapore, South Korea, Taiwan), China and Muslim countries in North Africa and the Near East are positioned roughly in the middle, with heights fluctuating around 170 cm.

The Lebanese (175.5 cm) and most likely even the people of Kazakhstan (ca. 175.6 cm) are by far the tallest in Asia. Somewhat surprisingly, the average height in highly-developed Israel (174.5 cm) is shorter than that in Lebanon, and this is true even after the exclusion of 19-year old recruits, who were sons of recent immigrants and were not born in Israel. The small sample of Algerians (174.6 cm) is the tallest in North Africa. However, their stature is still only comparable to that of the shortest nations of Europe. Remarkably, it is Polynesians, who reach the highest values among the 61 new samples, more specifically the inhabitants of French Polynesia (178.6 cm)[12], Tonga (176.7 cm)[13] and American Samoa (175.9 cm)[14].

Marked geographical changes in male stature are hidden in the national averages of the largest countries—China and India. Zhang and Wang (2011) recently analysed data from the nationwide health survey in China (2005) and found that the height in 30 Chinese provinces (except Tibet) ranged from 165.6 cm for men in rural areas of the Guizhou province to 175.4 cm for men in urban areas of the Liaoning province. If the data from urban and rural areas from this study are pooled, the tallest statures can generally be found in

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[11] R1a-M420 frequencies have a curvilinear relationship to height in Europe, but the genetic legacy of R1a populations is apparently clouded by the genetic drift of the Uralic marker N1c-M46 in Estonia, Latvia and Lithuania. After its exclusion from the local Y haplogroup pool, R1a frequencies rise dramatically (from 38.9% to 66.5% in Latvia) and can explain the striking tallness of the Baltic males. See our previous study (Grasgruber et al., 2014).

[12] The sample from French Polynesia (3467 persons aged 18–64 years) included 72.4% Polynesians, 14.0% 'mixed'and only 8.7% Europeans. However, the ethnic composition in the age category 18–24 years was not specified.

[13] The final report of the Tonga STEPS survey (http://www.who.int/chp/steps/2004_TongaSTEPSReport.pdf?ua=1) states that Polynesians make up 98% of the population.

[14] According to the 2000 census, quoted in the final report of the STEPS survey 2004, the inhabitants of American Samoa consist of 92.9% native Pacific Islanders, 2.9% Asians, 1.2% whites and 2.8% mixed.

Table 3a
Pearson linear correlations between male height and nutrition (daily protein consumption in grams and daily total energy intake, after FAOSTAT 1993–2009), sorted by *r*-values. Statistically significant correlations ($p < 0.05$) are in bold. Only protein sources with a mean daily intake ≥ 0.5 g protein/day in the total sample (93 countries) were included.

EUROPE (44 countries)					Asia, Oceania, North Africa (49 countries)				
	Daily mean	SD	*r*	*p*-value		Daily mean	SD	*r*	*p*-value
'HC PROTEINS'	**39.4**	**10.6**	**0.58**	**0.000**	**TOTAL PROTEIN**	**73.0**	**17.6**	**0.71**	**0.000**
Milk products (dairy) total	**18.5**	**5.6**	**0.50**	**0.001**	**Total energy (kcal)**	**2,646**	**432**	**0.70**	**0.000**
Cheese	**6.9**	**4.7**	**0.49**	**0.001**	**'HC PROTEINS'**	**13.8**	**8.3**	**0.67**	**0.000**
ANIMAL PROTEIN	**52.3**	**16.5**	**0.49**	**0.001**	**Wheat**	**20.0**	**14.2**	**0.62**	**0.000**
Pork	**8.1**	**4.6**	**0.45**	**0.002**	**Beef**	**3.3**	**2.9**	**0.56**	**0.000**
Fish total	**2.9**	**2.2**	**0.39**	**0.009**	**Meat total**	**12.0**	**8.8**	**0.56**	**0.000**
Meat total	**22.9**	**8.9**	**0.37**	**0.014**	**Milk products (dairy) total**	**6.3**	**5.3**	**0.55**	**0.000**
Pelagic marine fish	**2.0**	**1.9**	**0.34**	**0.025**	**ANIMAL PROTEIN**	**27.3**	**15.9**	**0.53**	**0.000**
Eggs	**3.2**	**1.0**	**0.32**	**0.032**	**Vegetables total**	**3.1**	**2.0**	**0.50**	**0.000**
TOTAL PROTEIN	95.6	14.4	0.30	0.051	**Poultry**	**4.7**	**5.4**	**0.46**	**0.001**
Freshwater fish	0.7	0.7	0.29	0.053	**Milk**	**4.2**	**4.1**	**0.46**	**0.001**
Fish & Seafood	5.4	5.0	0.29	0.054	**Cheese**	**1.0**	**1.9**	**0.46**	**0.001**
Total energy (kcal)	3,153	343	0.28	0.062	**Eggs**	**1.6**	**1.4**	**0.43**	**0.002**
Beef	6.3	3.1	0.23	0.13	**Potatoes**	**0.9**	**0.9**	**0.43**	**0.002**
Potatoes	3.3	1.4	0.18	0.24	**Fruits**	**1.0**	**0.7**	**0.41**	**0.003**
Oilcrops	0.8	0.6	0.15	0.33	**PLANT PROTEIN**	**45.7**	**10.3**	**0.38**	**0.007**
Offals	2.1	1.2	0.14	0.38	**Treenuts**	**0.4**	**0.6**	**0.37**	**0.009**
Poultry	6.5	3.3	0.10	0.53	**Offals**	**1.1**	**0.9**	**0.35**	**0.015**
Treenuts	0.6	0.4	0.04	0.80	**Mutton & Goat meat**	**1.9**	**2.8**	**0.33**	**0.022**
Maize	2.1	3.7	−0.06	0.72	Cereals total	33.3	9.8	0.18	0.23
Mutton & Goat meat	1.4	2.0	−0.06	0.71	Oilcrops	2.1	2.2	0.06	0.67
Fruits	1.2	0.4	−0.06	0.68	Legumes (incl. soy)	3.5	2.7	0.04	0.77
Legumes (incl. soy)	1.8	1.4	−0.07	0.66	Legumes	2.8	2.2	0.04	0.77
Legumes	1.7	1.4	−0.10	0.52	Pork	1.6	2.2	0.04	0.81
Milk	9.1	4.0	−0.12	0.45	Pelagic marine fish	2.9	5.3	0.02	0.89
RICE & LEGUMES	**2.6**	**1.6**	**−0.19**	**0.21**	Fish & Seafood	6.2	8.3	−0.03	0.85
Rice	**0.8**	**0.5**	**−0.34**	**0.025**	Fish total	4.8	6.7	−0.09	0.56
Vegetables total	**3.6**	**1.3**	**−0.36**	**0.018**	**Maize**	**2.1**	**3.3**	**−0.35**	**0.014**
PLANT PROTEIN	**43.3**	**8.2**	**−0.46**	**0.002**	**Freshwater fish**	**0.8**	**1.2**	**−0.41**	**0.003**
Cereals total	**29.8**	**7.5**	**−0.56**	**0.000**	**RICE & LEGUMES**	**12.9**	**9.3**	**−0.63**	**0.000**
Wheat	**24.9**	**7.6**	**−0.68**	**0.000**	**Rice**	**10.1**	**9.1**	**−0.65**	**0.000**

Abbreviation: HC PROTEINS = 'Highly correlated proteins'.
Note: Statistically significant correlations ($p < 0.05$) are in bold. The item 'Highly correlated proteins' includes proteins from milk products, eggs, pork & beef meat and potatoes. The item'Fish total' includes 'pelagic (marine) fish', 'freshwater fish' and 'other marine fish'.

northeastern provinces around the Yellow Sea such as Beijing (174.5 cm), Liaoning and Shandong (both 174.2 cm), while small statures are typical of southern regions, particularly the provinces of Chongqing (167.1 cm) and Guizhou (166.5 cm) (see Appendix Fig. 1).

The geographical changes of male stature in India are comparably large. According to the most recent Indian nationwide survey (NFHS 2005–2006; Mamidi et al., 2011), the highest male averages in the age category 20–29 years were documented in northwestern states—Punjab (168.4 cm), Haryana (168.1 cm) and Jammu and Kashmir (168.0 cm). The shortest statures are typical of northeastern states—Meghalaya (157.5 cm), Sikkim (160.0 cm) and Arunachal Pradesh (161.0 cm) (Appendix Fig. 2)[15].

3.2. *GDP per capita*

The correlations of male height with the GDP per capita and other socioeconomic indicators are summarized in Table 2. Although the growing GDP per capita has been the fundamental trigger of the positive height trend during the last century, it fails to be a good correlate of male height in 96 countries ($r = 0.30$; $p = 0.003$) (Fig. 2). This is primarily due to two reasons: First, as we showed in our previous study, the relationship between height and GDP in Europe was distorted by the historical division into the "Western" and "Communist" blocs. Communist countries lagged behind in terms of economic development, but historically, the wealthiest of them were characterized by a diet associated with tall statures, which is based on milk products, pork and fish. In contrast, the dietary customs in some "Western" countries such as Portugal, Spain, Italy and Greece were different and only began to change in a similar way during the most recent decades. Second, the high GDP per capita in Muslim oil superpowers, as well as in the wealthy countries of East Asia, is not accompanied by

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[15] In religious groups, the tallest men can be found among the Sikhs and Jains (170.0 cm), while Christians are the shortest (163.8 cm). The statures of Hindus (165.1 cm), Muslims (165.3 cm) and Buddhists (164.3 cm) are close to the Indian average.

Table 3b
Pearson linear correlations between male height, nutrition (daily protein consumption in grams and daily total energy intake, FAOSTAT 1993–2009) and socioeconomic factors, sorted by *r*-values. Statistically significant correlations ($p < 0.05$) are in bold. Only protein sources with a mean intake $\geq$ 0.5 g protein/day were included.

Nutrition (93 countries)					All examined variables (72 countries)				
	Daily mean	SD	*r*	*p*-value		Mean	SD	*r*	*p*-value
'HIGHLY CORR. PROTEINS'	**25.9**	**16.0**	**0.85**	**0.000**	**'HIGHLY CORR. PROTEINS'**	**29.3**	**16.0**	**0.85**	**0.000**
Milk products (dairy) total	**12.1**	**8.2**	**0.79**	**0.000**	**Human Development Index (2011)**	**0.76**	**0.13**	**0.84**	**0.000**
TOTAL PROTEIN	**83.7**	**19.7**	**0.74**	**0.000**	**Milk products (dairy) total**	**13.8**	**8.2**	**0.80**	**0.000**
ANIMAL PROTEIN	**39.2**	**20.4**	**0.73**	**0.000**	**TOTAL PROTEIN**	**86.4**	**19.6**	**0.77**	**0.000**
Total energy (kcal)	**2,886**	**466**	**0.73**	**0.000**	**ANIMAL PROTEIN**	**41.3**	**20.9**	**0.76**	**0.000**
Cheese	**3.8**	**4.5**	**0.69**	**0.000**	**Urbanization 1993–2009**	**59.1**	**20.2**	**0.75**	**0.000**
Potatoes	**2.1**	**1.7**	**0.68**	**0.000**	**Total energy (kcal)**	**2,949**	**453**	**0.74**	**0.000**
Meat total	**17.2**	**10.4**	**0.66**	**0.000**	**Cheese**	**4.5**	**4.9**	**0.69**	**0.000**
Eggs	**2.4**	**1.4**	**0.64**	**0.000**	**Potatoes**	**2.4**	**1.7**	**0.69**	**0.000**
Pork	**4.7**	**4.8**	**0.63**	**0.000**	**Eggs**	**2.6**	**1.5**	**0.67**	**0.000**
Beef	**4.7**	**3.3**	**0.59**	**0.000**	**Meat total**	**17.9**	**10.6**	**0.67**	**0.000**
Milk	**6.5**	**4.7**	**0.54**	**0.000**	**GDP per capita 1995–2009**	**14,497**	**11,571**	**0.66**	**0.000**
Offals	**1.5**	**1.2**	**0.47**	**0.000**	**Pork**	**5.4**	**4.9**	**0.62**	**0.000**
Poultry	**5.5**	**4.6**	**0.38**	**0.000**	**Health exp. per capita 1995–2009**	**1,114**	**1,221**	**0.62**	**0.000**
Wheat	**22.3**	**11.7**	**0.35**	**0.001**	**Beef**	**5.1**	**3.3**	**0.55**	**0.000**
Treenuts	**0.5**	**0.5**	**0.29**	**0.006**	**Milk**	**7.3**	**4.9**	**0.47**	**0.000**
Vegetables total	**3.3**	**1.7**	**0.28**	**0.007**	**Poultry**	**5.3**	**4.3**	**0.45**	**0.000**
Fruits	**1.1**	**0.6**	**0.28**	**0.008**	**Offals**	**1.7**	**1.2**	**0.41**	**0.000**
Mutton & Goat meat	1.6	2.5	0.05	0.62	**Treenuts**	**0.5**	**0.4**	**0.40**	**0.001**
Fish & Seafood	5.8	6.9	−0.01	0.92	**Fruits**	**1.0**	**0.5**	**0.30**	**0.010**
PLANT PROTEIN	44.6	9.4	−0.02	0.85	**Vegetables total**	**3.4**	**1.6**	**0.27**	**0.021**
Pelagic marine fish	2.5	4.1	−0.04	0.68	**Wheat**	**23.8**	**11.6**	**0.27**	**0.022**
Maize	2.1	3.5	−0.15	0.16	Pelagic marine fish	1.9	2.2	0.14	0.23
Fish total	3.9	5.2	−0.15	0.16	Fish & Seafood	5.2	5.1	0.14	0.24
Cereals total	31.6	9.0	−0.18	0.08	Mutton & Goat meat	1.5	2.5	0.01	0.92
Freshwater fish	**0.7**	**1.0**	**−0.21**	**0.047**	Fish total	3.2	2.8	−0.04	0.74
Legumes	**2.3**	**1.9**	**−0.22**	**0.038**	Maize	2.1	3.4	−0.08	0.51
Oilcrops	**1.5**	**1.8**	**−0.24**	**0.020**	PLANT PROTEIN	45.1	9.7	−0.08	0.48
Legumes (incl. soy)	**2.7**	**2.3**	**−0.28**	**0.007**	Oilcrops	1.2	1.6	−0.17	0.15
Rice	**5.7**	**8.0**	**−0.74**	**0.000**	**Legumes**	**2.0**	**1.6**	**−0.25**	**0.038**
RICE & LEGUMES	**8.0**	**8.5**	**−0.75**	**0.000**	**Legumes (incl. soy)**	**2.4**	**2.0**	**−0.30**	**0.009**
					Freshwater fish	**0.9**	**1.0**	**−0.31**	**0.009**
					Cereals total	**32.7**	**9.0**	**−0.31**	**0.008**
					Gini index 1990–2013	**34.2**	**6.1**	**−0.51**	**0.000**
					Total fertility 1993–2009	**2.2**	**1.0**	**−0.73**	**0.000**
					Rice	**5.0**	**8.5**	**−0.75**	**0.000**
					Children's mortality 1993–2009	**28.5**	**29.2**	**−0.77**	**0.000**
					RICE & LEGUMES	**7.0**	**8.8**	**−0.77**	**0.000**

Note: Statistically significant correlations ($p < 0.05$) are in bold. The item 'Highly correlated proteins' includes proteins from milk products, eggs, pork & beef meat and potatoes. The item 'Fish total' includes 'pelagic (marine) fish', 'freshwater fish' and 'other marine fish'.

the same type of nutrition or public expenses on healthcare that we find in the tallest nations. This will be the subject of the upcoming paragraphs in this section.

3.3. Health expenditure per capita

Health expenditure turns out to be a much better correlate of male height than the GDP ($r = 0.60$; $p < 0.001$ in 97 countries) (Appendix Fig. 3). This is mainly due to the fact that the public health expenses in Muslim oil superpowers are much lower than their GDP would predict and are more in line with the unimpressive height of the local young men. Such a striking discrepancy points to a strongly uneven redistribution of yields from the oil industry.

3.4. Children's mortality under five years

The most significant socioeconomic factor out of the six that we examined in our previous study is again children's mortality ($r = -0.73$; $p < 0.001$ in 101 countries) (Fig. 3). This result remains valid even in the sample of 72 countries, for which all the data were available ($r = -0.78$; $p < 0.001$) (Table 2). The range of values is enormous, from ~4 in Finland, Iceland, Singapore and Sweden up to 132 deaths/1000 live births in Afghanistan. Interestingly, the low children's mortality rate in tropical Asia, East Asia and Muslim oil superpowers has no influence on the stature of local males.

3.5. Total fertility

Total fertility ($r = -0.64$; $p < 0.001$ in 102 countries) follows children's mortality as the second strongest socioeconomic correlate (Fig. 4). Although total fertility plays only a marginal role in Europe ($r = -0.26$; $p = 0.09$), where fertility rates are almost unanimously very low, it reaches statistical significance in the global context, because the fertility level in developing countries is still high. It is logical to assume that the lower the number of

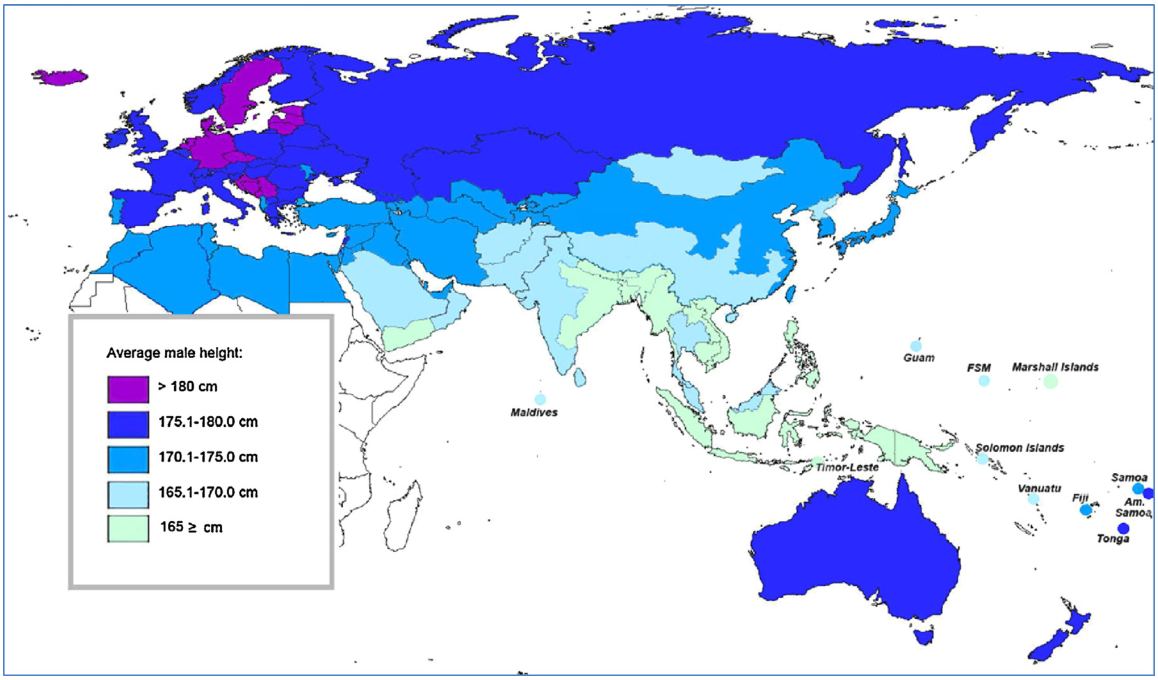

Fig. 1. *Distribution of male height in the examined areas (including regional differences in China and India). Source:* See Table 1 and Appendix Table 1.

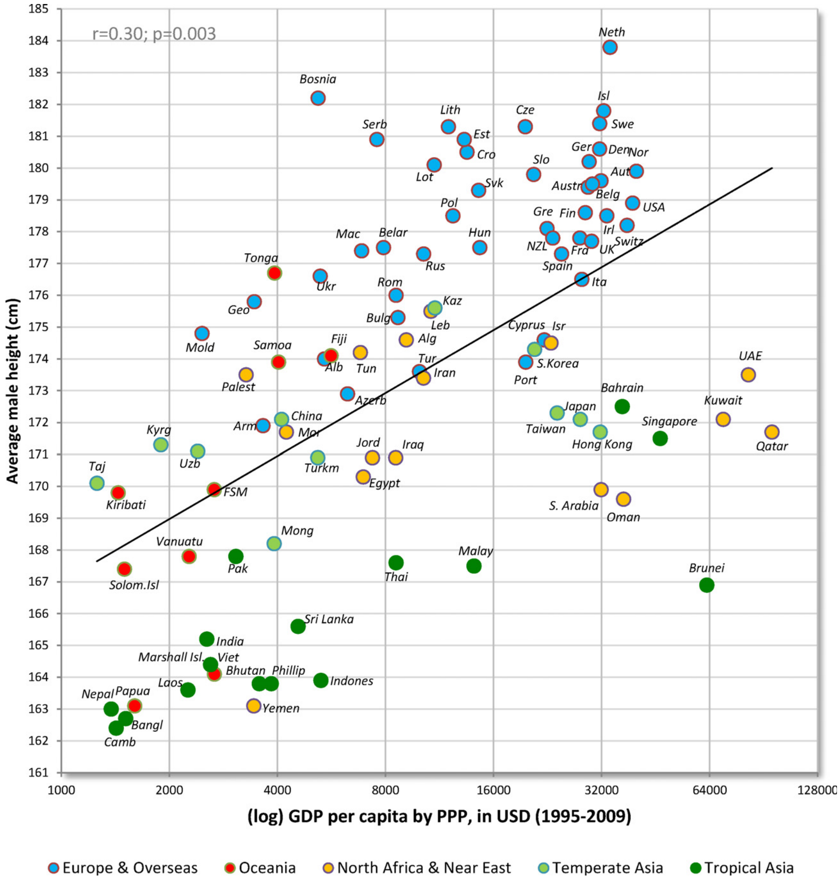

Fig. 2. Correlation between male height in 96 countries and the average annual (log) GDP per capita by purchasing power parity (PPP), in current international USD (period 1995–2009).

Fig. 3. Correlation between male height in 101 countries and the average annual children's mortality under 5 years, per 1000 live births (period 1993–2009).

children per family, the higher the financial expenditures per child would be, and hence the living conditions of the children would improve. Again, it is noteworthy that this assumption does not apply so well to tropical and East Asia, where the birth rates are similarly low or even lower than those in Europe, but the difference in body height is still 10–20 cm. On the other hand, the birth rates in Muslim oil superpowers are unusually high for the standards seen in developed countries, reaching almost 4.0 in Oman and Saudi Arabia, and exceeding other Arab countries with a substantially lower GDP. This could serve as further indirect evidence that their high GDP does not translate into adequately high living standards for most of the population and/or the degree of societal development.

3.6. *Urbanization (% of urban population)*

The correlation between urbanization and height is almost as strong as in the case of total fertility ($r = 0.58$; $p < 0.001$ in 105 countries) (Appendix Fig. 4). In general, the highest rates of urbanization are typical of Europe, Muslim countries and the highly developed countries of East Asia, but they have a much weaker correlation with height in the latter two.

3.7. *Gini index*

The Gini index, as the indicator of social inequality, does not show any statistical relationship with height in non-European countries ($r = -0.04$; $p = 0.80$), because the levels of social inequality are universally very high. This factor reaches significance only in Europe ($r = -0.36$; $p = 0.017$) and in the total sample of 80 countries ($r = -0.51$; $p < 0.001$) (Appendix Fig. 5). The Gini index tends to decrease with a growing GDP per capita ($r = -0.29$; $p = 0.010$), and countries in tropical Asia and Central Asia are the most affected by the combination of extreme poverty and deep social inequality (Appendix Fig. 6). It is symptomatic that data on the Gini index are not available from wealthy oil superpowers such as Saudi Arabia, Kuwait or Bahrain.

3.8. *Human development index (HDI)*

This comparison proved to be a very interesting addition to our analysis, because it shows one of the

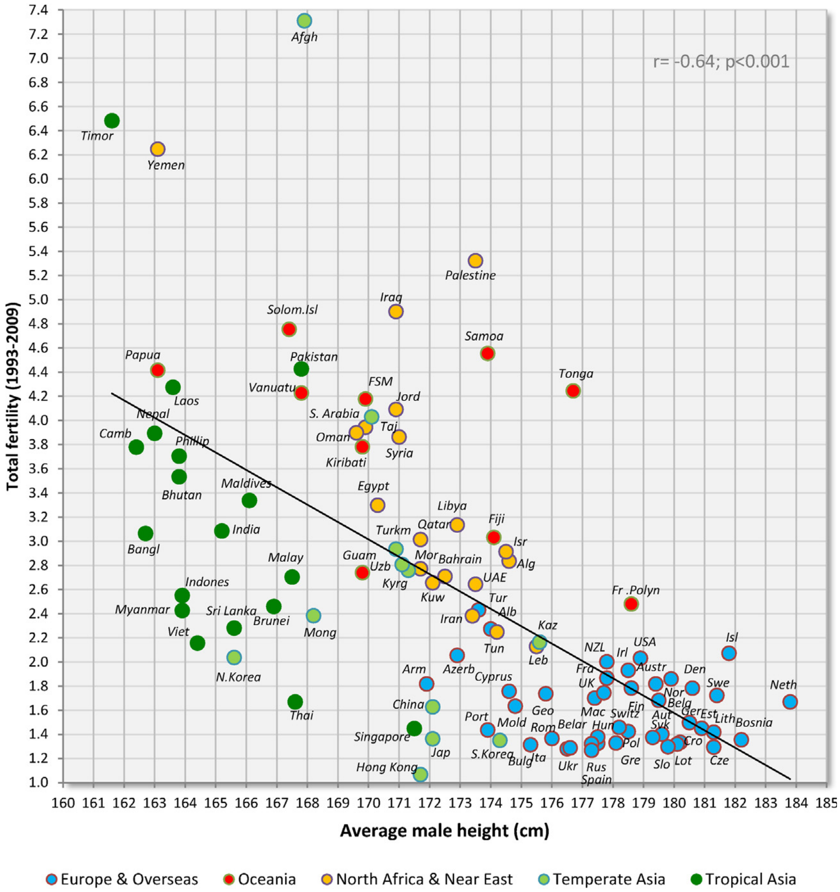

Fig. 4. Correlation between male height in 102 countries and the average annual total fertility per woman (period 1993–2009).

highest correlations with male height ($r = 0.80$; $p < 0.001$ in 100 countries) (Fig. 5). Height and the HDI seem to be largely interchangeable as indicators of human well-being. They are both related to the GDP per capita. High life expectancy is a factor that reflects the quality of healthcare and nutrition. Furthermore, better education of women translates into a lower fertility rate (Basu, 2002).

The relationship between male height and the IHDI (inequality-adjusted HDI) ($r = 0.87$; $p < 0.001$ in 72 countries) (Appendix Fig. 7) is even stronger than in the case of the HDI, but if we consider only this sample of 72 countries, for which both these indicators are available, we find no difference in r-values. The difference between the HDI and the IHDI (a benchmark for social equality) is a good correlate of male height as well ($r = -0.64$; $p < 0.001$) (Appendix Fig. 8).

3.9. Nutrition

Because our present study incorporated FAOSTAT data from a longer period of time (1993–2009), it is not surprising that the correlation coefficients in our European sample of 44 countries are often higher (Table 3a). Three additional protein sources (meat total, pelagic marine fish, eggs) reach significance and the position of milk products as key stimulators of physical growth is further strengthened ($r = 0.50$; $p < 0.001$). As already mentioned in our previous study, these findings have a very solid rationale, because milk products, red meat, eggs and some species of fish have the highest protein quality out of all common foods.

The situation in 49 non-European countries is very different. The main correlate of height is not protein quality, but total protein consumption (protein quantity) ($r = 0.71$; $p < 0.001$). Fig. 6 shows that total protein consumption in tropical Asia and some other countries such as Tajikistan, Iraq, Afghanistan or the Solomon Islands is extremely low. The main socioeconomic factor boosting total protein intake in 72 countries is the HDI ($r = 0.81$; $p < 0.001$), followed by urbanization ($r = 0.78$; $p < 0.001$) and the GDP per capita ($r = 0.76$; $p < 0.001$). When these variables were assessed individually and the number of countries examined was thus greater, the association between total protein and GDP per capita in 85 countries decreased ($r = 0.65$; $p < 0.001$), because Muslim oil superpowers such as the UAE, Kuwait and Brunei emerged as striking outliers that consume less protein than their high GDP would predict (Appendix Fig. 10a). With the increasing consumption of total protein, there are large differences in height at the same consumption level (10+ cm), which points to the importance of protein quality.

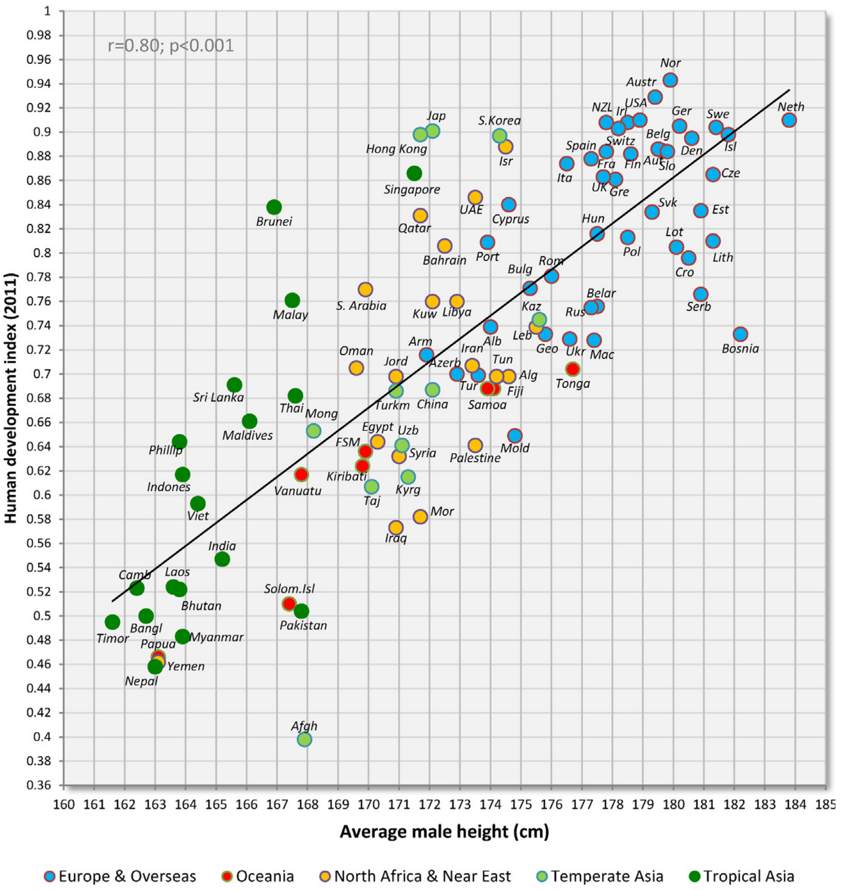

Fig. 5. Correlation between male height in 100 countries and the values of the human development index (HDI) for 2011.

Other highly significant nutritional correlates of male stature in 49 non-European countries are total energy intake ($r = 0.70$; $p < 0.001$) (Appendix Fig. 9), rice protein ($r = -0.65$; $p < 0.001$) and wheat protein ($r = 0.62$; $p < 0.001$) (Fig. 7). Rice is the main source of protein in tropical Asia (particularly in Laos, Cambodia and Bangladesh; >30 g/day), which is where we encounter extremely small height means of ~162–168 cm. The level of rice protein consumption is quite high even in Japan, China and both North and South Korea (>10 g/day). Remarkably, wheat protein correlates with male stature negatively in Europe ($r = -0.68$; $p < 0.001$), but positively outside Europe.

When rice consumption decreases, wheat consumption increases (Appendix Fig. 11a) and so do the values of male stature (Fig. 7 and Appendix Fig. 11b). The intake of total energy and total protein increases as well. The positive height tendencies tied to the increasing consumption rates of wheat reach a peak of ~174 cm in Muslim countries of North Africa and the Near East (Turkey, Tunisia, Azerbaijan). The consumption of vegetables and legumes in this region is very high as well and the proportion of animal proteins is moderate. As a result, some of these countries (Turkey, Egypt, Morocco) consume the largest amounts of plant protein in the world (Appendix Fig. 12).

In taller nations, the intake of total protein and total energy is no longer rising fundamentally, but plant proteins are substituted by animal proteins (particularly dairy proteins) (Appendix Fig. 13). Consequently, the relationship between most plant proteins and male height is curvilinear (Appendix Fig. 12), similar to that between GDP per capita and plant protein (Appendix Fig. 10b).

The animal protein intake in 72 countries rises very strongly with the HDI ($r = 0.89$; $p < 0.001$) and GDP per capita ($r = 0.87$; $p < 0.001$). Muslim oil superpowers consume much less animal protein than their high GDP per capita predicts, which again decreases the r-values, when 85 countries are considered ($r = 0.67$; $p < 0.001$) (Appendix Fig. 10c). The intake of protein from milk products (dairy proteins) emerges as the most significant nutritional correlate of stature not only in Europe, but in all 93 countries examined in this study ($r = 0.79$; $p < 0.001$) (Table 3b; Appendix Fig. 14), followed by total protein ($r = 0.74$; $p < 0.001$) and animal protein ($r = 0.73$; $p < 0.001$). The most negative nutritional correlate in the total sample is again rice ($r = -0.74$; $p < 0.001$).

Dairy proteins are most frequently consumed in the Netherlands, Sweden and Finland (almost 30 g/day), while in countries from the eastern half of Asia such as Cambodia, Laos or North Korea, their intake is virtually zero.

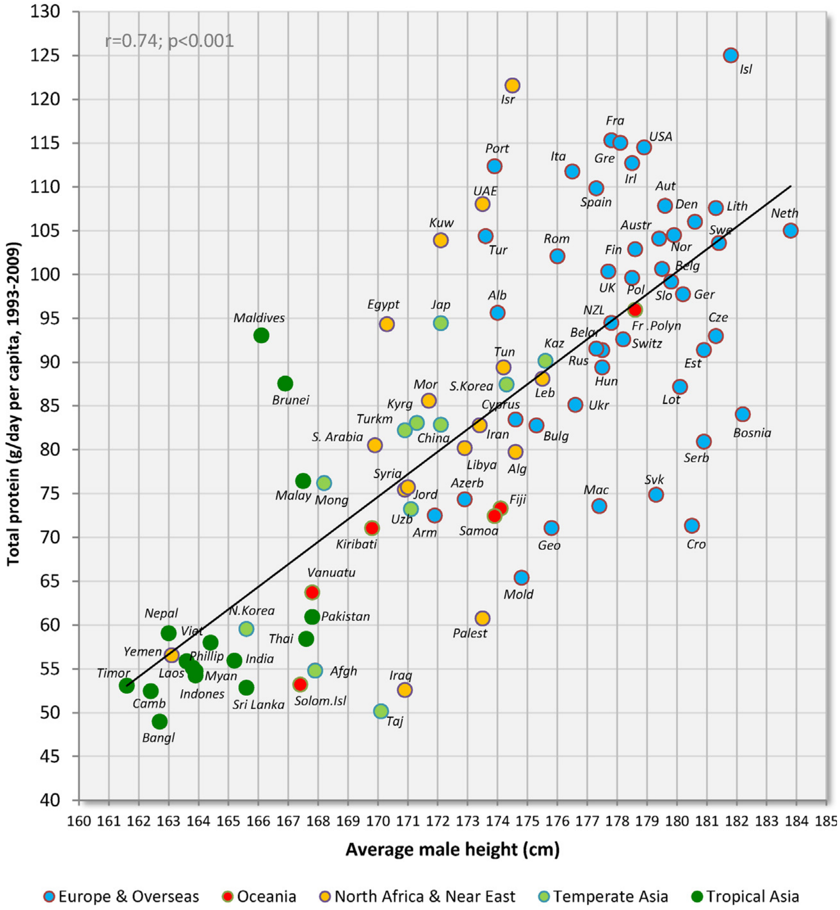

Fig. 6. Correlation between male height in 93 countries and the average daily consumption of total protein (FAOSTAT, 1993–2009).

Remarkably, this low intake of milk products is in accordance with the low prevalence of lactose tolerance in Southeast and East Asia (Appendix Fig. 15a) and the widespread undernutrition in this region. These facts confirm the fundamental evolutionary significance of lactose tolerance in a world, where the scarcity of valuable nutrients is an everyday reality[16].

Similarly to our previous study, we tried to find ratios or combinations of protein intake that would further improve the predictive power. The ratios between animal proteins and plant/cereal protein were not useful in this regard, but combinations of proteins were. Pork protein has the biggest additive effect, when combined with dairy proteins ($r = 0.82$; $p < 0.001$), followed by protein from eggs ($r = 0.81$) and potatoes ($r = 0.81$). The correlation reaches $r = 0.84$, when potatoes are added to dairy and pork. The highest r-value ($r = 0.85$) was achieved via the combination of proteins from dairy, pork, beef, eggs and potatoes ('highly correlated proteins'). The strength of this relationship is visually impressive (Fig. 8). 'Highly correlated proteins' are also the strongest correlate of male height ($r = 0.85$), when all the nutritional and socioeconomic variables from 72 countries are considered (Table 3b).

Interestingly, in this sample of 72 countries, 'highly correlated proteins' are strongly associated with the HDI ($r = 0.82$) and GDP per capita ($r = 0.77$; $p < 0.001$), but the addition of wealthy Arab countries again decreases the relationship with the GDP per capita very noticeably ($r = 0.49$; $p < 0.001$) (Appendix Fig. 10d). While Europeans often consume more of these proteins than their GDP per capita would predict, wealthy, short-statured Muslims and East Asians consume less. 'Highly correlated proteins' are also strongly associated with lactose tolerance ($r = 0.80$; $p < 0.001$), although in this case, the number of countries was limited to only 44. The relationships of nutrition with various socioeconomic factors and lactose tolerance are presented in Appendix Tables 5a–5e.

These results confirm that red meat and eggs are the most height-related components of the human diet after milk, which primarily stems from the complete amino acid

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[16] Ironically, the average intake of milk (1993–2009) in our European sample of 27 countries does not correlate well with lactose tolerance ($r = 0.17$; $p = 0.39$), because the most developed countries have substituted milk with cheese and other milk products (see further in the text). The highest intake of milk among all 93 countries can be found in Albania (225.1 kg/year per capita), Romania and Kazakhstan. This can also explain, why milk correlates slightly negatively with male stature in Europe, because it is virtually the only source of high-quality proteins in less developed countries, where height means are generally short.

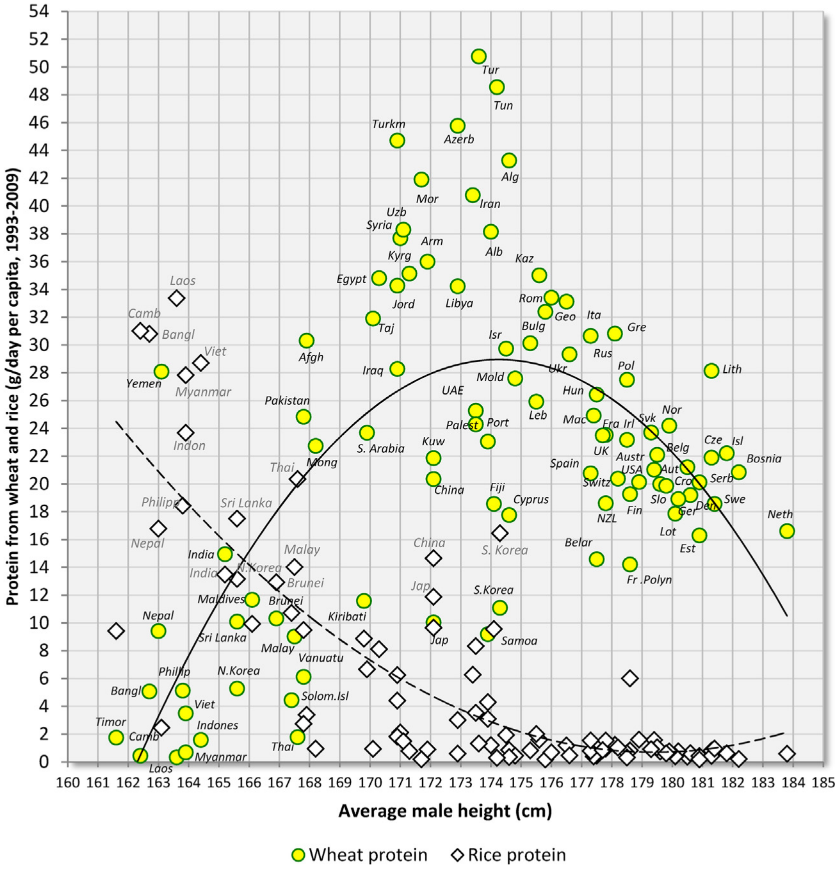

Fig. 7. Correlation between male height in 93 countries and the average daily consumption of protein from wheat and rice (FAOSTAT, 1993–2009).

spectrum of their proteins (Appendix Table 6). Our calculations show that at least in Europe and overseas, the correlation of eight main food items with height accords better with their amino acid scores based on the older FAO standard 1985 than the newer FAO standard 2007 (see Appendix Tables 7a and 7b). More concretely, the new FAO standard 2007 produces relatively higher amino acid scores for beef and fish, and a relatively lower amino acid score for pork. This is mainly due to the marked decrease of tryptophan content in the new standard[17]. The role of pork in our analysis is weakened because of its absence from the diet of Muslim countries (Appendix Fig. 17), but its statistical relationship with stature is still stronger than that of beef and fish, when all 93 countries are considered. Therefore, we think that in the light of the admitted imperfection of the current amino acid scores[18], the results of our ecological study should be taken into account seriously.

On the other hand, the significance of potatoes, even as an independent item ($r = 0.68$; $p < 0.001$), is unexpected because of the poor quality of potato proteins, their low consumption rate and a very low 'nutrient density'[19]. Therefore, we cannot exclude that the correlation

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[17] The content of tryptophan in the 1985 standard (children aged 2–5 years) was 11 mg/g of protein and decreased to 6.6 mg/g of protein in the new 2007 standard (children aged 3–10 years). According to Heine et al. (1995) "Low tryptophan serum concentrations when compared with similar values as observed in human milk feeding may reflect tryptophan depletion states, which are probably of importance for whole body protein synthesis and serotonin-related disturbances of the sleeping-waking-rhythm, appetite regulation and other serotonin-dependent abnormalities in behavior." The content of tryptophan in human milk (17 mg/g of protein) is higher than in any common food from the FAO database that we examined (aside from seaweeds and some oil seeds). The closest common foods are potatoes (16.5 mg/g of protein), champignons (15.9 mg) and spinach (15.5 mg).

[18] The report of the FAO 2011 consultation (http://www.fao.org/ag/humannutrition/35978-02317b979a686a57aa4593304ffc17f06.pdf) explicitly states that "there is a paucity of long-term prospective studies examining health outcomes [of the proposed amino-acid scoring patterns]".

[19] According to the FAO database (http://www.fao.org/docrep/005/AC854T/AC854T03.htm#chI.I), the amino acid score of potato protein is only 0.76 with 89% digestibility, which produces PDCAAS score of 0.68. The protein in potato is also weakly concentrated (2.0 g/100 g), which gives 13,412 kJ per 60 g of complete protein (acording to www.nutridatabaze.cz). However, as already mentioned, out of all common food items from the FAO database (http://www.fao.org/docrep/005/AC854T/AC854T03.htm#chI.I), potato protein stands out as the best source of tryptophan (amino acid score 1.50)—the rarest essential amino acid in the human diet that is limiting in milk products, meat and fish. In any case, the current rates of potato intake in 93 countries apparently do not interfere with physical growth.

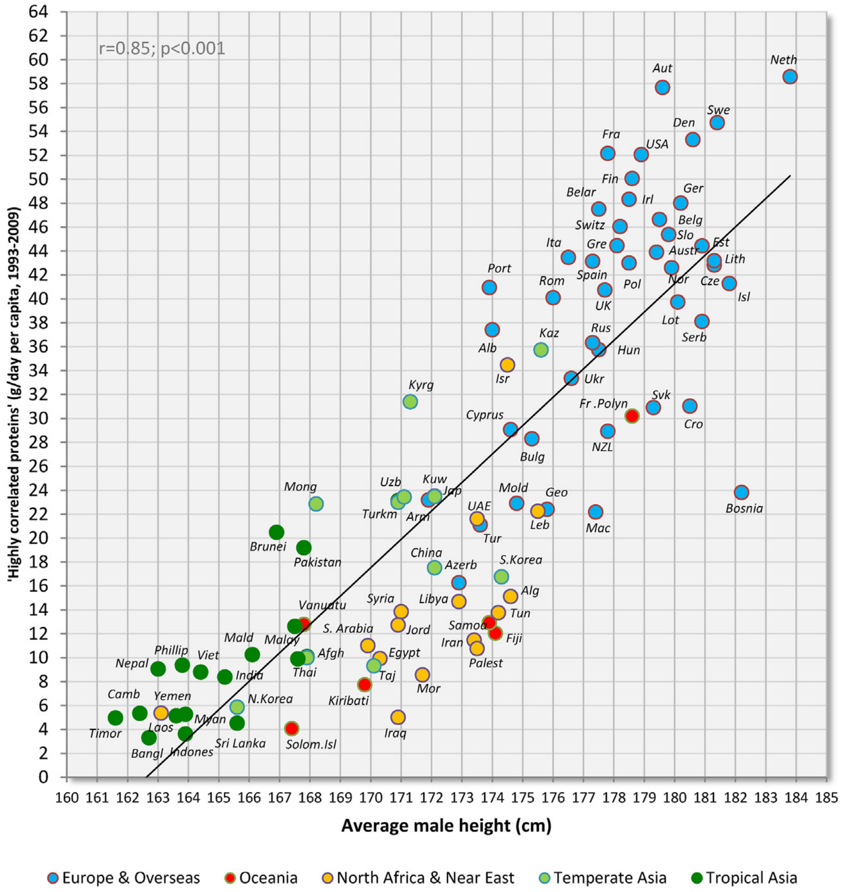

Fig. 8. Correlation between male height in 93 countries and the average daily consumption of 'highly correlated proteins' from milk products (dairy), potatoes, eggs, pork and beef (FAOSTAT, 1993–2009).

between potatoes and height is only spurious. Nevertheless, it is visually quite persuasive (Appendix Fig. 18) and the rationale behind this finding deserves further discussion[20].

In contrast with Europe, fish consumption does not contribute positively to male stature in the total sample of 93 countries ($r = -0.15$; $p = 0.16$) and freshwater fish even correlate slightly negatively ($r = -0.21$; $p = 0.047$). This result is largely deceptive, because fish consumption shows some positive relationship with male height, when the examined countries are divided according to regions (Appendix Fig. 19). In Southeast Asia, Japan and many countries in Oceania, fish remain the main source of animal protein. Other protein items with a high height correlation are not consumed in large quantities. Furthermore, there are big differences in protein quality among various species of fish.

When the food items with the most negative r-values (rice and legumes) are combined, a small additive effect is observed, when compared with rice alone ($r = -0.75$; $p < 0.001$) (Appendix Fig. 20). The proportion of energy intake from protein (assuming 4.1 kcal per 1 gram of protein) clearly highlights the low 'nutrient density' of the diet in tropical Asia (Appendix Fig. 21).

3.10. Current nutritional trends in Asia, North Africa and Oceania

The evidence presented in the previous paragraphs can persuasively explain, why many wealthy Asian countries have a smaller physical stature than European countries. A high GDP, high rates of urbanization, low children's mortality rate, high indices of human development and mostly above-average health expenditure and below-average fertility rates are not sufficient to compensate for the persisting low intake of the proteins that are most strongly associated with tall stature in the present study. In fact, the intake of 'highly correlated proteins' in Kuwait, the

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[20] The 'potato puzzle' is especially intriguing, when we consider that potato protein is a largely independent item in our analysis and correlates only moderately with proteins from dairy ($r = 0.65$) and milk ($r = 0.57$), and with total protein ($r = 0.52$; $p < 0.001$). Even after controlling for dairy protein consumption, the significance of potatoes remains high ($p < 0.001$).

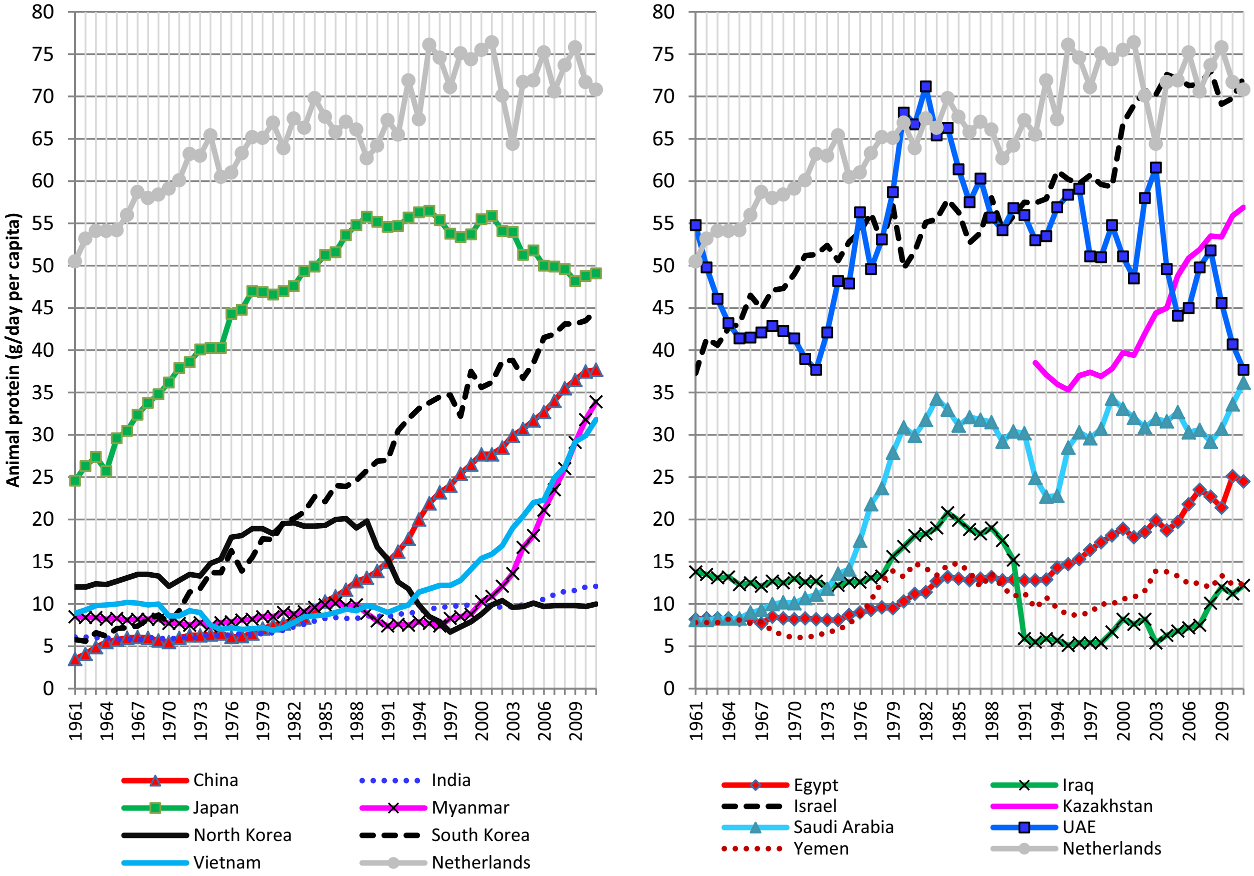

Fig. 9. *Trends in the consumption of animal protein in 14 countries between 1961 and 2011, compared with the Netherlands. Source:* FAOSTAT, http://faostat.fao.org/site/610/default.aspx#ancor.

UAE, Japan and South Korea is on the level of the poorest European countries such as Georgia and Moldova (Fig. 8). Furthermore, the level of social inequality is apparently higher than it is in the European nations with the tallest people. We can also justly suspect that the data on the Gini index from rich oil superpowers are not published for a good reason, because the disparity in the distribution of national wealth may have no parallel to the rest of the world.

Therefore, the consumption of high-quality animal proteins could theoretically predict future development. A particularly fast increase in stature can be expected in Kazakhstan, Myanmar and Vietnam, where the annual animal protein intake during the decade 2001–2011 rose by >15 g (Fig. 9). A fast upward rate (>8 g/decade) can even be observed in China, Morocco, Turkmenistan and South Korea. In contrast, the amount of animal proteins consumed has more or less declined in Afghanistan, Japan, Lebanon, Mongolia, Palestine, the Solomon Islands and the UAE. An extremely low level of consumption (~10 g/day) combined with a stagnating or only negligibly growing trend line, is typical of Bangladesh, India, Iraq, Laos, Nepal, North Korea, Tajikistan and Yemen.

3.11. Genetics: North Africa and the Near East

As already noted in the introduction, testing the relationship between height and genetic markers plays only a supplementary role in the present analysis, because the distribution of certain Y haplogroups is geographically limited. In 21 countries of the targeted regions of North Africa and the Near East, the only haplogroup that shows a significant, negative relationship with male height is J1-M267 ($r = -0.68$; $p < 0.001$) (Fig. 10a). J1-M267 is a signature of human populations that expanded from the Zagros Mountains during the Holocene and its dominant sublineage J1a2b-P58 (formerly J1e) has been connected with the spread of pastoral nomadism in the Arabian Peninsula (Chiaroni et al., 2010). Today, the frequencies of J1-M267 peak in Yemen (73%), followed by other countries of the Arabian Peninsula (~35–60%) and speakers of Northeast Caucasian languages (>50%). The role of J1-M267 remains robust ($p < 0.01$) even after controlling for protein consumption and all the socioeconomic variables, except total fertility ($p = 0.14$).

Among the four remaining haplogroups, G-M201 approaches significance as a correlate of taller statures

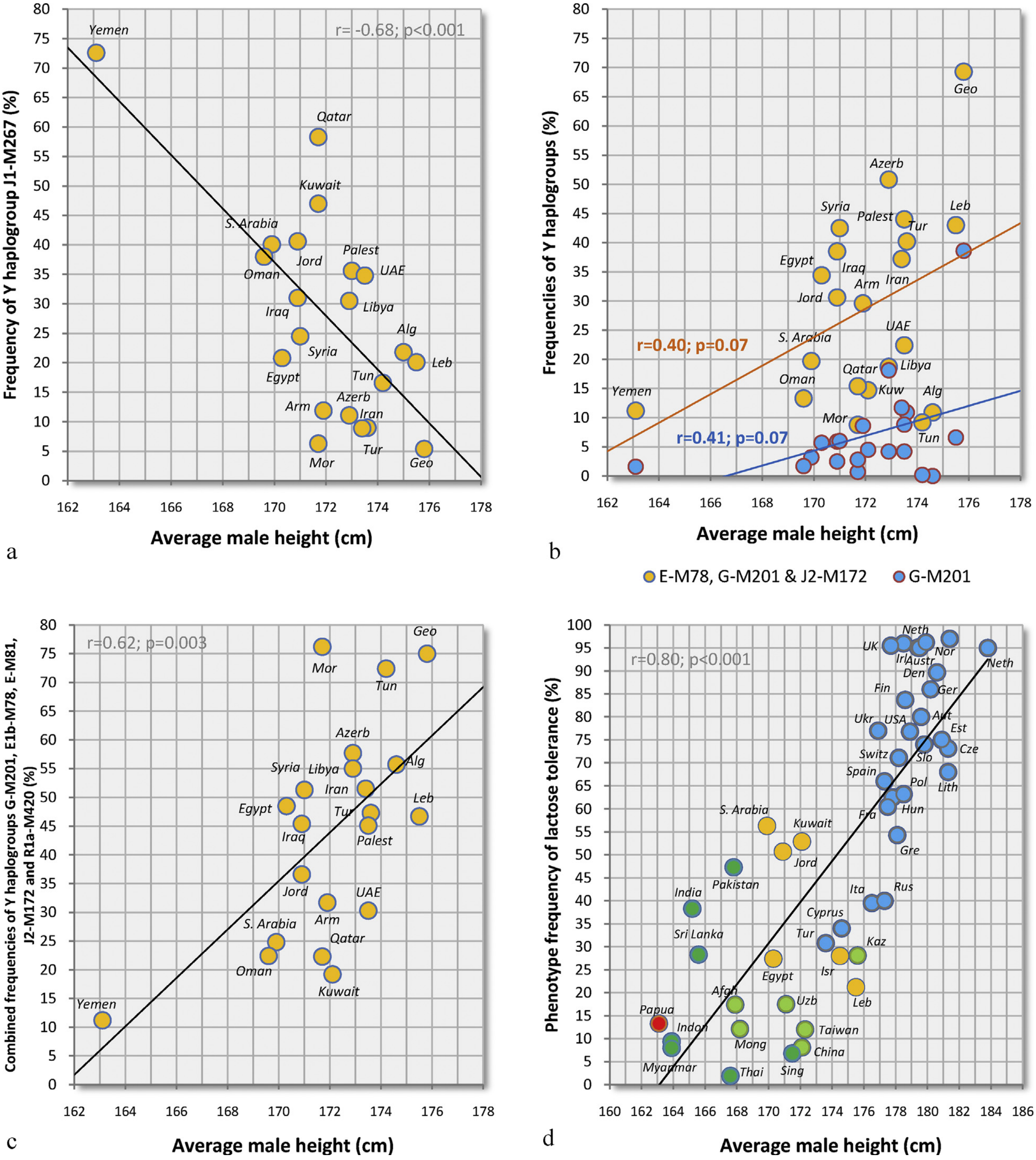

Fig. 10. (a) Correlation between the frequency of the 'pastoral' Y haplogroup J1-M267 and male height in 21 countries. (b) Correlation between the combined frequencies of the 'agricultural' Y haplogroups E-M78, G-M201 & J2-M172 and G-M201 alone, and male height in 21 countries. (c) Correlation between the combined frequencies of Y haplogroups G-M201, E1b-M78, E-M81, J2-M172 & R1a-M420 and male height in 21 countries. (d) Correlation between the phenotype frequency of lactose tolerance (%) and male height in 47 countries. *Sources:* See Appendix Table 3 and Grasgruber et al. (2014).

($r = 0.41$; $p = 0.07$) (Fig. 10b). This lineage reaches the highest frequencies in Georgia (39%) and is much rarer elsewhere (18% in Azerbaijan, 12% in Iran, 11% in Turkey). The positive effect of G-M201 becomes statistically significant, when North Africa is excluded ($r = 0.55$; $p = 0.028$). The Anatolian Neolithic lineage J2-M172 ($r = 0.21$; $p = 0.36$), as well as the East African haplogroup E1b-M78 ($r = 0.21$; $p = 0.36$) and the Northwest African

(Berber) haplogroup E1b-M81 ($r = 0.20$; $p = 0.38$) have a non-significant, but still somewhat positive association with height.

Interestingly, the combination of G-M201 and E-M78 correlates significantly positively with height ($r = 0.48$; $p = 0.027$) and three presumably 'agricultural' haplogroups G-M201, E1b-M78 and J2-M172 approach statistical significance ($r = 0.40$; $p = 0.07$) (Fig. 10b)[21]. When E-M81 is added to these three haplogroups, the r-value markedly rises to $r = 0.57$ ($p = 0.008$). The addition of the Indo-Iranian genetic signature R1a-M420 further increases the correlation coefficient to $r = 0.62$ ($p = 0.003$) (Fig. 10c), although R1a-M420 by itself shows no relationship with height ($r = 0.11$; $p = 0.63$), which must primarily be ascribed to its low frequencies across the examined regions. The significance ($p < 0.05$) of these five combined Y haplogroups persists after controlling for all the socioeconomic variables and nutrition, but again, total fertility decreases it the most relatively ($p = 0.04$).

These results indicate that J1-M267 is the major genetic correlate of short stature in the Near East and North Africa, whereas G-M201, E1b-M78, E1b-M81, J2-M172 and R1a-M420 appear to have a positive effect, although it manifests significantly only when the frequencies of these five haplogroups are combined. According to these data, the greatest potential for height could be expected in Moroccans, Tunisians and Georgians, and the lowest in Yemenites. The only other factor that markedly decreases the significance of these results is total fertility.

3.12. The independent evolution of lactose tolerance in Europe and Arabia

The polarity between the 'pastoral' haplogroup J1-M267 and the 'agricultural' haplogroups G-M201, J2-M172 and E1b-M78 does not seem to be limited to body height. J1-M267 namely lies at the epicentre of another global peak of lactose tolerance, as evidenced by relatively high prevalence values from Jordan (51%), Kuwait (53%) and Saudi Arabia (56%). Indeed, lactose tolerance has a high positive correlation with J1-M267 ($r = 0.87$; $p = 0.023$) (Appendix Fig. 22a), but a high negative correlation with E1b-M78, G-M201 and J2-M172 ($r = -0.89$; $p = 0.019$) (Appendix Fig. 22b).

Although these results are based on only six countries, they are definitely intriguing, because the evolution of lactose tolerance within pastoral communities of J1-M267 makes good sense. In addition, in our previous paper we found that the combined frequencies of E1b-M78, G-M201 and J-P209 correlated strongly negatively with lactose tolerance even in Europe ($r = -0.73$; $p < 0.001$). This finding could potentially question the calculations of Itan et al. (2009), who propose that the genes of lactose tolerance in Europe were inherited from early Central European farmers. At the same time, it is important to note that the alleles determining lactose tolerance in Europe ($-13910*T$) and in Arabia ($-13915*G$) are different, which shows that this genetic trait developed independently (Ingram et al., 2009).

The data from our previous study show that the spread of lactose tolerance in Europe is most closely tied to Y haplogroups I-M170 & R1b-U106 and the area of the North German plain[22]. The first appearance of this genetic trait can be dated to the Late Neolithic/Early Bronze Age (fourth to third millenium BC), which is already supported by paleogenetic data (Allentoft et al., 2015; Mathieson et al., 2015a). This period is characterized by the expansion of the Corded Ware culture in Northern and Central Europe, and a sudden dramatic increase in male stature of ~7 cm. However, the subsequent dissemination of lactose tolerance in Western Europe and the British Isles must be connected with some other cultural circles, most probably the Bell Beaker culture (in the late third millenium BC) and Y haplogroup R1b-S116[23]. This assumption can already be supported by the first concrete paleogenetic evidence (Cassidy et al., 2015).

Interestingly, other paleogenetic studies using autosomal DNA (Allentoft et al., 2015; Haak et al., 2015; Mathieson et al., 2015a, 2015b) suggest a more complex scenario. The populations carrying I-M170 & R1b-U106 may have originally acquired lactose tolerance from the pastoral Yamnaya people, who migrated to Central Europe from the Pontic/Caspian steppe around 3000 BC and formed the basis of the Corded Ware culture. This assumption is based on the strikingly high frequency of lactose tolerance in the Yamnaya culture and even other related steppe cultures of Central Asia (Afanasievo, Mezhovskaya, Karasuk; fourth to second millenium BC) (Allentoft et al., 2015), of which at least the latter two could be connected with Indo-Iranian speakers. Indeed, the allele that is responsible for the relatively high lactose tolerance in Pakistan (47%) and India (38%) is identical to $-13910*T$ from Europe (Ingram et al., 2009) (Appendix Fig. 15b). Furthermore, a positive geographical connection appears to exist between lactose tolerance in Central Asia/India and Y haplogroup R1a-Z93—a specific Indo-Iranian subbranch of R1a-M420 identified by Underhill et al. (2015) (Appendix Fig. 16).

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[21] In contrast, combined frequencies of E1b-M78, G-M201 and J-P209 (=overwhelmingly J2) correlated negatively with the height of young men in Europe ($r = -0.64$; $p < 0.001$).

[22] The correlation between I-M170 & R1b-U106 and lactose tolerance reached $r = 0.74$ ($p < 0.001$), but the drawback of this analysis is the low number of available countries ($n = 23$). The correlation coefficient would undoubtedly decrease, if we included data from Balkan countries with a moderate prevalence of lactose tolerance, but high frequencies of the local subbranch I2a1-P37.2, which apparently has little to do with the origin of the lactose tolerance allele. Nevertheless, we collected all available data on the frequency of I2a1-P37.2 in these 23 countries and after its exclusion, the r-value further slightly increased to $r = 0.76$ ($p < 0.001$).

[23] I-M170 & R1b-U106 deeply underestimate lactose prevalence in Ireland and in some Western European countries such as Spain, but the addition of R1b-S116 - a typical haplogroup of the Bell Beaker males (Mathieson et al., 2015b)—compensates for this discrepancy and improves the correlation to $r = 0.78$ ($p < 0.001$) in 21 countries. Even after the exclusion of I2a1-P37.2, the result does not drastically change ($r = 0.75$; $p < 0.001$). Furthermore, without the highly dubious value of lactose tolerance prevalence from Ukraine, it would have actually improved to $r = 0.79$ ($p < 0.001$).

An eastern migration to Central Europe during the Late Neolithic/Bronze Age is also reflected by the very high (50%) frequencies of R1a-M420 in the available samples of Corded Ware males (Mathieson et al., 2015b), but as we emphasized in our previous article, R1a-M420 correlates slightly negatively with lactose tolerance in today's Europe ($r = -0.10$; $p = 0.62$) (see Appendix Fig. 15a). Only the combined frequency of two minor subbranches typical of Germanic speaking nations (R1a-Z284 and R1a-M417*) shows a certain positive relationship ($r = 0.45$; $p = 0.045$ in 20 countries). Furthermore, the problem with the findings of Allentoft et al. (2015) is that lactose tolerance frequency was determined only indirectly (based on the presence of mutations that accompany $-13910*T$ today). Mathieson et al. (2015a) could not find any trace of $-13910*T$ in the available Yamnaya samples and the oldest sample containing $-13910*T$ belonged to a man from the Bell Beaker culture (ca. 2300 BC). In any case, irrespective of the origin of $-13910*T$, its frequencies started to increase markedly as late as the period after its emergence in Central Europe and all the above mentioned models are not mutually exclusive.

When the available data on lactose tolerance from Europe are combined with those from North Africa, Asia and Oceania, they correlate highly with dairy proteins ($r = 0.80$; $p < 0.001$ in 44 countries) (Appendix Fig. 23a), but much less with milk protein ($r = 0.39$; $p = 0.008$ in 44 countries) (Appendix Fig. 23b). This counterintuitive finding is in line with the results from Europe. It shows that lactose tolerance is not a good predictor of the contemporary rates of milk intake, but it is a fundamental prerequisite for the long-term incorporation of milk products into the diet. In developing countries, milk usually serves as the main source of high-quality proteins, irrespective of the lactose tolerance of the local population. Furthermore, it is often consumed in the fermented form (yoghurt) that retains the biological quality of milk. The highly developed, lactose tolerant nations of Europe have gradually replaced milk with more expensive milk products such as cheese. Although cheese and curd contain only casein (the predominant form of protein in milk), which is of a somewhat lower quality than the complete milk protein, the advantage of these products lies in the much higher protein concentration, relative to their volume and energy intake.

Not too surprisingly, lactose tolerance also has a strong relationship with the intake of 'highly correlated proteins' ($r = 0.80$) and animal protein in general ($r = 0.75$; $p < 0.001$) (Appendix Table 5e). On the other hand, it has the most negative relationship with rice protein ($r = -0.60$; $p < 0.001$) and protein from rice and legumes ($r = -0.62$; $p < 0.001$). Similar results are reported by Blum (2013), who suggests that lactose tolerance is a driving force of high animal protein intake.

In Europe, lactose tolerance by itself strongly predicts male height ($r = 0.71$; $p < 0.001$) and its predictive power remains significant even after controlling for all the other factors that we examined, except its own genetic signature (I-M170 & R1b-U106). This suggests that the genes for lactose tolerance are associated with some genes that determine tall stature in Europeans. Indeed, the sudden introduction of 'tall genes' into Central Europe during the Late Neolithic/Early Bronze Age is apparent even in the paleogenetic analysis conducted by Mathieson et al. (2015a). In our present extended sample, lactose tolerance also has a strong positive correlation with male height in 47 countries ($r = 0.80$; $p < 0.001$) (Fig. 10d). Its significance as a correlate of male height is retained even after controlling for all the other variables, except 'highly correlated proteins' ($p = 0.11$). Nevertheless, it is paradoxical that Y haplogroup J1-M267 is associated with both lactose tolerance and *shorter* stature. All we can say is that with the exception of Kuwait and the UAE, the consumption of milk and other dairy products in the Arabian Peninsula is currently low and lactose tolerance thus does not bring any practical benefits.

3.13. Genetics: South, Southeast and East Asia, and Oceania

Another analysis of Y haplogroups was performed for South, Southeast and East Asia, and Oceania. We found that the correlations of Y haplogroups with male height in these regions are generally weak, but they markedly increase, after countries with negligible frequencies (2% >) are excluded. In this case, O1-MSY2.2 ($r = -0.33$; $p = 0.20$ in 17 countries), O2-P31 ($r = -0.26$; $p = 0.37$ in 14 countries) and O2a-PK4 ($r = -0.43$; $p = 0.17$ in 12 countries) tend to correlate with shorter statures. Only the combination of O1 & O2a reaches significance ($r = -0.53$; $p = 0.017$ in 20 countries) (Fig. 11a). In contrast, O3-M122 is significantly associated with taller statures ($r = 0.42$; $p = 0.042$ in 24 countries) (Fig. 11b). Interestingly, it is O3, not O1 that dominates in the tall Austronesian speakers of Oceania.

3.14. Regression analysis of the total sample

As already stated above, only 72 countries with the complete data for the 38 variables were used for the multiple regression analysis (Table 3b). To obtain the simplest predictive model, only four nutritional variables that were significant in the bivariate correlations were selected: 'Highly correlated proteins', poultry, rice (or rice & legumes), and total energy intake. Protein sources with daily intakes below 5 g/day were eliminated, similarly like largely duplicit items strongly related to 'highly correlated proteins' (total protein, animal protein, meat total) and plant proteins with a curvilinear relationship with height. Among the socioeconomic variables, we excluded only the human development index, because it is characterized by the strongest degree of collinearity.

A separate regression with nutritional variables (Table 4) shows that when merely two items are considered, by far the highest percentage of variation (adj. R^2) is explained by the combination of 'highly correlated proteins' with rice (79.5%), or with rice & legumes (79.0%). Only total energy intake slightly improves this model (to 80.9% and 81.5%, respectively)[24]. Out of all the socioeconomic variables, total fertility (86.3%) and children's mortality (85.1%) have the

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[24] The inclusion of total protein – another factor inversely related to high rice intake – had no influence on the results, both with and without the Gini index. Total protein with rice explained only 70.8% of variation.

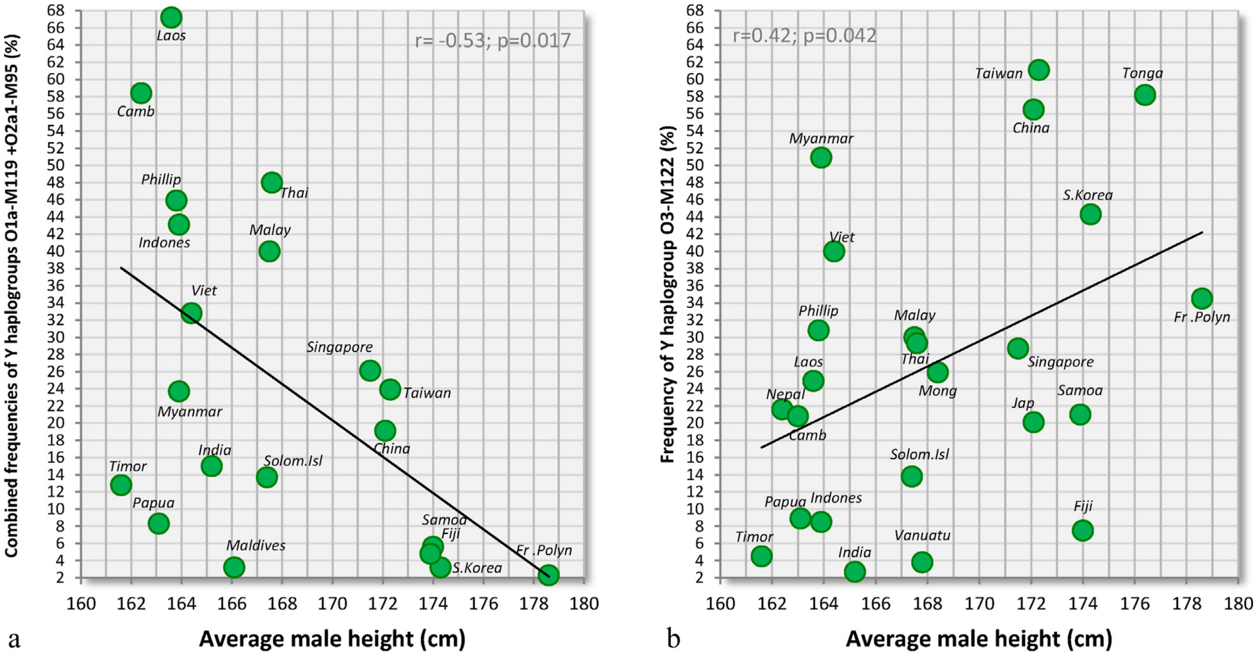

Fig. 11. (a) Correlation between male height and the combined frequencies of Y haplogroups O1-MSY2.2 and O2a-PK4 in 20 countries. *Note:* Countries with very low freequencies below 2% were excluded. The sample of Cambodia includes O1-MSY2.2 and O2-P31. (b) Correlation between male height and the frequency of Y haplogroup O3-M122 in 24 countries. *Note:* Countries with very low freequencies below 2% were excluded.

biggest additive effect, while urbanization influences the model only marginally (82.1%). The GDP per capita, health expenditure per capita and Gini index decrease it very slightly. Nevertheless, the best model explaining 87.2% of the variation was achieved via the combination of 7 variables. When we conducted a similar analysis with 83 countries, excluding the Gini index (for bivariate correlations, see Appendix Table 8), we obtained practically the same results, with only slightly lower adj. R^2 values (Appendix Table 9). In all these models, rice (or rice & legumes) is the only variable that always retains a very high level of significance ($p < 0.001$).

These findings point to rice as the most negatively correlated dietary factor, more so than wheat, which is somewhat unexpected. Although rice is a source of low-quality protein, similar to other cereals, it has a higher amino acid score, that is, a higher protein quality than wheat flour (0.63 vs. 0.48 according to the FAO standard 1985). Since rice protein correlates negatively not only with wheat protein ($r = -0.69$; $p < 0.001$), but even with many sources of high-quality animal proteins, especially total dairy ($r = -0.66$), 'highly correlated proteins' ($r = -0.62$; $p < 0.001$), and even total protein ($r = -0.56$) and total energy ($r = -0.51$, $p < 0.001$), it could be assumed that high rice consumption symbolizes a diet with a low content of milk and other important foodstuffs, and reflects general malnutrition.

This conclusion could also indicate that rice reflects general poverty, but the preference for rice or wheat apparently bears no close relation to the national GDP per capita (Appendix Figs. 24a and 24b) and rice is even more expensive to harvest than wheat[25]. Furthermore, the same strong polarity between height and rice/wheat that was documented in our sample of 93 countries exists in India and China (Appendix Figs. 25a–25d and 26a–26d). Rice and wheat do not show any significant association with the GDP per capita in 29 Indian states and 30 Chinese provinces, but rice correlates significantly negatively with male stature both in India ($r = -0.62$; $p < 0.001$) and China ($r = -0.41$; $p = 0.024$). In contrast, wheat shows a positive relationship with male stature in India ($r = 0.53$; $p = 0.003$) and tends to have the same effect in China ($r = 0.25$; $p = 0.19$). Wheat and rice correlate strongly negatively with each other, especially in China[26].

Therefore, it is not poverty *per se*, but mainly geography that influences rice consumption, because rice-producing regions are unsuitable for the cultivation of wheat (and *vice versa*). On the other hand, we should also explain, why the intake of protein and energy in poor, wheat-consuming nations

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[25] Indian Wheat and Rice Sector Policies and the Implications of Reform. Appendix Table 1.5, Base-year prices, pp. 40, http://www.ers.usda.gov/media/197077/err41_1_.pdf.

[26] Rice consumption in India has a strongly inverse relationship with both wheat ($r = -0.83$; $p < 0.001$ in urban areas, $r = -0.84$; $p < 0.001$ in rural areas) and milk ($r = -0.73$; $p < 0.001$ in urban areas and -0.77; $p < 0.001$ in rural areas). Interestingly, milk is the main correlate of male stature in 29 Indian states. This remains valid, when we consider both rural ($r = 0.72$; $p < 0.001$) and urban ($r = 0.67$; $p < 0.001$) data of the self-reported monthly milk consumption from 2004-2005. The consumption of milk in China is negligible and the main determinant of height in rural areas is eggs ($r = 0.80$; $p < 0.001$), although their consumption is rather low. In any case, rice correlates with wheat even more negatively than in India ($r = -0.90$; $p < 0.001$).

Table 4
Multiple regression models of height (including the Gini index, 72 countries).

	Nutrition				Nutrition + Socioeconomic variables					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
'Highly correlated proteins'	0.68 $r = 0.67$ ($p < 0.001$)	0.63 $r = 0.74$ ($p < 0.001$)	0.50 $r = 0.57$ ($p < 0.001$)	0.42 $r = 0.49$ ($p < 0.001$)		0.40 $r = 0.47$ ($p < 0.001$)	0.33 $r = 0.43$ ($p < 0.001$)	0.29 $r = 0.39$ ($p < 0.001$)	0.23 $r = 0.28$ ($p = 0.022$)	0.33 $r = 0.47$ ($p < 0.001$)
Total energy	0.23 $r = 0.30$ ($p = 0.011$)		0.20 $r = 0.29$ ($p = 0.015$)	0.25 $r = 0.36$ ($p = 0.002$)		0.17 $r = 0.23$ ($p = 0.056$)	0.10 $r = 0.16$ ($p = 0.20$)	0.18 $r = 0.31$ ($p = 0.009$)	0.15 $r = 0.22$ ($p = 0.08$)	0.08 $r = 0.13$ ($p = 0.31$)
Rice		−0.35 $r = -0.52$ ($p < 0.001$)	−0.33 $r = -0.52$ ($p < 0.001$)		−0.55 $r = -0.75$ ($p < 0.001$)					−0.32 $r = -0.57$ ($p < 0.001$)
Rice & Legumes				−0.36 $r = -0.54$ ($p < 0.001$)		−0.33 $r = -0.50$ ($p < 0.001$)	−0.36 $r = -0.57$ ($p < 0.001$)	−0.36 $r = -0.60$ ($p < 0.001$)	−0.33 $r = -0.56$ ($p < 0.001$)	
Poultry									−0.08 $r = -0.14$ ($p = 0.28$)	−0.10 $r = -0.19$ ($p = 0.12$)
Urbanization						0.15 $r = 0.22$ ($p = 0.07$)			0.10 $r = 0.15$ ($p = 0.22$)	0.13 $r = 0.20$ ($p = 0.11$)
Children's mortality							−0.30 $r = -0.45$ ($p < 0.001$)		−0.14 $r = -0.18$ ($p = 0.16$)	−0.14 $r = -0.17$ ($p = 0.16$)
Total fertility					−0.52 $r = -0.73$ ($p < 0.001$)			−0.29 $r = -0.52$ ($p < 0.001$)	−0.19 $r = -0.29$ ($p = 0.021$)	−0.20 $r = -0.30$ ($p = 0.014$)
Gini index									−0.06 $r = -0.13$ ($p = 0.30$)	
Observations (n)	2	2	3	3	2	4	4	4	8	7
Adj. R^2	0.744 ($p < 0.001$)	0.795 ($p < 0.001$)	0.809 ($p < 0.001$)	0.815 ($p < 0.001$)	0.790 ($p < 0.001$)	0.821 ($p < 0.001$)	0.851 ($p < 0.001$)	0.863 ($p < 0.001$)	0.868 ($p < 0.001$)	0.872 ($p < 0.001$)

Note: The first row in each cell displays standartized b^* coefficients illustrating how many standard deviations a dependent variable (height) will change, per standard deviation increase in the independent variable. The second row displays partial correlations (i.e. a correlation with height after controlling for other independent variables included in the regression). The third row displays probability p-values.

is much higher than in comparably poor, rice-consuming nations (Appendix Figs. 10a and 24c). In Vietnam, living in a farming community and having a lower socioeconomic status are the main determinants of a low energy intake and high carbohydrate consumption, the latter being directly related to rice (Nguyen et al., 2013). This points to limited food alternatives in isolated, poor farming regions of tropical Asia, which are not suitable for large-scale production of both wheat and livestock.

Indeed, another important factor from the World Bank database, arable land (% of land area, 1993–2009)[27], has the most positive relationship with the consumption of protein from beef ($r = 0.42$; $p < 0.001$) and milk ($r = 0.41$; $p < 0.001$) in 93 countries, and it is also positively tied to 'highly correlated proteins' ($r = 0.34$; $p < 0.001$), total protein ($r = 0.23$; $p = 0.029$) and wheat protein ($r = 0.21$; $p = 0.048$). On the other hand, it correlates most negatively with proteins from rice & legumes ($r = -0.31$; $p = 0.003$), rice protein ($r = -0.27$; $p = 0.008$) and legume protein (incl. soy) ($r = -0.27$; $p = 0.009$). In accordance with this finding, the consumption of milk and and the consumption of wheat in India are strongly associated with each other ($r = 0.81$; $p < 0.001$ in urban areas, $r = 0.73$; $p < 0.001$ in rural areas). Furthermore, when the complete data from 72 countries are considered, the socioeconomic factor with the strongest (negative) relationship with rice is urbanization ($r = -0.57$; $p < 0.001$), which also indicates the influence of narrow food choices.

Still, the lack of other food alternatives in the farming communities of tropical Asia cannot explain, why the maximum consumption rates of rice protein in the FAOSTAT database (~30 g/day) are much lower than those of wheat protein (~50 g/day). One possible explanation, already outlined above (see Appendix Fig. 21), is that rice is characterized by a very low nutrient density. The content of protein in rice is much lower than that in wheat[28] and when protein digestibility (PDCAAS score) is taken into account, roughly 24% more energy from cooked white rice must be consumed per gram of complete protein, when compared with wheat flour, in addition to the weight being nearly 4-times greater[29]. The data from the Czech Nutridatabaze.cz indicate even greater differences (43% more energy) between white bread and husked parboiled rice[30]. Therefore, rice may not only further exacerbate the negative effect of a low total protein and energy intake, but its high consumption may also directly contribute to it[31].

3.15. Residuals of observed and predicted height in the total sample

The comparison of observed and predicted height (Table 5 and Fig. 12a and b), based on model (10) from Table 4, shows that the region of tropical Asia is characterized by a clear tendency towards shorter heights than the model predicts (−0.5 cm). Furthermore, after the exclusion of the outlier urban sample from Laos, the difference rises to −0.8 cm. In contrast, China and South Korea are above the predicted value. Apparently, these results are compatible with the presumed relationships between height and various subbranches of Y haplogroup O-M175 in East and Southeast Asia, although the supposed genetic impact would be relatively small. The influence of genetics in North Africa and the Near East also appears to be plausible, when only nutrition is considered, but it diminishes markedly after socioeconomic factors are taken into account. Perhaps the most interesting observation is thus the position of five Altaic-speaking nations of Central Asia, which are consistently below the predicted value (−2.0 cm on average). Not too surprisingly, countries from Western and Southwestern Europe have negative residuals, whereas positive residuals are generally the most prevalent in the Western Balkans and Central/Northern Europe (as much as +6.3 cm in Bosnia and Herzegovina, +3.6 cm in Croatia and +3.1 cm in the Netherlands).

Without the Gini index, we again get very similar results (Appendix Table 10 and Appendix Figs. 27a and 27b), but this time we can even assess Oceania and more Muslim countries. Interestingly, three countries from Remote Oceania (Fiji, Kiribati, Samoa) are considerably above the predicted height, and the positive residual in Samoa reaches +4.2 cm. Two countries from Near Oceania (the Solomon Islands, Vanuatu) do not come close to these values.

4. Conclusion

The current study extends our previous data from Europe and enables a better understanding of the enviromental determinants of physical growth in the developing world. The most fundamental finding is that the nutritional correlates of male height in North

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[27] http://data.worldbank.org/indicator/AG.LND.ARBL.ZS/countries/1W?display=map. According to the definition of the World Bank, "arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded."

[28] According to the USDA.org database (http://ndb.nal.usda.gov/ndb/nutrients/index), raw long-grain rice contains 7.1 g protein per 100 g (215 kJ/g of protein) and cooked white rice contains only 2.7 g protein per 100 g (202 kJ/g of protein). In contrast, the content of protein in wheat flour is 12 g per 100 g (126 kJ/g of protein).

[29] The protein digestibility of rice in humans (90%) and white wheat flour in humans (92%) was taken from the Report of a Sub-Committee of the 2011 FAO Consultation, http://www.fao.org/ag/humannutrition/36216-04a2f02ec02eafd4f457dd2c9851b4c45.pdf). The PDCAAS scores of rice and wheat flour are thus 0.57 and 0.44, respectively. This means that 100 g of cooked rice contains an equivalent of 1.5 g of complete protein, whereas 100 g of wheat flour contains an equivalent of 5.3 g of complete protein. In order to consume an equivalent of 60 g of complete protein, roughly 3.9 kg of cooked rice (21,186 kJ) or 1.1 kg of wheat flour (17,125 kJ) would have to be eaten. In contrast with these extreme numbers, the same amount of complete protein can be supplied by 1.54 L of half-fat milk (2972 kJ) or full-fat milk (4066 kJ).

[30] The exact numbers are 16,861 kJ (1.6 kg) for white bread and 24,145 kJ (4.0 kg) for husked parboiled rice, when 60 g of complete protein is to be consumed.

[31] Indeed, the only negative nutritional correlates of the protein energy/total energy ratio are proteins from rice & legumes ($r = -0.48$; $p < 0.001$) and rice ($r = -0.47$; $p < 0.001$). Rice protein ($r = -0.51$; $p < 0.001$) and proteins from rice & legumes ($r = -0.47$; $p < 0.001$) are also the only negative nutritional correlates of total energy intake.

Table 5
Observed and predicted values of male height, based on model (10) from Table 4.

	Observed	Predicted	Residual		Observed	Predicted	Residual
Albania	174.0	175.7	−1.7	Laos	163.6	159.1	4.5
Algeria	174.6	173.1	1.5	Latvia	180.1	178.5	1.6
Armenia	171.9	175.0	−3.1	Lithuania	181.3	178.9	2.4
Australia	179.4	178.1	1.3	Macedonia	177.4	175.3	2.1
Austria	179.6	180.9	−1.3	Malaysia	167.5	169.5	−2.0
Azerbaijan	172.9	172.6	0.3	Moldova	174.8	174.7	0.1
Bangladesh	162.7	161.9	0.8	Mongolia	168.2	173.2	−5.0
Belarus	177.5	179.7	−2.2	Morocco	171.7	171.8	−0.1
Belgium	179.5	180.2	−0.7	Nepal	163.0	164.4	−1.4
Bosnia & Herzegovina	182.2	175.9	6.3	Netherlands	183.8	180.7	3.1
Bulgaria	175.3	176.5	−1.2	New Zealand	177.8	176.3	1.5
Cambodia	162.4	160.7	1.7	Norway	179.9	179.0	0.9
Croatia	180.5	176.9	3.6	Pakistan	167.8	167.8	0.0
Cyprus	174.6	175.7	−1.1	Philippines	163.8	166.4	−2.6
Czech Republic	181.3	179.0	2.3	Poland	178.5	178.7	−0.2
Denmark	180.6	180.3	0.3	Portugal	173.9	177.4	−3.5
Egypt	170.3	169.8	0.5	Romania	176.0	177.5	−1.5
Estonia	180.9	178.9	2.0	Russian Federation	177.3	177.9	−0.6
Finland	178.6	179.8	−1.2	Slovakia	179.3	176.7	2.6
France	177.8	179.6	−1.8	Slovenia	179.8	178.2	1.6
Georgia	175.8	174.9	0.9	South Korea	174.3	173.1	1.2
Germany	180.2	180.0	0.2	Spain	177.3	178.7	−1.4
Greece	178.1	179.6	−1.5	Sri Lanka	165.6	167.4	−1.8
Hungary	177.5	176.9	0.6	Sweden	181.4	180.5	0.9
China	172.1	170.8	1.3	Switzerland	178.2	179.6	−1.4
Iceland	181.8	178.9	2.9	Tajikistan	170.1	167.6	2.5
India	165.2	166.3	−1.1	Thailand	167.6	168.5	−0.9
Indonesia	163.9	165.7	−1.8	Tunisia	174.2	174.0	0.2
Iran	173.4	171.9	1.5	Turkey	173.6	174.7	−1.1
Ireland	178.5	178.2	0.3	Turkmenistan	170.9	171.9	−1.0
Israel	174.5	174.3	0.2	Ukraine	176.6	177.8	−1.2
Italy	176.5	179.2	−2.7	United Kingdom	177.7	178.0	−0.3
Japan	172.1	174.5	−2.4	USA	178.9	178.2	0.7
Jordan	170.9	170.4	0.5	Uzbekistan	171.1	172.2	−1.1
Kazakhstan	175.6	175.8	−0.2	Viet Nam	164.4	165.4	−1.0
Kyrgyzstan	171.3	173.7	−2.4	Yemen	163.1	163.8	−0.7

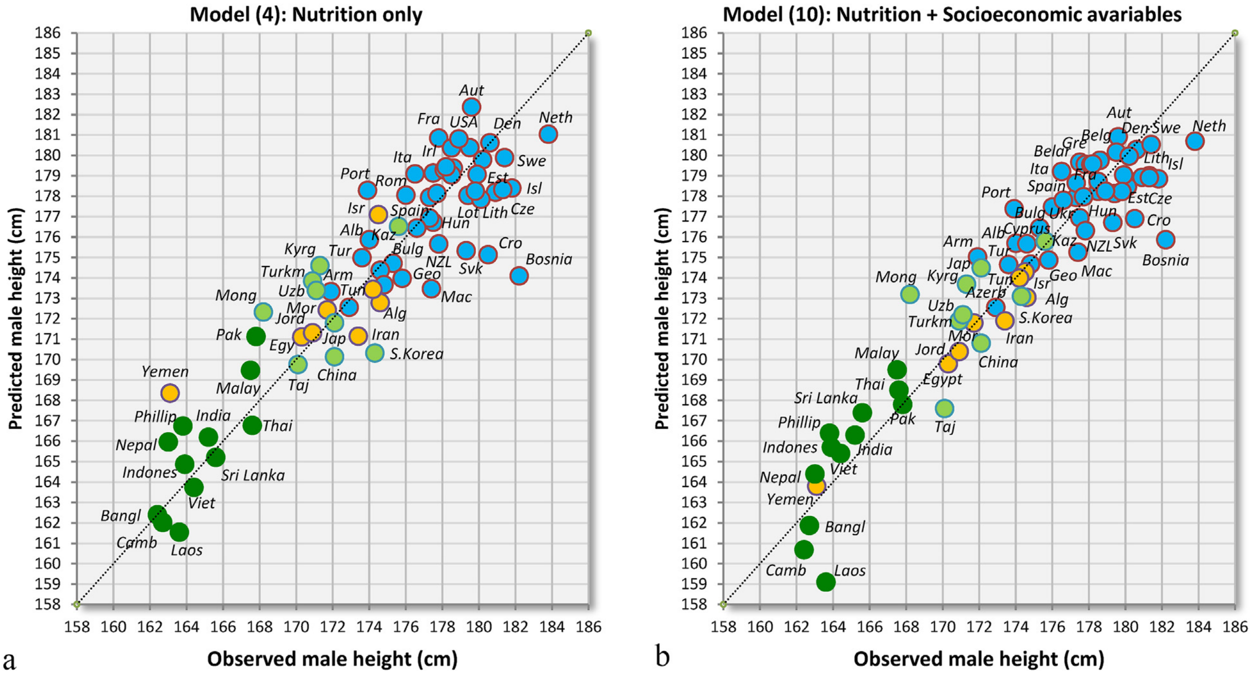

Fig. 12. (a) Correlation between the observed and predicted values of male height–model (4) (see Table 4). (b) Correlation between the observed and predicted values of male height–model (10) (see Table 4).

Africa, Asia and Oceania are very different and primarily depend on protein quantity, not protein quality. Furthermore, three basic nutritional styles can be distinguished, depending on the major source of protein:

- The first nutritional style (in tropical Asia) is based on rice and is also characterized by a very low consumption of protein and energy. It is accompanied by very small statures between 162 and 168 cm.
- The second one (in the Muslim countries of North Africa and the Near East) is based on wheat and the consumption of plant protein reaches the highest values in the world. The intake of total protein and total energy is relatively high as well and comparable with Europe, but the average height of young males is still rather short and does not exceed 174 cm.
- The third one is based on animal proteins (particularly those from dairy) and is typical of Northern/Central Europe. This region is characterized by the tallest statures in the world (>180 cm), being matched only by the inhabitants of the Western Balkans, in which we can presume extraordinary genetic predispositions.

These world patterns in protein consumption have already been described in detail by Grigg (1995). Although our present study is based on a non-experimental, ecological comparison, its findings can provide useful insights into the relationship between these nutritional styles and the final adult stature. Most importantly, our results indicate that plant-based diets are not able to provide the optimal stimuli for physical growth, even if the intake of total protein and total energy poses no problem. In fact, we observed a difference of 10 cm (174 cm vs. 184 cm) between nations relying on the surplus of plant and animal proteins, respectively[32]. A low consumption of proteins that correlate highly with height can explain the seemingly perplexing, small stature in the developed countries of East Asia and the Muslim oil superpowers.

Besides low protein quality, a frequently forgotten limiting factor of plant-based diets is their low nutritional density, with a disproportionate load of ‘empty calories’ from starch and oils that must be consumed per unit of a key nutrient. The countries with the highest plant protein intake already belong to the most obese in the world, particularly among females[33], so it is not likely that the deficit of protein quality could easily be compensated by protein quantity.

Last, but not least, our study can potentially question the current dietary recommendations regarding the intake of essential amino acids, because some foods that score highly according to the new FAO standard 2007 do not appear among the best correlates of height. In fact, recent studies indicate that even the contemporary total protein requirements for children are underestimated (Elango et al., 2011)[34], which also agrees with our data, because we do not observe any levelling-off in many graphic comparisons of male height and protein consumption.

Of all other variables examined in this study, the human development index (HDI) is the only factor that shows a comparably strong relationship with male height like to nutrition. This indicates that the factors leading to the increase in the average height intertwine with public policies that improve the overall quality of life. As in our previous study, children’s mortality (i.e. a disease free environment) is the strongest correlate of stature among all the remaining socioeconomic indicators, but the forward stepwise regression also highlights the role of a lower total fertility rate (i.e. the amount of resources that can be expended per child) and partly urbanization as additional factors that can be targeted, when trying to speed up the pace of the positive height trend.

Besides that, our study shows that, similar to the situation in Europe, the final height in non-European regions may be influenced by genetic factors. Their role in North Africa and the Near East appears to be similarly strong like in Europe, and the inverse relationship between height/lactose tolerance in this region is intriguing. The results are less persuasive concerning the southeastern part of Asia and Oceania, but genetic, socioeconomic and nutritional data from many local countries are still lacking. In any case, the verification of these findings is possible only via studies of autosomal DNA.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ehb.2016.01.005.

References

Allentoft, M.E., Sikora, M., Sjögren, K.G., Rasmussen, S., Rasmussen, M., Stenderup, J., et al., 2015. Population genomics of Bronze Age Eurasia. Nature 522, 167–172.

Balanovsky, O., Dibirova, K., Dybo, A., Mudrak, O., Frolova, S., Pocheshkhova, E., et al., Genographic Consortium, 2011. Parallel evolution of genes and languages in the Caucasus region. Mol. Biol. Evol. 28, 2905–2920.

Basu, A.M., 2002. Why does education lead to lower fertility? A critical review of some of the possibilities. World Dev. 30, 1779–1790.

Baten, J., Blum, M., 2014. Why are you tall while others are short? Agricultural production and other proximate determinants of global heights. Eur. Rev. Econ. Hist. 18, 144–165.

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[32] However, the difference would probably be somewhat smaller, when genetic predispositions were considered.

[33] http://gamapserver.who.int/gho/interactive_charts/ncd/risk_factors/obesity/atlas.html.

[34] For a more detailed discussion on this topic, see http://ajcn.nutrition.org/content/95/6/1498.full.pdf+html.

Blum, M., 2013. Cultural and genetic influences on the biological standard of living. Hist. Methods 46, 19–30.

Cassidy, L.M., Martiniano, R., Murphy, E.M., Teasdale, M.D., Mallory, J., Hartwell, B., Bradley, D.G., 2015. Neolithic and bronze age migration to Ireland and establishment of the insular Atlantic genome. Proc. Natl. Acad. Sci. U.S.A. 1844, 5, [Epub ahead of print], pii.

Chiaroni, J., et al., 2010. The emergence of Y-chromosome haplogroup J1e among Arabic-speaking populations. Eur. J. Hum. Genet. 18, 348–353.

Elango, R., Humayun, M.A., Ball, R.O., Pencharz, P.B., 2011. Protein requirement of healthy school-age children determined by the indicator amino acid oxidation method. Am. J. Clin. Nutr. 94, 1545–1552.

Grasgruber, P., Cacek, J., Kalina, T., Sebera, M., 2014. The role of nutrition and genetics as key determinants of the positive height trend. Econ. Hum. Biol. 15, 81–100.

Grigg, D., 1995. The pattern of world protein consumption. Geoforum 26, 1–17.

Haak, W., Lazaridis, I., Patterson, N., Rohland, N., Mallick, S., Llamas, B., et al., 2015. Massive migration from the steppe was a source for Indo-European languages in Europe. Nature 522, 207–211.

Hatton, T.J., 2013. How Have Europeans Grown So Tall? Oxford Economic Papers. , http://dx.doi.org/10.1093/oep/gpt030 ⟨http://oep.oxfordjournals.org/content/early/2013/08/29/oep.gpt030.full.pdf+html⟩

Heine, W., Radke, M., Wutzke, K.D., 1995. The significance of tryptophan in human nutrition. Amino Acids 9, 91L 205.

Ingram, C.J., et al., 2009. Lactose digestion and the evolutionary genetics of lactase persistence. Hum. Genet. 124, 579–591.

Itan, Y., Powell, A., Beaumont, M.A., Burger, J., Thomas, M.G., 2009. The origins of lactase persistence in Europe. PLoS Comput. Biol. 5 (8), e1000491.

Karafet, T.M., Mendez, F.L., Meilerman, M.B., Underhill, P.A., Zegura, S.L., Hammer, M.F., 2008. New binary polymorphisms reshape and increase resolution of the human Y chromosomal haplogroup tree. Genome Res. 18, 830–838.

Kim, S.H., Kim, K.C., Shin, D.J., Jin, H.J., Kwak, K.D., Han, M.S., et al., 2011. High frequencies of Y-chromosome haplogroup O2b-SRY465 lineages in Korea: a genetic perspective on the peopling of Korea. Investig. Genet. 2, 10.

Mamidi, R.S., et al., 2011. Secular trends in height in different states of India in relation to socioeconomic characteristics and dietary intake. Food Nutr. Bull. 32, 23–34.

Mathieson, I., Lazaridis, I., Rohland, N., Mallick, S., Llamas, B., Pickrell, J., et al., 2015a. Eight thousand years of natural selection in EuropeIn: bioRxiv, pp. 016477, ⟨http://www.biorxiv.org/content/biorxiv/early/2015/03/13/016477.full.pdf⟩

Mathieson, I., Lazaridis, I., Rohland, N., Mallick, S., Patterson, N., Roodenberg, S.A., et al., 2015b. Genome-wide patterns of selection in 230 ancient Eurasians. Nature, http://dx.doi.org/10.1038/nature16152.

Meydan, C., Afek, A., Derazne, E., Tzur, D., Twig, G., Gordon, B., Shamiss, A., 2013. Population-based trends in overweight and obesity: a comparative study of 2 148 342 Israeli male and female adolescents born 1950–1993. Pediatr. Obes. 8, 98–111.

Mirabal, S., Regueiro, M., Cadenas, A.M., Cavalli-Sforza, L.L., Underhill, P.A., Verbenko, D.A., et al., 2009. Y-chromosome distribution within the geo-linguistic landscape of northwestern Russia. Eur. J. Hum. Genet. 17, 1260–1273.

Nguyen, P.H., Strizich, G., Lowe, A., Nguyen, H., Pham, H., Truong, T.V., et al., 2013. Food consumption patterns and associated factors among Vietnamese women of reproductive age. Nutr. J. 12, 126.

Robinson, M.R., Hemani, G., Medina-Gomez, C., Mezzavilla, M., Esko, T., Shakhbazov, K., et al., 2015. Population genetic differentiation of height and body mass index across Europe. Nat. Genet. 47, 1357–1362.

Rosser, Z.H., Zerjal, T., Hurles, M.E., Adojaan, M., Alavantic, D., Amorim, A., et al., 2000. Y-chromosomal diversity in Europe is clinal and influenced primarily by geography rather than by language. Am. J. Hum. Genet. 67, 1526–1543.

Stegl, M., Baten, J., 2009. Tall and shrinking muslims, short and growing Europeans: an anthropometric history of the Middle East, 1840–2007. Explorations Econ. Hist. 46, 132–148.

Underhill, P.A., Poznik, G.D., Rootsi, S., Järve, M., Lin, A.A., Wang, J., et al., 2015. The phylogenetic and geographic structure of Y-chromosome haplogroup R1a. Eur. J. Hum. Genet. 23, 124–131.

Van Driem, G., 2011. Rice and the Austroasiatic and Hmong-Mien Homelands. In: Enfield, N.J. (Ed.), Dynamics of Human Diversity. Pacific Linguistics, Canberra, ⟨http://www.himalayanlanguages.org/files/driem/pdfs/2011Rice%20and%20the%20Austroasiatic%20and%20Hmong-Mien%20homelands.pdf⟩, pp. 361–390.

Zhang, Y., Wang, S., 2011. Geographic variation of stature in Chinese youth of age 18+. Anthropologist 117, 103–106.