Assessment and optimization of the nutritional situation in Croatian boarding schools

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Abstract

The aim of this study was to assess the nutritional quality of the food supply in Croatian boarding schools and to provide suggestions aimed at its improvement. The work is based on a nutritional survey and nutrition optimization. The survey assessed the food supply in female, male and co-educational boarding schools in Zagreb, Croatia. Particularly, the diets of students aged 15–19 years were investigated and the relationship between students' anthropometric measurements and the supply of energy, protein, fat and carbohydrates was analysed. Based on the survey results, nutrition optimization was applied to determine diets meeting the recommended dietary allowances (RDAs) of selected nutrients at least cost. The survey showed that the diets provided in Croatian boarding schools are generally characterized by an oversupply of energy and fat to female pupils and an undersupply of many micronutrients to pupils of both genders. This seems to promote the development of obesity in female students. Furthermore, it could be shown by means of nutrition optimization that the nutritional situation in the boarding schools could easily be improved by a reasonable selection and combination of dishes that would also lead to a reduction of food costs. Menu planning by means of nutrition optimization could help to improve the nutritional quality of the food supply in Croatian boarding schools and simultaneously decrease the corresponding food costs.

Introduction

The quality of adolescents' nutrition is of great individual and social importance (Hendrix *et al.* 1995; Torun *et al.* 1996; Kersting *et al.* 1998). Wholesome nutrition is an important factor for the healthy physical and psychological development of young people (Moore 1988; Crawley 1993; Sichert-Hellert *et al.* 1998; Vokk & Boeing 1998). However, the principles of a healthy diet are widely unknown in the Croatian population (Hadžihalilović & Hadžiselimović 2001) and there is evidence that the nutritional status of many Croatian adolescents is sub-optimal (Mišigoj-Duraković 1995; Gajdoš unpublished; Gajdoš *et al.* 2001).

From an economist's point of view, an unsatisfactory nutritional situation is caused either by inadequacy of supply or demand or, most likely, by a combination of both factors. Depending on people's living conditions, the influence of supply and demand on the nutritional situation varies considerably (Maloney *et al.* 1989, Moore 1993, Mulvihill *et al.* 1996). Most obviously, the poor nutritional situation of many people in Ethiopia, for instance, is related to insufficient food supply. Most of the nutritional problems in industrialized countries, however, exist because of unreasonable demand (Bull 1985; Briefel *et al.* 1995). But even in these countries there are some situations where supply rather than demand determines people's nutritional quality. A typical example is the institutional feeding of so-called 'captive consumers' such as prisoners in jail or students at boarding schools. Captive consumers are given only a limited food choice, if any at all. Therefore, the feeding institution is primarily responsible for the quality of nutrition of its members.

For these reasons, the nutritional situation in boarding schools in Croatia was investigated. The analysis includes a nutritional survey and nutrition optimization.

The aim of this survey was to evaluate the actual food supply provided by selected Croatian boarding schools with respect to the supply of energy and nutrients. It was postulated that the food provided by the schools should be wholesome on its own, meeting the pupils' nutritional needs independently of any possible extra-institutional food supply that pupils might make use of (e.g. snacks or sweets). The nutritional quality of the food supply of the boarding schools was evaluated in a cross-sectional as well as a longitudinal manner.

The aim of the nutrition optimization was to evaluate the theoretical possibilities of improving the dietary quality of the food supply provided by the boarding schools. Generally, in nutrition optimization, a certain target is pursued taking various additional constraints into account. Numerous applications of nutrition optimization have been developed (e.g. Stigler 1945; Balintfy 1964; Karg 1982; Steinel & Karg 1993; Wirsam & Uthus 1996; Gedrich *et al.* 1999; Darmon *et al.* 2002). In many cases, the target function aims to either minimize the costs of nutrition or maximize the utility of nutrition characterized by their physiological and/or sensory properties. Also, various types of constraints were applied concerning, for instance, the availability of certain food stuffs as well as the availability of financial means to purchase these foods on the market. Other constraints in nutrition optimization are given by desirable intakes of nutritional components or by cultural as well as individual food preferences (Karg 1982; Colavita & D'Orsi 1990; Steinel & Karg 1993). Because of the variability of biological systems in general and nutritional needs in particular, fuzzy logic approaches to nutrition optimization have also been proposed (e.g. Cox 1994; Wirsam & Uthus 1996).

Methodology

Nutritional survey

Study population

The nutritional survey was conducted in 1997/98. All boarding schools in Zagreb, the capital of Croatia, six schools exclusively for female students, six for males only and five co-educational, were investigated. About 75% of the students attending these schools were willing and able to participate. Thus, a total of 1117 pupils took part in the survey; of which, 599 were females (54%) and 518 were males (46%) aged 15–19 years (Table 1). In all the boarding schools, three meals per day (breakfast, lunch and dinner) were offered to the pupils.

Dietary assessment

During a period of 7 days, three samples of the dishes provided by each boarding school for every meal (breakfast, lunch and dinner) were randomly chosen to be analysed. All 1071 samples (3 samples/meal × 3 meals/day × 7 days/school × 17 schools) were collected immediately before consumption (i.e. in a processed state) and weighed. Then, the average weight per portion of every dish was calculated and the energy and nutrient contents of the dishes were computed using the original recipes of the boarding schools and the USDA Nutrient Database, Release 12 (USDA 1998).

Additionally, all 1117 survey participants were asked to fill out a self-administered questionnaire that included 19 questions on the pupils' physical activities, their personal assessment of the nutritional quality of the dishes provided by the boarding schools, their snacking habits at school and their general nutritional habits at home. The questionnaire was reviewed by a psychologist at the Faculty of Medicine of the University of Zagreb.

Furthermore, the following anthropometric measures were determined: body height and weight, circumferences of triceps, chest, abdomen, and hips as well as skin-fold thicknesses of triceps and subscapula. The measurements were conducted in accordance with the WHO recommendations (WHO 1995).

Food supply evaluation

The nutritional quality of the food supply at the schools was evaluated using a cross-sectional as well as a longitudinal approach.

For the cross-sectional approach, the supply of energy and nutrients was compared to the corre-

Table 1 Number of survey participants with respect to their gender and the boarding school attended

	Boarding schools										
Gender	**1**	**2**	**3**	**4**	**5**	**6**	**1***	**2***	**3***	**4***	**5***	**Total**
Female	49	54	51	66	73	91	32	42	50	35	56	599
Male	45	41	88	56	78	69	36	15	25	33	32	518

*Co-educational schools.

sponding recommended dietary allowances (RDAs). This makes four different scenarios depending on the kind of dietary requirement (minimum or maximum) and the actual quantity of supply (oversupply or undersupply):

Considering nutrients with a minimum requirement (like most of the vitamins, minerals or trace elements) a supply higher than the RDAs (oversupply) is desirable, but an undersupply is problematic, because extra-institutional food sources cannot be relied on to fill the gap.

Considering nutrients with a maximum requirement (like fat or cholesterol) a supply lower than the RDAs (undersupply) should be achieved, while an oversupply might be – but is not necessarily – problematic, depending whether or not the dietary surplus is actually consumed by the pupils.

For the longitudinal approach, the effect of the duration of exposure to the food supply at the schools on the health status of the pupils was investigated. The duration of school attendance of the pupils was determined by their age minus a certain constant that corresponds to the age at which pupils enter the boarding schools. Thus, it is assumed that older pupils have consumed more boarding school meals than younger ones neglecting the possible, but rare fluctuation of the pupils in the schools. The pupils' health status was assessed by anthropometric measures. It is assumed that in the long run a sound physical development of the pupils would be an indicator of a sound health status brought about by a well-balanced food supply. Contrariwise, an abnormal physical development would indicate a sub-optimal health status of the pupils induced by an inadequate supply of food. Furthermore, a sound physical development of the adolescents is assumed to be associated with a steady increase of mass while the body mass index (BMI) and triceps as well as subscapular skin-fold thicknesses remain quite constant. Finally, the assumption is made that the nutritional quality of the school feeding did not change substantially between the years 1993 and 1998, that is, the food supply assessed in the year $t = t_0$ (the year the survey was conducted) is similar to the unknown supplies in the years $t = t_{0-x}$ (with $x = 1, 2, 3, 4$).

Statistical analysis

The data of the anthropometric measurements were analysed by determination of the corresponding probability density distributions and by calculation of the first three distribution moments (average, variance and skewness) (Gajdoš 1998).

For the longitudinal approach to the evaluation of the food supply at the boarding schools, the data obtained from the survey were used for modelling the influence of the supply of energy and macronutrients on anthropometric measures (Wolfram 1999). It was hypothesized that the pupils' anthropometric measures are functions of their energy and macronutrient supply plus certain error terms. The closer the relationship between these anthropometric measures and the supply, that is, the smaller the absolute values of the the error terms, the greater is the responsibility of the food supply at the schools for the pupils' anthopometry.

In particular, the following output (i.e. dependent) variables y_{as} regarding anthropometric measure a ($a = 1, 2, \ldots, 4$) of pupils of boarding school s ($s = 1, 2, \ldots, 17$) were considered:

$y_{1s} = \mathrm{TSF}_s$ = mean triceps skin-fold thickness ($a = 1$) of pupils of boarding school s,

$y_{2s} = \mathrm{SSF}_s$ = mean subscapular skin-fold thickness ($a = 2$) of pupils of boarding school s,

$y_{3s} = \mathrm{BM}_s$ = mean body mass ($a = 3$) of pupils of boarding school s,

$y_{4s} = \mathrm{BMI}_s$ = mean body mass index ($a = 4$) of pupils of boarding school s.

The following nutritional attributes of the pupils served as exposure (i.e. independent) variables z_{ns} regarding nutritional parameter n ($n = 0, 1, \ldots, 3$) of pupils of boarding school s ($s = 1, 2, \ldots, 17$):

$z_{0s} = E_s$ = mean daily supply of energy ($n = 0$) to pupils of boarding school s,

$z_{1s} = P_s$ = mean daily supply of protein ($n = 1$) to pupils of boarding school s,

$z_{2s} = F_s$ = mean daily supply of fat ($n = 2$) to pupils of boarding school s,

$z_{3s} = C_s$ = mean daily supply of carbohydrates ($n = 3$) to pupils of boarding school s.

Based on these data, the following general model was analysed:

$$y_{as} = \alpha_{m,a} + \sum_{n=0}^{3} \beta_{m,an}\, z_{ns} + e_{m,as} \qquad (1)$$

where,

a = index variable for the anthropometric measures ($a = 1, \ldots, 4$),

s = index variable for the boarding schools ($s = 1, \ldots, 17$),

m = index variable for specific variants of the general model ($m = 1, 2$), as described below,

n = index variable for the nutritional parameters ($n = 0, \ldots, 3$)

$\alpha_{m,a}$ = unknown constants (regression intercepts) for model m ($m = 1, 2$) and anthropometric measure a ($a = 1, \ldots, 4$),

$\beta_{m,an}$ = unknown constants (regression slopes) for model m ($m = 1, 2$), anthropometric measure a ($a = 1, \ldots, 4$) and nutritional parameter n ($n = 0, \ldots, 3$),

$e_{m,as}$ = residual (i.e. error term) in model m for anthropometric measure a in boarding school s.

Based on the general model given in Eq. 1, two model variants ($m = 1, 2$) are distinguished.

Energy supply model (ESM)
In this model variant ($m = 1$) the intake of energy ($n = 0$) is the only independent variable, that is,

$\beta_{1,an} = 0 \; \forall \; n \in \{1,\ldots,3\}$ and $a \in \{1,\ldots,4\}$.,
which yields

$$y_{as} = \alpha_{1,a} + \beta_{1,a0}\, z_{0s} + e_{1,as}. \tag{2}$$

Macronutrient supply model (MSM)
In this model variant ($m = 2$) the supply of the macronutrients (protein, fat and carbohydrates) is used as independent variables, that is,

$\beta_{2,a0} = 0 \; \forall \; a \in \{1,\ldots,4\}$.,
which yields

$$y_{as} = \alpha_{2,a} + \sum_{n=1}^{3} \beta_{2,an}\, z_{ns} + e_{2,as}. \tag{3}$$

The unknown coefficients (regression parameters) were estimated by means of least squares regression stratifying the data with respect to the pupils' age and gender.

Nutrition optimization

Nutrition optimization can aid in determining a diet that provides physiological benefits to the pupils and economical benefits to the management of boarding schools. As an illustrative example, a daily diet of a typical Croatian boarding school is optimized using linear programming with a mixed-integer-real Simplex algorithm (Petric & Zlobec 1983, Dantzig & Thapa 1997, Schneider 1997). For practical purposes, the example can easily be extended to a longer period of time (say a week or a month).

The target function (F) aims at minimizing the food costs of a boarding school. The function is defined as the product of a transposed vector **c** (including the costs per portion of a set of available menus) and a vector **x** (including the values of 1 or 0 showing for every menu available whether or not it is selected for the diet of a day, that is,

$$\min F(\mathbf{x}) = \mathbf{c}^{\mathrm{T}} \cdot \mathbf{x}. \tag{4}$$

The vector **x** comprises the different menus found in the survey. Out of the total of 357 menus assessed only 40 were substantially different and are therefore regarded for optimization. Among them there are 10 different types of breakfasts, 12 types of lunches and 18 types of dinners.

The minimum of the target function F (referring to food costs) is determined subject to three different types of constraints, that is,

$$\mathbf{A}_1 \cdot \mathbf{x} \le \mathbf{b}_1 \tag{5}$$

$$\mathbf{A}_2 \cdot \mathbf{x} \ge \mathbf{b}_2 \tag{6}$$

$$\mathbf{A}_3 \cdot \mathbf{x} = \mathbf{b}_3. \tag{7}$$

In inequalities (5) and (6), matrix $\mathbf{A}_1$ represents the contents of energy and energy-providing nutrients (protein, fat and carbohydrates) per portion of the menus considered, and matrix $\mathbf{A}_2$ gives the corresponding contents of energy and energy-providing nutrients, once again, but additionally also the contents of calcium, magnesium, phosphorus, iron, zinc, niacin and vitamins B_1, B_2, B_6 and C. On the right hand side of constraints (5) and (6) the vectors $\mathbf{b}_1$ and $\mathbf{b}_2$ consist of the maximal and minimal bounds, respectively, for the intakes of energy and the nutrients mentioned. They are defined by corresponding nutrient intake recommendations that are adopted for Croatia by the Croatian Ministry of Health (Table 2) (The National Academy of Science 1989; Food and Nutrition Board 1999). For energy and macronutrients the recommendations are given as ranges of intake with upper and lower bounds, whereas for micronutrients (i.e. minerals, trace elements and vitamins) the recommendations are to be interpreted as lower bounds of desirable intakes. However, because the recommendations for the intake of micronutrients are defined as quantities that meet the requirements of almost any healthy person of a group, the recommendations are considerably higher than the corresponding average requirements of a group. A deviation of the mean nutrient supply by no more than 10% of the corresponding recommendations is therefore still regarded as acceptable. Thus, inequalities (5) and (6) ensure that the resulting optimal diet provides such quantities of energy and nutrients that are in good agreement with the corresponding intake recommendation.

Finally, in Eq. 7, matrix $\mathbf{A}_3$ assigns the menus considered to corresponding meals. It includes three rows (representing breakfast, lunch and dinner, respectively) with elements equal to 0 (inappropriate assignment) or 1 (appropriate assignment). If, for example, a menu (say menu No. 5) is appropriate for breakfast (1. meal), but inappropriate for lunch (2. meal) or dinner (3. meal), then the elements in column 5 of the matrix $\mathbf{A}_3$ are 1 in the first row (appropriate for the 1. meal) and 0 in the second and third row (inappropriate for the 2. and the 3. meal). Vector $\mathbf{b}_3$ in Eq. 7 comprises three rows with all three elements equal to 1 ensuring that out of a group of possible menus exactly one is chosen for every meal. Thus, Eq. 7 ensures that the resulting diet includes exactly one menu for breakfast, one for lunch and one for dinner.

Altogether, the problem consists of 40 variables (representing 40 different menus), 18 inequalities (because

Table 2 Average daily supply and recommended intake of energy and selected nutrients with respect to the pupils' gender

	Average daily supply		Recommended daily intake	
Energy and nutrients	**Female**	**Male**	**Female**	**Male**
Energy (kJ)	10804	12310	8284–10125	11297–13807
Proteins (g)	108	120	44–77	59–105
Fats (g)	95	104	60–73	82–99
Carbohydrates (g)	307	362	295–322	403–441
Minerals, trace elements				
Ca (mg)	820	660	1000	1000
Mg (mg)	213	223	300	400
P (mg)	900	1048	1200	1200
Fe (mg)	15.0	11.4	15.0	12.0
Zn (mg)	5.4	4.5	12.0	15.0
Vitamins				
Niacin (mg)	12.2	20.2	15.0	20.0
B_1 (mg)	0.6	1.1	1.1	1.5
B_2 (mg)	1.3	1.7	1.3	1.8
B_6 (mg)	0.9	1.0	1.5	2.0
C (mg)	35	40	60	60

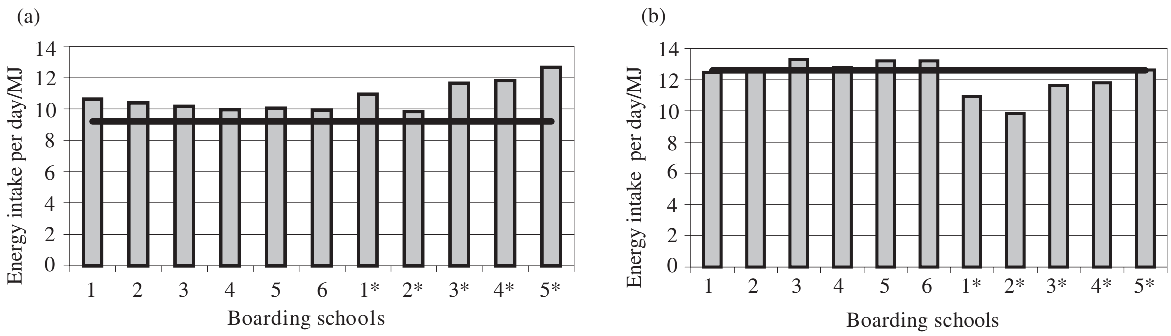

Figure 1 Average energy supply to female (a) and male (b) pupils compared to the recommended dietary allowances (solid horizontal line) with respect to the boarding school attended [purely female and male boarding schools are denoted by 1–6 and co-educational ones by 1*–5*].

of the restrictions concerning energy and nutrient intakes) and 3 equalities (corresponding to the selection of exactly one menu per meal). The problem is solved using the computer software LINDO/PC (Release 6.01, LINDO Systems, Inc., Chicago, IL) (LINDO Systems Inc. 1995).

Results

Survey results

Food supply

The *breakfasts* provided by the schools typically consist of a hot beverage (either milk, cocoa or tea), bread, margarine or butter, some spread (such as marmalade, honey or processed cheese), and sometimes hard cheese, salami or boiled eggs or pastries. The *lunches* typically consist of a soup, a meat or fish dish, a side dish (such as potatoes, rice, pasta or vegetables), seasonal salads, bread, and sometimes a dessert. The *dinners* typically include a hot beverage (similar to breakfast), rolls with yoghurt or sandwiches, pasta with cheese, french fries, hamburgers, or hot dogs.

Energy and nutrient supply

Figure 1 presents the results of the average energy supply to female and male pupils in each of the boarding schools investigated compared to the corresponding energy intake recommendations. It shows that the energy supply to females exceeds the recommendations in every boarding school, but especially in co-educational ones. Depending on the boarding school considered, the average surplus of energy provided to female pupils ranges from 840 to 1800 kJ/d. The energy supply to male pupils, however, is quite close to the recommendations as long as purely male boarding schools are considered. But in co-educational schools, the energy supply to male pupils is mostly below the recommendations.

The energy supplies to female and male pupils in purely female and male boarding schools, respectively, are significantly different from those found in co-educational schools. The differences are statistically significant, as evaluated by *t*-tests (for female pupils $t = 2.53$ with $P = 0.032$ and for male pupils $t = 3.24$ with $P = 0.01$).

The contributions of protein, fat and carbohydrates to the energy supply to the pupils are presented in Fig. 2 differentiating for the pupils' gender and the different boarding schools they attend. In all the schools, the supplies of fat and protein exceed the recommendations, whereas the supply of carbohydrates is lower than recommended (Pemberton *et al.* 1988; Brown *et al.* 1990). The amounts of fat provided to female and male pupils were found to make up 30.1–39.7% and 32.3–37.9% of the energy supply, respectively. The contribution of protein to the supply of energy ranged from 17.6% to 22.7% among females and 17.8% to 20.2% among males.

The actual average daily supply of energy and selected nutrients is given in Table 2. From these data it is evident that the supplies mostly deviate from the corresponding intake recommendations. There is an oversupply of energy and fat to female pupils and an undersupply of calcium, magnesium, phosphorus, and zinc as well as the vitamins B_1, B_6 and C to all pupils regardless of their gender. Considering the supply of iron, however, it shows that the boarding schools seem to care quite well for the different needs of female and male pupils and correspondingly provide females, on average, with considerably higher amounts of iron than males.

Dietary habits

In Table 3 selected results of the questionnaire on the pupils' dietary habits are given with respect to the gender of the pupils. It shows that female pupils consume boarding school meals less regularly and therefore less intensively than their male counterparts. For example, a lower percentage of female pupils (66%) took three meals a day at school than male pupils (76%).

When the pupils were asked to compare the food supply of the boarding schools with the supply in their families, it was found that most female pupils complained about a smaller supply of fruits in school (52%) and many students of both genders wished they were offered more milk and dairy products and a greater overall variety of foods and dishes (30–50%).

Considering snacking habits of the pupils, fruits appeared to be the most frequently chosen food (48% of females and 64% of males). But other types of snacks, like ice cream, chocolate, chips or bread with jam, were also selected quite frequently.

Anthropometry

The results of the anthropometric measurements for triceps skin-fold thickness, subscapular skin-fold thickness, body mass (BM), and BMI are given in Table 4. Data are broken down by the age of the pupils and the

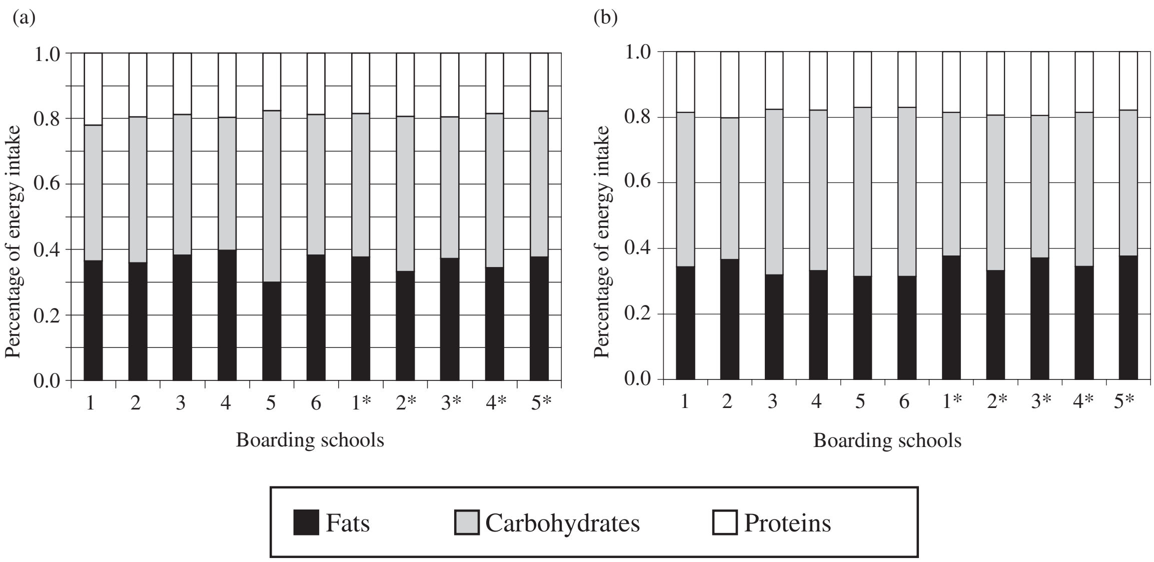

Figure 2 Contribution of fat, carbohydrates and protein to the energy supply to female (a) and male (b) pupils.

boarding schools they attend. The values show quite a variation resulting in relatively high values of standard deviation (SD). Compared to the results of the National Health and Nutrition Examination Survey (NHANES I) in the US (WHO 1995) no substantial differences of anthropological variables could be found.

In most of the boarding schools, there was a tendency that BM as well as BMI increased with age. The relationship between BM and age was stronger among male pupils, whereas the relationship between BMI and age was stronger among female pupils especially in coeducational boarding schools (marked by an asterisk in Table 4). BM and BMI of female pupils tended to increase from 15 to 19 years of age (most notably in boarding school No. 5*). A striking exception from the general tendency was found in the female boarding school No. 4, where BM as well as BMI consistently decreased with age.

Impact of the supply of energy and macronutrients on anthropometric measures

The results of the analyses of the impact of the feeding at the boarding schools on anthropometric measures of the pupils are given in Fig. 3 as well as in Tables 5 (for the ESM) and 6 (for the MSM).

Figure 3 shows the coefficients of the correlations of the actual BM (BMIs) with the corresponding estimated values obtained by the ESM and the MSM. Not surprisingly, the coefficients achieved by the simple ESM are mostly lower and never higher than the ones obtained by the more complex MSM. In Fig. 3a,b one can see that the strength of the correlation between energy intake (ESM) and BM increases with the age of the pupils. This tendency, however, is not that clearly approved by the MSM. Considering BMI instead of BM (Fig. 3c,d), the MSM rather than the ESM shows a certain tendency of growing strength in the relationship between food supply and the pupils' BMI with increasing age of the pupils.

Detailed results of the analyses of the ESM are presented in Table 5. It can be seen that among the female pupils aged 17 years or older, energy supply is significantly and inversely associated with BM and BMI. Among male pupils, however, the situation is different: there is no significant effect of the energy supply on their BM and BMI, except for the 19-year-olds whose energy supply is positively associated with their BM (BMI).

Table 6 gives the results obtained by the analyses using the MSM. It shows that most of the regression coefficients are not significant, except for some that are related to the supply of carbohydrates for females, indicating that a high supply of carbohydrates is associated with low BM (BMIs). Among males, no significant influence was detected for the supply of macronutrients on BM and BMI. The only exception to this rule is indicated by male students aged 18 years. Their BMI is positively associated with protein supply and – to a lesser extent – negatively associated with fat supply.

Further results of the survey are given elsewhere (Gajdoš unpublished).

Nutrition optimization

The menus chosen for the optimized diets of female and male pupils are presented in Table 7. It shows that for both genders, bread or comparable bakery products (i.e. rolls) are part of every meal. The optimized

Table 3 Selected characteristics of the dietary habits of the pupils with respect to their gender

Characteristics of dietary habits	Females	Males
1. Percentages of pupils usually consuming . . .		
One meal per day at school	12	1
Two meals per day at school	32	23
Three meals per day at school	66	76
2. Mean number of slices of bread usually consumed at school		
• Per meal	2	5
• Additionally per day (between meals)	2	1
3. Percentages of pupils stating that food supply at school provides . . . than at home		
• Less fruit	52	42
• Less milk and dairy products	30	42
• Less diversity	50	43
4. Percentages of pupils stating that their most frequently consumed snacks are . . .*		
• Sweets (ice cream, chocolate, bread with jam)	29	28
• Salted snacks (chips, sandwiches)	28	27
• Sweets and salted snacks in equal quantities	41	36
• Fruits	48	64

*More than one answer possible.

Table 4 Anthropometric measures of female and male pupils (means ± SD) with respect to their age and the boarding school attended

	Boarding schools										
Age (years)	1	2	3	4	5	6	1*	2*	3*	4*	5*
Female pupils											
Triceps skin fold thickness (mm)											
15	12.0 ± 4.2	14.8 ± 2.7	16.1 ± 3.0	13.7 ± 5.2	13.4 ± 4.1	15.8 ± 2.9	15.7 ± 2.0	13.7 ± 5.1	13.3 ± 4.5	–	12.1 ± 5.1
16	17.0 ± 3.5	16.2 ± 3.1	14.4 ± 4.4	12.4 ± 4.8	14.6 ± 3.4	14.7 ± 3.2	14.4 ± 3.6	9.0 ± 6.2	17.0 ± 2.5	12.3 ± 2.6	13.2 ± 4.4
17	16.6 ± 4.8	15.8 ± 4.5	13.2 ± 4.2	12.8 ± 4.2	13.5 ± 3.9	21.7 ± 12.9	16.7 ± 4.0	20.0 ± 8.3	16.3 ± 4.7	12.1 ± 4.3	13.5 ± 3.8
18	15.3 ± 4.0	16.5 ± 2.9	14.4 ± 3.8	9.8 ± 5.2	14.8 ± 2.5	13.8 ± 5.1	16.1 ± 3.2	14.8 ± 3.2	13.6 ± 4.1	11.3 ± 3.7	14.2 ± 4.2
19	15.1 ± 3.2	14.4 ± 1.9	13.0 ± 3.5	15.4 ± 3.4	15.6 ± 3.2	14.1 ± 3.8	13.4 ± 4.1	–	17.2 ± 3.0	–	15.4 ± 3.1
Subscapular skin fold thickness (mm)											
15	8.9 ± 1.3	10.6 ± 2.4	13.6 ± 3.1	15.2 ± 2.9	9.8 ± 4.1	13.2 ± 3.1	9.1 ± 4.1	12.5 ± 3.2	8.6 ± 4.2	–	10.3 ± 4.3
16	13.7 ± 2.1	11.9 ± 2.2	10.4 ± 3.8	10.5 ± 3.5	12.6 ± 4.0	12.8 ± 2.9	12.9 ± 2.3	10.8 ± 4.2	15.8 ± 4.3	12.8 ± 3.6	12.2 ± 4.1
17	12.6 ± 1.9	11.6 ± 1.6	10.7 ± 2.9	9.9 ± 4.2	11.9 ± 2.7	15.0 ± 3.6	9.9 ± 3.7	12.8 ± 3.6	12.2 ± 3.8	10.8 ± 3.2	11.7 ± 3.9
18	14.1 ± 2.2	12.5 ± 2.4	12.3 ± 1.9	9.8 ± 3.0	12.9 ± 3.6	15.2 ± 2.5	11.0 ± 4.2	11.8 ± 3.3	11.7 ± 3.7	8.1 ± 4.7	12.9 ± 3.7
19	13.2 ± 3.0	11.8 ± 2.9	12.2 ± 2.0	10.3 ± 2.8	12.0 ± 3.1	13.7 ± 3.2	11.4 ± 2.2	–	13.7 ± 4.0	–	14.7 ± 4.2
Body mass (kg)											
15	47.8 ± 7.6	59.4 ± 10.8	54.8 ± 4.4	62.0 ± 8.8	50.8 ± 1.8	54.8 ± 5.7	52.5 ± 12.3	60.0 ± 3.5	55.6 ± 9.2	–	53.0 ± 3.3
16	61.7 ± 8.4	56.5 ± 6.4	56.2 ± 5.5	58.1 ± 7.2	53.0 ± 6.2	56.7 ± 8.8	57.3 ± 7.7	52.0 ± 15.6	60.2 ± 8.8	56.0 ± 3.5	53.8 ± 13.8
17	56.5 ± 4.6	57.7 ± 6.5	57.1 ± 8.7	53.8 ± 5.4	57.8 ± 6.9	61.6 ± 7.2	55.8 ± 6.0	71.0 ± 2.8	57.1 ± 6.2	57.2 ± 6.8	57.8 ± 6.9
18	59.0 ± 7.6	60.2 ± 5.0	56.0 ± 7.1	51.6 ± 5.9	58.8 ± 5.3	60.4 ± 7.8	59.0 ± 7.4	63.0 ± 10.6	54.2 ± 5.2	63.5 ± 0.7	58.6 ± 7.3
19	59.1 ± 5.8	58.4 ± 5.3	57.2 ± 5.3	50.9 ± 5.6	58.1 ± 6.1	58.4 ± 6.3	58.4 ± 5.0	–	63.2 ± 7.1	–	62.6 ± 12.8
Body height (cm)											
15	159.8 ± 6.2	167.9 ± 6.9	161.4 ± 5.6	167.8 ± 10.2	161.0 ± 4.8	162.8 ± 7.1	162.9 ± 5.1	166.2 ± 9.5	171.0 ± 9.6	–	169.6 ± 3.4
16	169.1 ± 7.7	166.0 ± 5.9	167.5 ± 6.0	167.2 ± 6.3	164.0 ± 5.4	166.3 ± 6.8	164.8 ± 4.9	159.0 ± 9.2	164.3 ± 6.0	160.2 ± 0.2	167.0 ± 7.0
17	167.4 ± 5.2	165.4 ± 5.6	165.0 ± 7.0	164.7 ± 4.7	167.0 ± 6.6	169.1 ± 7.0	165.8 ± 6.4	161.0 ± 2.8	165.1 ± 6.8	169.0 ± 3.5	170.4 ± 6.9
18	168.0 ± 7.6	166.9 ± 6.4	167.8 ± 6.7	166.7 ± 3.4	167.7 ± 3.8	167.6 ± 6.1	167.3 ± 6.4	171.0 ± 4.9	166.6 ± 3.1	175.5 ± 0.7	169.3 ± 4.0
19	170.7 ± 5.8	168.0 ± 6.7	164.5 ± 2.3	163.5 ± 4.2	167.0 ± 4.5	167.1 ± 4.9	164.4 ± 2.8	–	168.3 ± 5.5	–	169.0 ± 5.2
Body mass index (kg/m^2)											
15	18.7 ± 2.4	21.1 ± 3.8	21.0 ± 2.3	22.0 ± 3.7	19.6 ± 1.3	20.7 ± 1.5	19.8 ± 4.7	21.3 ± 1.4	19.0 ± 1.3	–	18.4 ± 1.4
16	21.6 ± 2.5	20.5 ± 2.3	20.0 ± 1.9	20.8 ± 2.3	20.8 ± 2.1	20.5 ± 2.7	21.1 ± 2.4	20.6 ± 3.3	22.3 ± 2.9	21.9 ± 1.4	19.3 ± 5.1
17	21.2 ± 1.7	21.1 ± 2.5	21.0 ± 2.0	19.9 ± 1.5	20.8 ± 2.2	21.5 ± 2.9	20.3 ± 2.0	23.3 ± 0.4	20.9 ± 2.2	20.4 ± 2.4	19.9 ± 2.3
18	21.1 ± 2.0	21.5 ± 1.5	19.9 ± 1.6	18.6 ± 1.5	20.9 ± 2.2	21.5 ± 2.2	21.1 ± 3.2	21.5 ± 2.4	19.5 ± 2.4	20.6 ± 0.4	20.4 ± 2.3
19	20.3 ± 2.1	20.7 ± 1.2	21.1 ± 1.7	19.0 ± 1.3	20.9 ± 2.3	20.9 ± 1.5	19.8 ± 1.4	–	22.3 ± 1.4	–	21.9 ± 3.9

Male pupils											
Triceps skin fold thickness (mm)											
15	8.1 ± 4.8	7.8 ± 5.2	13.4 ± 4.9	9.4 ± 3.5	–	–	8.7 ± 5.1	12.9 ± 4.3	9.9 ± 2.7	–	8.4 ± 3.4
16	9.5 ± 3.8	8.9 ± 2.5	9.3 ± 4.0	10 ± 5.2	–	–	7.8 ± 6.1	10.1 ± 3.2	7.8 ± 4.2	8.7 ± 4.0	8.5 ± 3.6
17	16.5 ± 7.3	9.1 ± 3.8	9.1 ± 2.5	8.6 ± 4.2	10.4 ± 3.2	11 ± 5.7	8.3 ± 6.0	6.8 ± 5.3	11.1 ± 4.5	7.0 ± 6.2	12.7 ± 5.3
18	8.2 ± 2.6	8.2 ± 3.1	9.7 ± 2.6	9.2 ± 3.1	10.3 ± 2.5	8.1 ± 2.1	10.7 ± 3.7	12.2 ± 4.2	6.8 ± 3.1	7.5 ± 2.5	8.9 ± 1.7
19	7.7 ± 3.1	8.8 ± 2.2	8.3 ± 2.9	6.9 ± 3.7	8.7 ± 2.5	7.9 ± 3.0	9.0 ± 2.5	–	7.7 ± 2.8	5.9 ± 4.0	7.5 ± 3.6
Subscapular skin fold thickness (mm)											
15	6.7 ± 4.5	7.4 ± 4.1	13 ± 7.2	9.1 ± 5.2	–	–	9.7 ± 4.3	10.5 ± 5.2	7.7 ± 5.5	–	7.7 ± 3.9
16	8.7 ± 2.9	8.9 ± 2.7	8.8 ± 1.7	9.4 ± 3.2	–	–	7.1 ± 4.5	8.9 ±	7.9 ± 2.7	7.4 ± 4.0	8.6 ± 4.2
17	9.4 ± 3.0	8.9 ± 5.1	9.5 ± 4.2	8.7 ± 3.1	10.2 ± 4.1	9.3 ± 2.5	7.8 ± 2.6	9 ± 2.4	12.1 ± 3.8	8.3 ± 2.1	8.8 ± 2.8
18	8.3 ± 3.8	9.5 ± 3.2	10.2 ± 2.9	12.2 ± 3.8	11.3 ± 3.0	9.5 ± 3.2	9.9 ± 3.5	12.2 ± 4.9	9.8 ± 5.0	9.6 ± 3.2	10 ± 4.0
19	6.9 ± 3.2	11.9 ± 5.1	8.5 ± 4.4	8.9 ± 3.7	9.3 ± 2.2	10.5 ± 3.9	8.7 ± 4.7	–	10.6 ± 4.3	7.7 ± 4.0	9.1 ± 2.5
Body mass (kg)											
15	52.6 ± 8.2	63.1 ± 9.2	68.5 ± 13.4	63.6 ± 15.7	–	–	64 ± 5.4	72.5 ± 3.5	57.8 ± 11.3	–	63.7 ± 12.0
16	66.1 ± 10.3	63.4 ± 11.3	69.2 ± 7.2	70.2 ± 13.4	–	–	65.5 ± 8.7	62.0 ± 10.1	63 ± 10.4	69.3 ± 5.0	67.8 ± 9.4
17	72.8 ± 13.4	72.0 ± 10.6	70.8 ± 9.5	69.3 ± 8.8	72.6 ± 9.0	69.1 ± 7.1	67.5 ± 10.1	62.5 ± 4.9	73.2 ± 13.0	66.8 ± 5.8	66.3 ± 7.7
18	67.6 ± 7.7	67.0 ± 9.8	70.7 ± 10.1	77.8 ± 11.2	72.9 ± 9.1	71.3 ± 9.0	81.0 ± 3.0	82.0 ± 7.6	72.5 ± 9.0	75.3 ± 12.5	68.8 ± 6.4
19	67.1 ± 4.9	67.3 ± 14.5	71.3 ± 6.3	68.4 ± 8.5	73.7 ± 6.7	71.7 ± 10.0	79.1 ± 7.7	–	68.5 ± 6.3	67.3 ± 5.5	77.8 ± 3.4
Body height (cm)											
15	170.3 ± 5.8	176.8 ± 7.6	174.9 ± 9.4	172.7 ± 9.3	–	–	172.0 ± 3.7	171.8 ± 2.5	169.2 ± 7.8	–	170.5 ± 9.7
16	175.4 ± 7.9	175.4 ± 5.5	177.2 ± 7.9	175.8 ± 8.4	–	–	176.8 ± 5.3	172.3 ± 3.1	175.3 ± 9.0	178.7 ± 5.8	180.8 ± 7.2
17	179.1 ± 8.1	180.3 ± 6.9	180.0 ± 6.3	182.2 ± 5.5	177.1 ± 6.2	181.6 ± 5.9	179.1 ± 4.9	178.5 ± 3.5	178.7 ± 5.6	179.4 ± 5.5	181.0 ± 4.8
18	180.4 ± 5.5	178.3 ± 5.3	179.2 ± 8.0	181.5 ± 6.7	178.4 ± 5.5	179.3 ± 5.7	186.8 ± 8.0	188.0 ± 4.0	182.1 ± 4.2	181.8 ± 4.0	180.1 ± 6.9
19	182.0 ± 5.9	173.8 ± 11.7	180.4 ± 6.9	181.3 ± 7.5	182.8 ± 6.3	178.2 ± 5.5	186.7 ± 6.8	–	175.5 ± 5.7	180.0 ± 5.3	186.7 ± 6.0
Body mass index (kg/m^2)											
15	21.3 ± 1.8	20.2 ± 2.3	24.6 ± 3.3	21.6 ± 3.1	–	–	21.3 ± 1.4	22.4 ± 0.5	20.2 ± 2.2	–	21.1 ± 2.5
16	21.7 ± 2.2	20.5 ± 3.4	20.9 ± 1.0	21.0 ± 3.8	–	–	22.7 ± 1.0	22.0 ± 3.1	20.6 ± 2.3	21.7 ± 2.2	20.7 ± 2.2
17	22.7 ± 2.7	22.0 ± 2.2	21.9 ± 2.4	20.9 ± 2.2	23.2 ± 2.2	21.0 ± 2.5	21.0 ± 2.8	19.6 ± 0.8	22.9 ± 3.8	20.8 ± 2.2	20.2 ± 1.6
18	20.8 ± 2.1	21.1 ± 2.4	22.0 ± 2.3	23.6 ± 3.1	22.9 ± 2.5	22.2 ± 2.5	23.2 ± 1.4	23.2 ± 0.9	21.8 ± 2.6	22.8 ± 3.6	21.2 ± 1.8
19	20.3 ± 1.2	22.1 ± 4.0	23.9 ± 2.3	20.8 ± 2.2	22.1 ± 1.9	22.6 ± 2.6	22.7 ± 1.5	–	22.2 ± 1.4	20.8 ± 1.0	22.3 ± 1.0

*Co-educational schools.

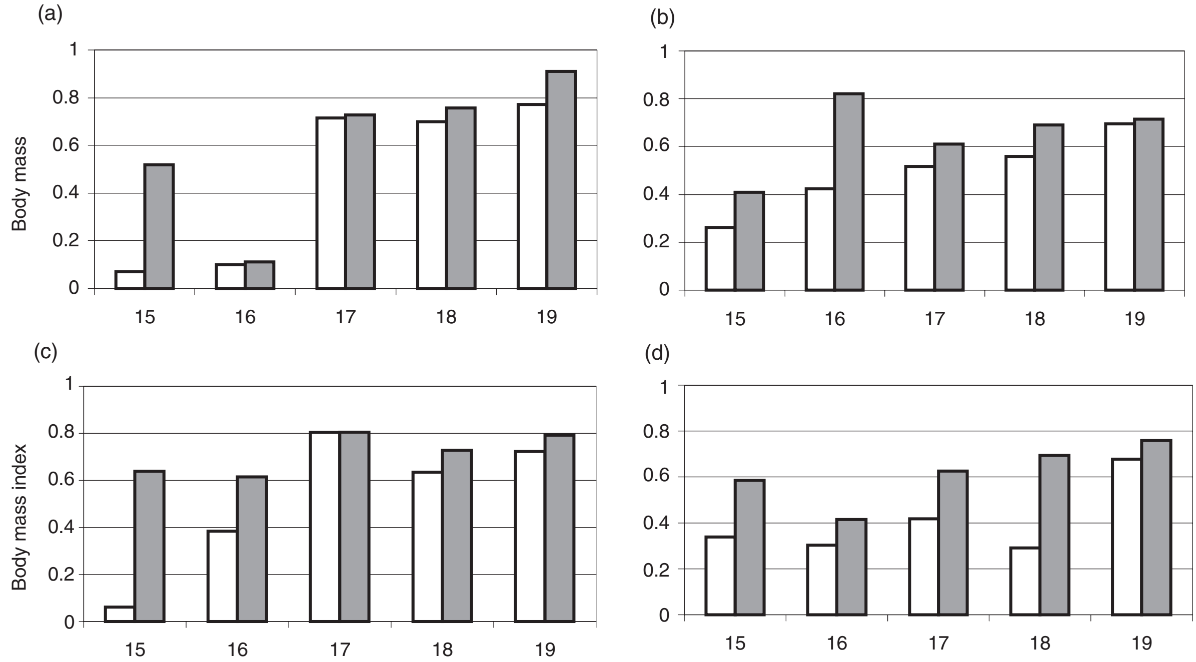

Figure 3 Correlation coefficients of actual and estimated body mass and body mass index of female (a,c) and male (b,d) pupils as obtained by the energy supply model (ESM) (□) and the macronutrient supply model (MSM) (▒), by years of age respectively.

Table 5 Estimated regression parameters of the energy supply model (ESM) (i.e. $m = 1$, $n = 0$) for body mass (i.e. $a = 3$) and body mass index (i.e. $a = 4$) with respect to the pupils' age and gender

	Regression parameters*				
	Age groups				
Parameter specification	**15**	**16**	**17**	**18**	**19**
Females					
Body mass					
$\alpha_{1,3}$ (kg)	**54.88**	**52.55**	**102.67**	**92.18**	**105.99**
$\beta_{1,30}$ (kg/kJ)	$7.93 \cdot 10^{-6}$	$3.23 \cdot 10^{-4}$	$\mathbf{-3.07 \cdot 10^{-3}}$	$\mathbf{-2.75 \cdot 10^{-3}}$	$\mathbf{-3.77 \cdot 10^{-3}}$
r^2	0.005	0.010	**0.511**	**0.490**	**0.595**
Body mass index					
$\alpha_{1,4}$ (kg/m^2)	**19.19**	**25.26**	**31.36**	**28.70**	**35.44**
$\beta_{1,40}$ (kg/m^2/kJ)	$7.93 \cdot 10^{-5}$	$-3.61 \cdot 10^{-4}$	$\mathbf{-8.51 \cdot 10^{-4}}$	$\mathbf{-6.61 \cdot 10^{-4}}$	$\mathbf{-1.16 \cdot 10^{-3}}$
r^2	0.004	0.147	**0.645**	**0.402**	**0.522**
Males					
Body mass					
$\alpha_{1,3}$ (kg)	**83.54**	**48.95**	**47.89**	**108.39**	18.64
$\beta_{1,30}$ (kg/kJ)	$-1.63 \cdot 10^{-3}$	$1.40 \cdot 10^{-3}$	$1.70 \cdot 10^{-3}$	$-2.77 \cdot 10^{-3}$	$\mathbf{4.07 \cdot 10^{-3}}$
r^2	0.068	0.180	0.267	0.314	**0.459**
Body mass index					
$\alpha_{1,4}$ (kg/m^2)	13.24	**24.45**	**15.44**	**25.70**	**12.01**
$\beta_{1,40}$ (kg/m^2/kJ)	$6.45 \cdot 10^{-4}$	$-2.52 \cdot 10^{-4}$	$4.79 \cdot 10^{-4}$	$-2.73 \cdot 10^{-4}$	$\mathbf{7.76 \cdot 10^{-4}}$
r^2	0.114	0.092	0.175	0.084	**0.457**

*Parameters significantly different from zero are in bold.

Table 6 Estimated regression parameters of the macronutrient supply model (MSM) (i.e. $m = 2$, $n = 1, 2, 3$*) for body mass (i.e. $a = 3$) and body mass index (i.e. $a = 4$) with respect to the pupils' age and gender

	Regression parameters†				
	Age groups				
Parameter specification	**15**	**16**	**17**	**18**	**19**
Females					
Body mass					
$\alpha_{2,3}$ (kg)	**46.80**	**52.49**	**104.21**	**95.29**	**110.63**
$\beta_{2,31}$ (kg/g)	$2.55 \cdot 10^{-1}$	$1.73 \cdot 10^{-2}$	$-1.45 \cdot 10^{-1}$	$-1.02 \cdot 10^{-1}$	$3.29 \cdot 10^{-1}$
$\beta_{2,32}$ (kg/g)	$-1.95 \cdot 10^{-1}$	$1.14 \cdot 10^{-2}$	$-1.02 \cdot 10^{-1}$	$-2.74 \cdot 10^{-2}$	$-3.75 \cdot 10^{-2}$
$\beta_{2,33}$ (kg/g)	$3.59 \cdot 10^{-2}$	$8.67 \cdot 10^{-3}$	$-5.85 \cdot 10^{-2}$	$\mathbf{-7.52 \cdot 10^{-2}}$	$\mathbf{-4.81 \cdot 10^{-2}}$
r^2	0.269	0.013	0.530	**0.574**	**0.828**
Body mass index					
$\alpha_{2,4}$ (kg/m^2)	**17.06**	**23.90**	**31.45**	**29.71**	**36.4**
$\beta_{2,41}$ (kg/m^2/g)	$9.93 \cdot 10^{-2}$	$2.26 \cdot 10^{-2}$	$-1.41 \cdot 10^{-2}$	$-2.89 \cdot 10^{-2}$	$-7.73 \cdot 10^{-2}$
$\beta_{2,42}$ (kg/m^2/g)	$-4.71 \cdot 10^{-2}$	$-4.73 \cdot 10^{-2}$	$-3.03 \cdot 10^{-2}$	$-1.84 \cdot 10^{-4}$	$-2.23 \cdot 10^{-2}$
$\beta_{2,43}$ (kg/m^2/g)	$1.00 \cdot 10^{-3}$	$4.33 \cdot 10^{-3}$	$\mathbf{-1.62 \cdot 10^{-2}}$	$\mathbf{-2.05 \cdot 10^{-2}}$	$-1.56 \cdot 10^{-2}$
r^2	0.406	0.378	0.649	0.528	0.627
Males					
Body mass					
$\alpha_{2,3}$ (kg)	116.81	30.83	36.60	**67.69**	20.19
$\beta_{2,31}$ (kg/g)	$-3.12 \cdot 10^{-1}$	$3.77 \cdot 10^{-1}$	$9.74 \cdot 10^{-2}$	$5.20 \cdot 10^{-1}$	$3.27 \cdot 10^{-2}$
$\beta_{2,32}$ (kg/g)	$1.68 \cdot 10^{-1}$	$5.01 \cdot 10^{-2}$	$-7.01 \cdot 10^{-2}$	$-4.22 \cdot 10^{-1}$	$1.57 \cdot 10^{-1}$
$\beta_{2,33}$ (kg/g)	$-1.51 \cdot 10^{-1}$	$-1.20 \cdot 10^{-2}$	$1.02 \cdot 10^{-1}$	$5.67 \cdot 10^{-1}$	$7.46 \cdot 10^{-2}$
r^2	0.1670	0.676	0.372	0.476	0.511
Body mass index					
$\alpha_{2,4}$ (kg/m^2)	30.24	18.68	10.46	**14.95**	**14.09**
$\beta_{2,41}$ (kg/m^2/g)	$-2.23 \cdot 10^{-1}$	$5.60 \cdot 10^{-2}$	$3.71 \cdot 10^{-2}$	$\mathbf{1.64 \cdot 10^{-1}}$	$-4.77 \cdot 10^{-2}$
$\beta_{2,42}$ (kg/m^2/g)	$8.67 \cdot 10^{-2}$	$-4.24 \cdot 10^{-2}$	$-4.22 \cdot 10^{-2}$	$\mathbf{-8.42 \cdot 10^{-2}}$	$2.85 \cdot 10^{-2}$
$\beta_{2,43}$ (kg/m^2/g)	$4.83 \cdot 10^{-3}$	$1.09 \cdot 10^{-2}$	$4.09 \cdot 10^{-2}$	$1.40 \cdot 10^{-2}$	$2.37 \cdot 10^{-2}$
r^2	0.343	0.172	0.393	0.480	0.574

*$n = 1, 2, 3$ refers to protein, fat and carbohydrates, respectively.
†Parameters significantly different from zero are in bold.

breakfast for female as well as for male students are dominated by dairy products (milk or cocoa and cheese). The optimized lunch consists of a meat dish, potatoes (females) or rice (males) and vegetables. Finally, the dinner chosen by the optimization process is a rather light one for the female students, whereas the optimized dinner for males is quite heavy, mainly including fried dishes.

The energy and nutrients provided by the optimized diet are presented in Table 8. Compared to the nutrient intake recommendations given in Table 2, it shows that the optimized supplies to female as well as to male pupils are in accordance with the corresponding RDAs. On comparing the optimized supply with the actual one (Table 2), the supply of energy, protein and fat to females decreased considerably, whereas the supply of calcium, magnesium and zinc, and of the vitamins B_1, B_6 and C increased. For males, the results of the optimization are similar to those of females, but not completely identical: the optimization procedure hardly

Table 7 Composition of an optimized daily diet with respect to the meals and the pupils' gender

	Dishes provided to . . .	
Meals	**Females**	**Males**
Breakfast	Cocoa	Milk
	Cream cheese	Egg
	Bread	Hard cheese
		Bread
Lunch	Vegetable soup	Vegetable soup
	Chicken (fried)	Lamb (boiled)
	Potatoes (boiled)	Rice (boiled)
	Broccoli (boiled)	Vegetable sauce
	Bread	Bread
	Banana	Fruit cake
Dinner	Rolls	Tea
	Yoghurt	Fish (fried)
		Potatoes (fried)
		Ketchup
		Bread

Table 8 Optimized daily supply of energy and selected nutrients for female and male pupils

	Optimized daily supply	
Energy and nutrients	**Females**	**Males**
Energy (kJ)	9300	12700
Proteins (g)	59	78
Fats (g)	73	98
Carbohydrates (g)	318	441
Minerals, trace elements		
Ca (mg)	1020	1100
Mg (mg)	395	386
P (mg)	1210	1278
Fe (mg)	16.0	11.5
Zn (mg)	11.1	13.5
Vitamins		
Niacin (mg)	14.0	21.0
B_1 (mg)	1.2	1.5
B_2 (mg)	1.2	1.8
B_6 (mg)	1.4	1.9
C (mg)	75	64

changed the supply of energy and fat, but significantly decreased the supply of protein and substantially increased the supply of calcium, magnesium, zinc, and again of the vitamins B_1, B_6 and C.

Furthermore, the optimization led to a decrease of the food costs by 12.5% for males and almost 18% for females.

Discussion

Food supply evaluation

Cross-sectional approach

The study reveals that the nutrient supply to pupils is sub-optimal in the boarding schools of Zagreb, Croatia. For most of the micronutrients with a minimum requirement (calcium, magnesium, zinc, and the vitamins B_1, B_6 and C) an undersupply was shown. In contrast to male pupils, females were undersupplied with niacin. Only the supplies of iron and vitamin B_2 are in good agreement with the corresponding recommendations. The gap between the nutrient supply provided by the boarding schools and the corresponding intake recommendations could theoretically be filled by extra-institutional food sources. But practically, this cannot be expected, as has been shown by the results of the questionnaires concerning the pupils' snacking habits (Table 3). Their frequent choices of fruit as snacks certainly improve their supply of most vitamins, but the deficient supplies of calcium, magnesium and zinc are probably not completely corrected.

For energy and macronutrients, a minimum as well as a maximum requirement can be assumed. Thus, neither an oversupply nor an undersupply is desirable. But, comparison between the average energy supply to the pupils and the corresponding RDAs (Table 2) shows quite an oversupply for females, whereas there is quite a well-balanced supply for males.

Considering fat supply, its upper limit is substantially exceeded for female pupils, whereas the fat supply to males is quite close to the corresponding RDAs (Table 2). However, if the contribution of fat to the pupils' total energy supply is considered, instead of the absolute amounts of fat provided to the pupils (Fig. 2), then an oversupply of fat to females as well as to males is revealed. This is associated with a low contribution of carbohydrates, which has been shown to promote serious and undesirable health impacts (Dunne 1996).

Thus, for female pupils there is an oversupply of energy and fat. On the one hand, this would not be a problem, if the pupils did not actually consume all the food they are provided with. To a certain extent, the results of the questionnaire hint towards this direction (Table 3): only two-thirds of the female students in the survey regularly have breakfast, lunch and dinner at school. But on the other hand, the extra-institutional food that the pupils enjoy is mostly rich in fat and energy as well, still adding to the problem of oversupply by the boarding schools. This might have negative effects on the females' physical development leading to an non-physiological increase in BM and an unnecessary increase in the feeding costs of the boarding schools.

Overall, the amount of essential micronutrients provided by the boarding schools per unit of dietary energy (i.e. the nutrient density of the food supply) is too low, especially if the requirements of female pupils are considered. In co-educational boarding schools, meals proved to be critical because the type and quantity of food provided to female and male pupils were identical, whereas their needs are different. But because of the policy of providing an identical menu to both male and female students, females face a substantial excess in daily energy and fat supply. The use of different portion sizes for male and female students could alleviate the problem but would not solve it completely, because the nutrient density of the food supply would remain the same. Its increase, however, could be achieved if nutritious snacks such as fruit or low-fat dairy products (yoghurt) are additionally offered to the students.

Longitudinal approach

Generally, the anthropometric characteristics of individuals, such as BM or BMI, are mainly affected by their food intake and their physical activity. In most cases, however, the effects are too small to be immediately observable. But because the effect is cumulative, it can easily be seen in the long run. Therefore, it is assumed that the quality of the diets provided by the boarding schools is increasingly responsible for the pupils' anthropometric measures. Furthermore, it is assumed that older pupils have consumed more boarding school meals than younger ones.

The effect of the boarding school feeding on the pupils' anthropometric characteristics can be seen in Table 4. One would expect that adolescents' age and BM are positively correlated because of their growth, whereas their triceps and subscapular skin-fold thicknesses as well as their BMI should be independent of their age. This, however, is not the case in many of the boarding schools considered. On the one hand, female students mostly show the expected association between age and BM, but triceps/subscapular skin-fold thicknesses and BMI are also positively associated with age, especially in co-educational boarding schools. This corresponds well to the oversupply of energy provided to female students in most of the schools (as shown in the cross-sectional approach) and proves that the surplus of energy supplied is obviously consumed by the girls. Male students, on the other hand, hardly show any consistent relationship between anthropometric characteristics and age indicating that the food supply to males is better adapted to their needs than the supply to females. This is also in good agreement with the results obtained by the cross-sectional approach.

Whether the food supply of the boarding schools could be responsible for this undesirable physical development was analysed by means of statistical modelling. It was expected that the correlations of the pupils' anthropometric measures and nutritional parameters of the boarding school feeding increased with the pupils' age, that is, with the duration of their boarding school attendance. This hypothesis was examined using linear and non-linear models of possible dependencies of anthropometric variables on nutrition. In order to detect potential interactions between nutrients the products of their supplies were added to the non-linear model as further regressors. But this did not considerably improve the model performance, and therefore interactions are not considered here. Thus, finally, a simple model with energy supply as the only regressor (ESM) and a more complex one based on the supply of the macronutrients (protein, fat and carbohydrates) as regressors (MSM) were proposed.

In Fig. 3 and Tables 5 and 6, the expected relationship between feeding and anthropometry is mostly confirmed. Considering BM of females, for example, the MSM provided a correlation coefficient $r = 0.5$ for the youngest group (aged 15 years), but after 4 years of boarding school feeding the correlation coefficient reached the value of $r = 0.9$. A similar trend was found for male pupils, for whom the MSM yielded correlation coefficients $r = 0.71$ and $r = 0.76$ for BM and BMI of 19-year-olds, respectively.

Correlation coefficients for triceps and subscapular skin-fold thicknesses ($a = 1, 2$) on the one hand and nutritional parameters of the feeding at the boarding schools on the other hand also show the same trend, but at lower levels (not given in the tables). For female pupils, for instance, the triceps skin-fold model has a correlation coefficient of about $r = 0.4$ at the age of 15 which increases up to $r = 0.68$ at the age of 19. These lower correlation coefficients for the skin-fold thickness models as compared to the BM-related models are probably because of measurement errors as it is more difficult to obtain valid measures of skin-fold thickness than of body weight and height.

The general observation that models derived for female pupils have lower correlations than for males can probably be attributed to differences in dietary habits as shown in Table 3. The males' participation in school feeding is higher than that of the females. Therefore, the amounts of energy and macronutrients provided by the boarding schools are better predictors for the anthropometric characteristics of males than of females.

Finally, the estimated regression parameters presented in Tables 5 and 6 deserve further attention. They generally reflect a combined effect of physiology and behaviour. Considering the ESM, one might expect that energy supply is positively associated with BM and BMI. This, however, was significant only for the 19-year-old males. For the other groups of students, there was no such significant association or in some cases even a significant negative one (females aged 17–19 years). These findings, that might appear surprising at first sight, can partly be attributed to physical activity which could not be assessed within the study. Generally, however, a person's anthropometric measures are the result of a balance or an imbalance of energy intake and actual energy need. Considering just one side, that is, energy intake (approximated by energy supply), it cannot be decided whether there is a balance or an imbalance. The results in Table 5 also indicate that females' nutritional behaviour in the boarding schools might be more autonomous from the food supply at the schools than males'. Females might tend to reject dishes with high energy content, possibly because of their taste preferences, their idea of 'beauty' or their general health consciousness. This behaviour would lead to the observed negative association between energy supply and BM (BMI).

It also needs to be considered that the boarding schools are not the only sources of food available to the pupils. As was shown in Table 3, only two-thirds of the female pupils and three-quarters of the male pupils consume all three meals supplied at the boarding schools on a regular basis. Thus, the boarding schools have a great but not an exclusive impact on the pupils' food consumption and therefore the influence of the food supply at the boarding schools on the pupils' anthropometric measures is limited.

The estimated regression parameters obtained on the basis of the MSM (Table 6) show that the influence of the intake of macronutrients on the pupils' anthropometric measures is not just defined by energy content of the nutrients. Otherwise, all the macronutrients would need to have positive effects while the effect of fat would be dominating and that of protein and carbohydrates would be close to each other. Contrarily, however, the analyses indicate that there might even be a negative correlation between the intake of carbohydrates and BM (BMI). This, again, might be because of physiological or behavioural reasons. Physiological reasons could be attributed to the limited and inefficient ways to store energy provided as carbohydrates. Behavioural reasons could be seen if one assumes that slim persons tend to prefer dishes that are rich in carbohydrates.

Nutrition optimization

The analyses proved that it is theoretically possible for the boarding schools to offer their pupils daily diets that are in good agreement with the RDAs. This would not require any dramatic changes to the actual food supply, only a reasonable selection and combination of already existing menus would be necessary to provide nutritionally adequate feeding.

Such an improvement of the food supply would not necessarily be associated with increased feeding costs, but, on the contrary, could even help to save money. Table 7 presents the cheapest wholesome combination of menus that could be offered to the pupils based on the 40 menus taken into account. Other wholesome combinations of menus are possible as well, but would be more expensive. Altogether, in an iterative optimization process, nine different combinations of menus were found which were all in agreement with the RDAs and yet less expensive than the actual average food costs of the schools. Thus, based on the 40 different menus regarded for the optimization, different diets for 9 days could be arranged, each meeting the corresponding nutrient requirements while still being less expensive than the average cost of the actual food supply of the schools. An even greater variety could probably be achieved if more than those 40 menus were entered into the optimization process.

But the reasonable selection and combination of menus providing adequate quantities of energy and nutrients is not a trivial task. Nutrition optimization with corresponding computer software, however, could be helpful in achieving this task. The necessary investments could easily be financed by the savings in feeding costs. Future applications of nutrition optimization techniques as an aid for menu planning in boarding schools should try to incorporate the palatability of the available menus and the corresponding likings of the pupils in order to provide food that is not just healthy and inexpensive but enjoyable as well.

Conclusions and recommendations

The study leads to the following conclusions and recommendations:

1 The survey showed that the nutritional quality of the food supply at the boarding schools in Zagreb, Croatia, is sub-optimal and should be improved. The supply of calcium, magnesium and most of the vitamins needs to be increased, and especially for female pupils, the supply of fat should be decreased. One solution might be to offer additional fruit and low-fat dairy products such as snacks in all boarding schools to increase the nutrient density of the food supply, and to provide at least two different types of menus in co-educational boarding schools to account for the different nutritional needs of female and male pupils.

2 The nutrition optimization showed that diet planning using nutrition computer software could help to avoid dietary deficiencies and the development of overweight and to simultaneously decrease the food costs of the schools.

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References

Balintfy JL (1964). Menu planning by computer. *Communication of the ACM* **7**:255–9.

Briefel RR *et al.* (1995). Total energy intake of the US population: the third national health and nutrition examination survey, 1988–1991. *American Journal of Clinical Nutrition* **62**:1072S–80S.

Brown ML *et al.* (1990). *Present Knowledge in Nutrition*. International Life Science Institute Nutrition Foundation: Washington D.C.

Bull NL (1985). Dietary habits of 15 to 25 year olds. *Human Nutrition/Applied Nutrition* **39A** (Suppl. 1):1–68.

Colavita C, D'Orsi R (1990). Linear programming and pediatric dietetics. *British Journal of Nutrition* **64**:307–17.

Cox E (1994). *The Fuzzy Systems Handbook*. Academic Press, Inc.: Cambridge, MA.

Crawley HF (1993). The energy, nutrient and food intakes of teenagers aged 16–17 years in Britain. *British Journal of Nutrition* **70**:15–26.

Dantzig GB, Thapa MN (1997). *Linear Programming*. Springer: New York, NY.

Darmon N *et al.* (2002). Linear and nonlinear programming to optimize the nutrient density of a population's diet: an example based on diets of preschool children in rural Malawi. *American Journal of Clinical Nutrition* **75**:245–53.

Dunne LJ (1996). *Sve o zdravoj prehrani*. MATE: Zagreb.

Food and Nutrition Board, Institute of Medicine (1999). *Dietary Reference Intakes: Application in Dietary Assessment*. National Academy Press: Washington D.C.

Gajdoš J *et al.* (2001). Meal planning in boarding schools in Croatia using optimisation of food components. *Current Studies of Biotechnology* **2** (Environment):217–22.

Gedrich K *et al.* (1999). How optimal are computer-calculated optimal diets? *European Journal of Clinical Nutrition* **53**:309–18.

Hadžihalilović J, Hadžiselimović R (2001). Growth and development of male children and youth in Tuzla's region after the war in Bosnia and Herzegovina. *Collegium Antropologicum* **25**:41–58.

Hendrix P *et al.* (1995). Measurement of the daily dietary calcium and magnesium intake in Belgium, using duplicate portion sampling. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung* **201**:213–7.

Karg G (1982). Modelle zur Bestimmung einer optimalen menschlichen Ernährung. *Hauswirtschaft und Wissenschaft* **30**:34–47.

Kersting M *et al.* (1998). Energy intake of 1 to 18 year old German children and adolescents. *Zeitschrift für Ernährungwissenschaft* **37**:45–55.

LINDO Systems Inc. (1995). *Solver Suite-LINDO, LINGO and What's Best* LINDO Systems Inc.: Chicago.

Maloney MJ *et al.* (1989). Dieting behaviour and eating attitudes in children. *Pediatrics* **84**:482–9.

Mišigoj-Duraković M (1995). *Morfološka antropometrija u športu*. Fakultet za fizičku kulturu: Zagreb.

Moore DC (1988). Body image and eating behavior in adolescent girl. *American Journal of Diseases of Children* **142**:1114–8.

Moore DC (1993). Body image and eating behavior in adolescents. *Journal of the American College of Nutrition* **15**:505–10.

Mulvihill CB *et al.* (1996). Dietary restraint and nutrient intakes of adolescents. *Proceedings of the Nutrition Society* **55**:217A.

National Academy of Science (1989). *Recommended Dietary Allowances*. National Academy Press: Washington, D. C.

Pemberton C *et al.* (1988). *Mayo Clinic Diet Manual*. B.C. Decker Inc.: Toronto.

Petrić J, Zlobec S (1983). *Nelinearno Programiranje*. Naučna knjiga: Beograd.

Schneider R (1997). *Vom Umgang mit Zahlen und Daten*. Umschau: Frankfurt am Main.

Sichert-Hellert W *et al.* (1998). Underreporting of energy intake in 1 to 18 year old German children and adolescents. *Zeitschrift für Ernährungwissenschaft* **37**:242–51.

Steinel M, Karg G (1993). Übersicht über Modelle zur Bestimmung einer optimalen Ernährung. In: *Sozialökonomische Forschung zum Ernährungsverhalten in den Alten und Neuen Bundesländern* (ed. G Ulbricht et al.), pp. 157–70. Bundesforschungsanstalt für Ernährung: Karlsruhe.

Stigler GJ (1945). The cost of subsistence. *Journal of Farm Economics* **27**:303–14.

Torun B *et al.* (1996). Energy requirements and dietary energy recommendations for children and adolescents 1 to 18 years old. *European Journal of Clinical Nutrition* **50** (Suppl. 1):S37–81.

US Department of Agriculture (USDA) (1998). *Nutrient Database for Standard Reference, Release 12*. U.S. Department of Agriculture, Agricultural. Research Service, Nutrient Data Laboratory (http://www.nal.usda.gov/fnic/foodcomp).

Vokk R, Boeing H (1998). Public health aspects of nutritional science in Estonia: status, research activities, and perspectives. *Zeitschrift für Ernährungswissenschaft* **37**:221–6.

WHO (1995). *Technical Report Series: Physical Status, the Use and Interpretation of Anthropometry*. WHO: Geneva.

Wirsam B, Uthus EO (1996). The use of fuzzy logic in nutrition. *Journal of Nutrition* **126** (9S):2337S–41S.

Wolfram S (1999). *The Mathematica v. 4 Book*. Cambridge University Press: Cambridge.