

Nutrition

The efficiency of Governmental and WFP UN Programs for improvement of nutritional status in Tajik schoolchildren as assessed by dietary intake and hair trace element content

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ABSTRACT

Background: The objective of the study was to assess hair trace element and mineral content in children undergoing WFP UN and the governmental programs of school nutrition in Tajikistan.

Methods: WFP program included provision of wheat flour fortified with micronutrients including Fe and Zn, and iodized salt, whereas within the governmental program hot meals were provided. A total of 202 children studying in schools that were not (Type 1, n = 100) or were involved in dietary intervention programs (Type 2, n = 102). Food and hair trace element content was assessed using ICP-MS.

Results: Daily intake of Fe, I, Zn, B, Co, Mg, Si, and Sr in Type 2 schools was more than 2.5, 12, 4, 2.9, 2.6, 2, 3, and 2-fold higher than that in Type 1 schools. Correspondingly, anthropometric parameters in children from Type 2 schools exceeded the control values. Surprisingly, no significant difference in hair iodine levels was detected. Hair analysis demonstrated a significant increase in hair Ca, Mg, Na, Co, Cr, Cu, Fe, Li, Mn, Se, V, Zn content. Certain toxic elements including Al, As, and Be were also characterized by an increase in Type 2 schools. At the same time, nutritional intervention was associated with a significant decrease in hair B, Hg, and Sn levels.

Conclusions: Nutritional intervention within WFP and the governmental program was effective in increasing essential trace element supply in Tajik schoolchildren. However, further studies including a detailed assessment of nutritional and health status with a special focus on iodine and thyroid functioning are required.

1. Introduction

Essential trace elements play a significant role in human health through their signaling, cofactor, and structural role [1,2], whereas toxic metals and metalloids are known to damage organism's systems

through their prooxidant and proinflammatory effects [3,4], as well as interference with essential trace element metabolism [5,6]. Trace element status was shown to be a significant determinant of population health and demography [7].

Children are especially prone to adverse health effects of essential

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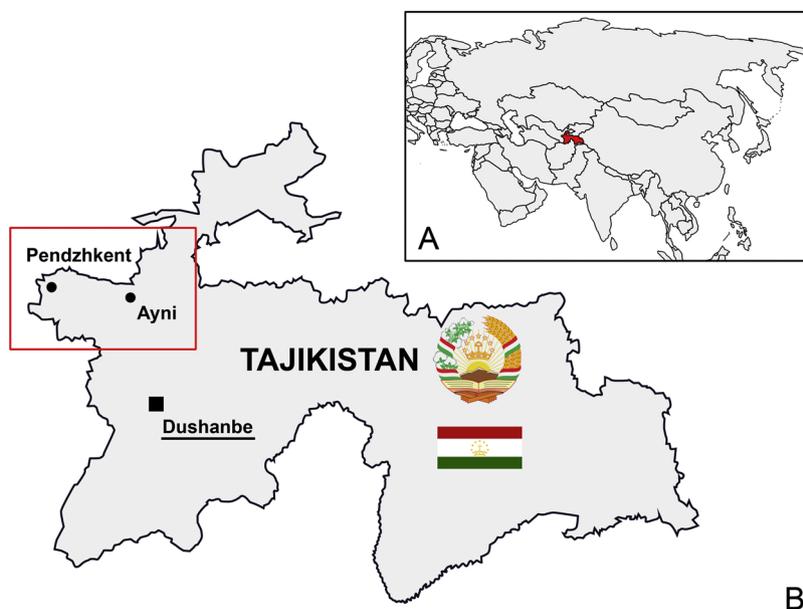


Fig. 1. The geographic location of Tajikistan (red marker) (A) and the studied areas (red box) (B).

element deficiency [8] and toxic metal overload [9]. Particularly, developing the nervous system is especially vulnerable [10] and deficiency of iodine [11], zinc [12], and iron [13] were shown to be associated with reduced cognitive and motor skills. Although Mn plays an essential role in brain development [14], its overexposure is associated with increased risk of neurodevelopmental disorders, reduced cognitive and motor functions [15]. At the same time, prenatal and early-life exposure to toxic metals including mercury, lead, and arsenic were shown to reduce IQ, cause behavioral disorders, and neurodegeneration in later life [16].

Prenatal trace element deficiency is also associated with immune deficiency and increased risk of infectious diseases [17]. In turn, Zn supplementation was shown to reduce the incidence of diarrhea in infants reducing infant mortality [18]. Arsenic exposure was also shown to be associated with impaired immunity and higher susceptibility to infectious diseases [19]. Therefore, monitoring and improvement of essential and toxic trace element levels in children is an effective tool in health management.

The global burden of micronutrient deficiency is estimated to be 2 billion people worldwide with Central Asia being one of the most deficient regions [20]. Tajikistan is characterized by the lowest human development index (HDI) and of all countries of the Commonwealth of Independent States with serious problems in children health and nutrition [21]. According to UNICEF 2009 report, the incidence of anemia in children in Tajikistan exceeded 30%, whereas the frequency of mild and moderate-to-severe iodine deficiency varied from 45% in urban to 55% in urban areas [22]. Correspondingly, of 623 children examined in Southern Tajikistan, nearly 47% were goitrous [23]. The causes of micronutrient deficiency in Tajik schoolchildren may include low trace element content in local foods [24], limited food diversity due to economic or other causes [25], or high prevalence of helminths and intestinal protozoa infections [26]. Although certain efforts to improve micronutrient status of the Tajik children have been made, especially in the case of iodine [27] and iron [28], deficiency of essential trace elements continues to be a serious public health problem [29]. Therefore, further strategies are to be developed to meet the requirement of adequate trace element intakes to improve health status of the schoolchildren in Tajikistan.

Current programs aimed at improvement of childhood nutrition in Tajikistan include i) the WFP program, and ii) the Ministry of Health program. Therefore, the objective of the present study was to assess hair

trace element and mineral content in children undergoing different programs of school nutrition in Tajikistan in order to estimate the relationship between improved nutrient intake and hair content as a marker of dietary intervention efficiency.

2. Materials and methods

2.1. Ethics

All procedures performed within the study were in agreement with the principles of the Declaration of Helsinki (1964) and later amendments. The Local Ethics Committee approved the protocol of the present study. The parents of the examined children signed the informed consent forms before the inclusion in the study. The study was performed within an agreement between Center for Biotic Medicine, Social and Industrial Foodservice Institute, and WFP UN (2016).

2.2. Participants and diets

The study was performed in agreement with the principles of the Declaration of Helsinki and its later amendments and approved by the Local Ethics Committee. Parents of the examined children signed the informed consent form. All experimental procedures (registration of anthropometric data, hair sampling) involving children were performed in the presence of their parents.

A total of 202 schoolchildren (106 girls, 96 boys) living in the Republic of Tajikistan in Penjikent and Nurek regions were enrolled in the current study (Fig. 1). The age of the examined children attending 1–4 classes of the secondary schools was 7–10 years old.

Anthropometric characteristics of children such as height and weight were registered (Table 1). Body mass index (BMI, kg / m^2) was calculated in agreement with the formula $\text{BMI} = \text{weight (kg)} / \text{height}^2 (\text{m}^2)$.

Generally, only healthy children were involved in the present study. In addition, exclusion criteria were used in order to avoid the impact of side factors: i) acute inflammatory and infectious diseases; ii) metal implants including dental amalgams; iii) living in a proximity of industrial pollution sources (or occupational exposure of parents); iv) endocrine disorders; v) surgical and traumatic diseases; vi) irregular food habits including vegetarian diet; vii) neurodevelopmental disorders; viii) growth delay.

Table 1
Comparison of anthropometric data of students of different type schools.

Parameter	Boys		Girls	
	Type 1 schools n = 44	Type 2 schools n = 52	Type 1 schools n = 56	Type 2 schools n = 50
Weight (kg)	24 (23 - 28)	27* (24 - 30)	24.5 (21.5-27)	25.5 (23.5-28)
Height (cm)	127 (123 - 131)	131* (126 - 135)	129 (123-131)	131* (127 - 135)
BMI (kg/m ²)	15 (14.6 - 16)	15.8* (14.9 - 16.6)	15.0 (13.9 - 15.6)	15.1 (14.2 - 16.0)

Data are expressed as median and the respective 25–75 percentile boundaries; * - The difference is significant at $p < 0.05$ in comparison to Type 1 schools.

The study was performed in two types of schools that were not involved (Type 1) or were involved in the World Food Programme (WFP) for the last 5–6 years and the governmental program for improvement of infrastructure and provision of hot meals for schoolchildren (Type 2). Schools of the second type were provided by flour, peas, vegetable oil fortified with micronutrients (vitamins A, B₁, B₂, B₃, folic acid, Zn, Fe) and iodized salt.

Daily menu for the whole week (5 days) of Type 1 schools included traditional Tajik “Ugro” soup (250 g), black tea (200 ml), bread (105 g), corresponding to wheat flour (602 g), peas (50 g), salt (6 g), tomato paste (0.6 g), potato (75 g), carrot (75 g), onion (60 g), vegetable oil (1.5 g), leaf tea (5 g), dry yeast (3 g), margarine (33 g), sugar (107 g), egg (0.6) per week.

Within the governmental program of the Tajikistan Republic, the daily menus in Type 2 schools were different for all days of the week, being also different for each of two weeks. The week menu for Type 2 schools included everyday items including black tea (200 ml), bread (105 g), baked roll (50 g) and different main dish (Table 2). Generally, average weekly consumption accounted for 40 g of peas, 3 g of dry yeast, 31 g of cabbage, 75 g of potato, 65 g of onion, 25 g of margarine, 89 g of chickasano pea, 38 g of carrot, 605 g of wheat flour, 35 g of vegetable oil, 66 g of head rice, 95 g of sugar, 3 g of salt, 1.6 g of dried fruits, 1 g of tomato paste, 153 g of pumpkin, 97 g of beans, 5 g of leaf tea, 0.19 egg per week.

2.3. Sampling

Proximal parts of the hair strands from the occipital region were collected using ethanol-precleaned stainless steel scissors. Prior analysis the samples were cleaned with acetone (Chimmed, Russia) for the 10–15 min and subsequently washed three times with deionized distilled water (18 M Ω cm⁻¹) (Milli-Q, Millipore, Merck, Darmstadt, Germany) and dried at 60 °C on air.

Food products were collected directly in school kitchens from different batches delivered for cooking. Not less than three samples of a particular foodstuff in each of the schools were used for assessment of trace element and mineral content.

A quantity of 50 mg washed hair samples or studied foodstuffs were subjected to microwave decomposition in 65% nitric acid (Chimmed, Russia) in Berghof Speed Wave 4 Microwave System (Berghof

Table 2
Daily dinner menus in schoolchildren from Type 1 and 2 schools.

Day	Type 1	Type 2	
	Weeks 1 and 2	Week 1	Week 2
1-5	Black tea (200 ml), bread (105 g)	Black tea (200 ml), bread (105 g), baked roll (50 g)	
1	Traditional “Ugro” soup (250 g)	Traditional “Ugro” soup (250 g)	Potato soup with rice (250 g)
2	Traditional “Ugro” soup (250 g)	Boiled beans (200 g)	Boiled peas (200 g)
3	Traditional “Ugro” soup (250 g)	Cabbage soup (250 g)	Homemade noodle soup (250 g)
4	Traditional “Ugro” soup (250 g)	Khanum with pumpkin (200 g)	Rice porridge with pumpkin (230 g)
5	Traditional “Ugro” soup (250 g)	Pea soup (250 g)	“Shavliya-shurbo” (national Tajik soup)

Only data on school dinners are provided. Out-of-school dietary intake was not monitored.

Products + Instruments, Germany) at 200 °C. The obtained solutions were quantitatively transferred to polypropylene tubes, adjusted to a total volume of 15 ml with deionized water, and thoroughly mixed.

2.4. Trace element analysis

The levels of Al, As, B, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, I, K, Li, Mg, Mn, Na, Ni, P, Pb, Se, Si, Sn, V, and Zn in hair samples was assessed using mass spectrometry with inductively coupled plasma in dynamic reaction cell mode (ICP-DRC-MS) at NexION 300D + NWR213 spectrometer (Perkin Elmer, USA) equipped with ESI SC-2 DX4 autosampler (Elemental Scientific Inc., USA). System calibration was performed using standard solutions with a total concentration of trace elements of 0.5, 5, 10, and 50 μ g/L prepared from the Universal Data Acquisition Standards Kit (PerkinElmer Inc., Shelton, CT 06484, USA) by dilution with deionized water acidified with 1% HNO₃. A standard solution containing 10–25 μ g/L of yttrium prepared from pure single-element standard Yttrium (Y) (PerkinElmer Inc., Shelton, CT 06484, USA) on a matrix containing 8% 1-butanol (Merck KGaA), 0.8% Triton X-1 100 (Sigma-Aldrich, Co.), 0.02% tetramethylammonium hydroxide (Alfa-Aesar, Ward Hill, MA 2 01835 USA) and 0.02% EDTA (Sigma-Aldrich, Co) was used for internal online standardization.

2.5. Laboratory quality control

Laboratory quality control of hair analysis was performed using the certified reference material of human hair GBW09101b (SINP, People's Republic of China), whereas food analysis was quality controlled by using the certified reference materials of Pork liver GBW08551, Pork muscle GBW08552 (SINP, People's Republic of China), as well as Animal Muscle H-4, Cabbage IAEA-359, and Mixed Human Diet H5 (International Atomic Energy Agency, Austria). The procedures were performed daily both before and after each set of analyses. The recovery rates for all trace elements analyzed were within a range of 89–110% and 85–117% for hair and food samples, respectively.

2.6. Statistics

Analysis of the primary data was performed using the integrated statistical software package Statistica 10.0 (StatSoft Inc., Tulsa, OK,

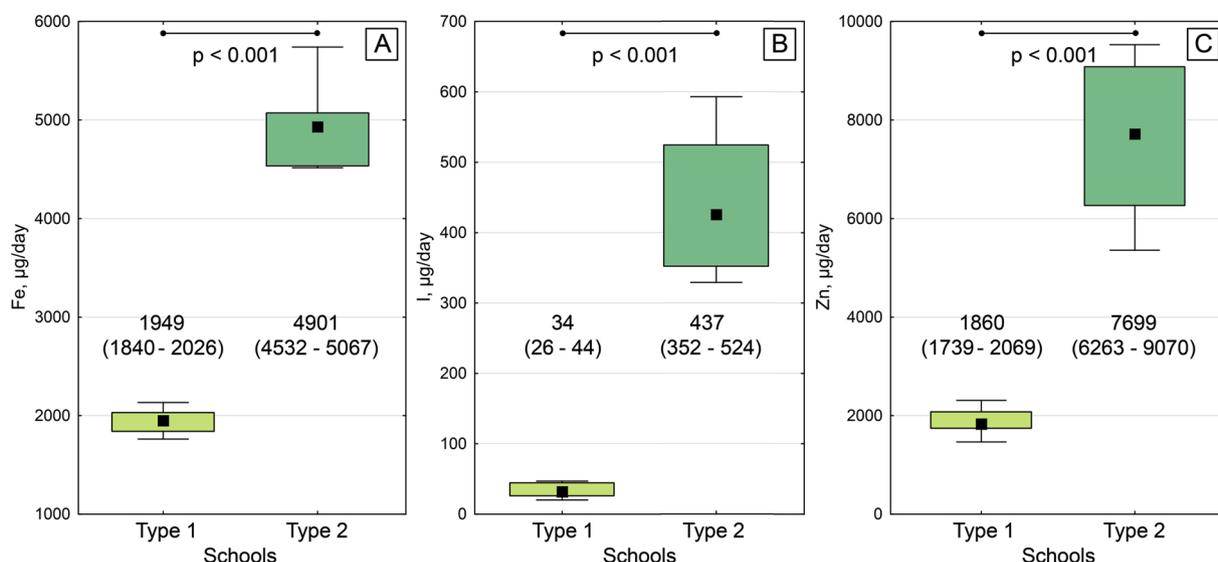


Fig. 2. Intake ($\mu\text{g}/\text{g}$) of iron (A), iodine (B), and zinc (C) with dinner in types 1 and 2 schools. Data are expressed as median (point), interquartile range (box), and non-outlier range (whiskers).

USA). Data distribution was evaluated using the Shapiro-Wilk test. As the distribution of data on hair trace element content was characterized by non-Gaussian distribution, median and the respective 25 and 75 percentile boundaries were used as descriptive statistics. Non-parametric Mann-Whitney *U* test was used for paired group comparisons at the level of significance of $p < 0.05$.

3. Results

3.1. Trace element and mineral content of diets and daily intake

The obtained data demonstrate that trace element content in enriched foods consumed in Type 2 schools was significantly higher than the respective products in Type 1 schools. Particularly, iodine content in WFP salt exceeded the control values by a factor of more than 12 (134 ± 63 vs. $12 \pm 7 \mu\text{g}/\text{g}$, $p < 0.001$). Fe and Zn content in wheat flour provided within WFP program were more than 2.3-fold (23.2 ± 2.8 vs. $10.4 \pm 2.5 \mu\text{g}/\text{g}$, $p < 0.001$) and 4.7-fold (47.2 ± 9.6 vs. $10.1 \pm 3.9 \mu\text{g}/\text{g}$, $p < 0.001$) higher as compared to the local product. Trace element and mineral content of the local foodstuffs used for cooking in both types of schools is provided in the Appendix (Supplementary material).

Involvement in the WFP program resulted in a significant increase in daily trace element and mineral intake in Tajik schoolchildren. Particularly, daily intake of iron, iodine, and zinc that were introduced

into WFP products in Type 2 schools was more than 2.5, 12, and 4-fold higher than that in Type 1 schools (Fig. 2). The intake of other essential as well as toxic trace elements was also significantly affected by the nutritional intervention (Table 3). The intake of B, Co, Mg, Si, and Sr exceeded the control values by a factor of more than 2.9, 2.6, 2.0, 3.0, and 2.0, respectively.

3.2. Anthropometric data

The obtained data demonstrate that nutritional interventions had a significant impact on anthropometric parameters (Table 1). Boys studying in Type 2 schools were characterized by an increase in body weight, height, and BMI values by 13, 3, and 5% compared with boys attending Type 1 schools, respectively. In girls from Type 2 schools only height significantly exceeded the control values by 2%.

3.3. Hair mineral content

The results are indicative of significant differences in hair mineral content in schoolchildren with different types of nutrition (Table 4). In particular, hair Mg level was increased by 23% and 35% in boys and girls from Type 2 schools in comparison with controls, respectively. Significantly higher Ca level was also observed in boys from Type 2 schools, exceeding the respective control values by 23%. In girls from Type 2 schools, a 45% elevation of hair Ca levels was observed

Table 3
Daily intakes of trace elements and minerals from school meals of Tajik children.

Element	mg/day		P value	Element	$\mu\text{g}/\text{day}$		P value
	Type 1 school	Type 2 school			Type 1 school	Type 2 school	
Na	542.1 (220.7-816.8)	1255.3 (708.2-1234.7)	0.014 *	Ni	44.1 (24.3-57.7)	110.7 (56.5-149.7)	0.018 *
K	458.2 (208-452.1)	998.5 (502.7-1514.1)	0.002 *	Se	13.4 (4.2-17.9)	16.7 (5.4-23.6)	0.473
P	220.5 (97.8-296)	369.6 (293.3-566.8)	0.031 *	Cr	9.00 (5.65-14.48)	11.51 (7.72-17.05)	0.412
Mg	54.97 (41.39-79.07)	109.79 (61.45-133.69)	0.036 *	Pb	4.38 (2.68-5.38)	6.51 (3.92-9.33)	0.040 *
Ca	50.23 (35.76-59.33)	89.41 (34.6-89.72)	0.330	Li	6.41 (4.49-7.83)	5.84 (3.94-8.17)	0.837
Si	1.488 (1.301-2.333)	4.582 (2.154-5.437)	0.010 *	Co	2.17 (2.12-3.14)	5.64 (2.27-8.01)	0.061
Mn	2.375 (1.592-3.26)	2.678 (1.438-2.733)	0.573	As	2.1 (0.54-2.77)	4.29 (1.95-4.97)	0.012 *
Al	1.517 (0.997-2.25)	1.81 (1.29-2.803)	0.218	V	2.19 (1-2.42)	3.12 (3.04-4.71)	< 0.001 *
Cu	0.500 (0.301-0.652)	0.877 (0.442-1.095)	0.182	Cd	1.24 (1.07-1.98)	2.85 (1.59-4.76)	0.036 *
Sr	0.415 (0.281-0.65)	0.861 (0.595-1.253)	0.027 *	Sn	1.31 (0.81-1.33)	2.11 (1.74-2.36)	0.009 *
B	0.247 (0.176-0.373)	0.724 (0.308-0.859)	0.024 *	Hg	0.77 (0.41-1.22)	1.11 (0.75-1.37)	0.144

Data are expressed as median and the respective 25–75 percentile boundaries; * - The difference is significant at $p < 0.05$ in comparison to Type 1 schools.

Table 4
Hair mineral content ($\mu\text{g/g}$) in girls and boys attending different types of schools.

Element	Boys		Girls	
	Type 1 schools n = 44	Type 2 schools n = 52	Type 1 schools n = 56	Type 2 schools n = 50
Ca	430 (351 - 518)	540* (468 - 622)	400 (334 - 456)	579* (480 - 715)
K	579 (243 - 1363)	655 (357 - 1072)	304 (189 - 822)	371 (229 - 620)
Mg	58.6 (48.4 - 72.4)	72.2* (61.6 - 84)	67.5 (50.7 - 84.5)	91.4* (69 - 119.6)
Na	590 (248 - 1444)	1397* (510 - 2278)	313 (216 - 670)	512 (270 - 865)
P	170 (157 - 187)	163 (153 - 176)	171 (158 - 187)	163 (154 - 181)

Data are expressed as median and the respective 25–75 percentile boundaries; * - The difference is significant at $p < 0.05$ in comparison to Type 1 schools.

Table 5
Hair content ($\mu\text{g/g}$) of trace elements schoolchildren.

Element	Boys		Girls	
	Type 1 schools n = 44	Type 2 schools n = 52	Type 1 schools n = 56	Type 2 schools n = 50
Al	26.6 (16 - 38.4)	37.9* (27.7 - 49.4)	14.8 (10.0 - 19.1)	21.6 (11.7 - 33.5)
As	0.104 (0.083 - 0.124)	0.111* (0.086 - 0.136)	0.084 (0.074 - 0.096)	0.070 (0.056 - 0.087)
B	1.051 (0.676 - 1.485)	0.744* (0.548 - 1.128)	0.753 (0.49 - 1.077)	0.404* (0.303 - 0.595)
Be	0.0021 (0.0014 - 0.0027)	0.0028* (0.0022 - 0.0036)	0.0013 (0.0007 - 0.0022)	0.0015 (0.0008 - 0.0025)
Cd	0.0232 (0.0136 - 0.0355)	0.0194 (0.0115 - 0.0336)	0.0096 (0.0075 - 0.0151)	0.0103 (0.0070 - 0.0146)
Co	0.024 (0.018 - 0.035)	0.039* (0.159 - 0.222)	0.014 (0.010 - 0.026)	0.023 (0.011 - 0.031)
Cr	0.134 (0.098 - 0.171)	0.182* (0.084 - 0.154)	0.095 (0.067 - 0.136)	0.117* (0.084 - 0.154)
Cu	7.70 (7.10 - 8.54)	9.29* (7.96 - 9.97)	7.62 (6.95 - 8.35)	8.70* (7.91 - 9.74)
Fe	31.6 (23.5 - 46.9)	67.7* (40.3 - 78.0)	21.3 (16 - 34.2)	40.5* (23.5 - 58.3)
Hg	0.162 (0.092 - 0.275)	0.051* (0.033 - 0.077)	0.193 (0.104 - 0.242)	0.034* (0.026 - 0.053)
I	0.122 (0.083 - 0.356)	0.171 (0.090 - 0.376)	0.098 (0.054 - 0.160)	0.102 (0.069 - 0.202)
Li	0.052 (0.039 - 0.078)	0.073* (0.048 - 0.093)	0.035 (0.025 - 0.049)	0.042 (0.030 - 0.055)
Mn	0.947 (0.767 - 1.583)	1.631* (1.150 - 2.109)	0.493 (0.366 - 0.825)	0.757* (0.431 - 1.045)
Ni	0.146 (0.111 - 0.214)	0.182 (0.146 - 0.223)	0.151 (0.091 - 0.185)	0.133 (0.099 - 0.182)
Pb	0.802 (0.485 - 1.092)	0.759 (0.499 - 1.793)	0.313 (0.235 - 0.567)	0.296 (0.211 - 0.424)
Se	0.371 (0.347 - 0.407)	0.434* (0.396 - 0.479)	0.359 (0.328 - 0.383)	0.440* (0.419 - 0.474)
Si	14.6 (12.3 - 32.4)	15.3 (12 - 19.9)	13.8 (11.1 - 24.2)	15.3 (12 - 19.9)
Sn	0.047 (0.033 - 0.070)	0.045 (0.034 - 0.067)	0.038 (0.021 - 0.063)	0.033* (0.021 - 0.048)
V	0.063 (0.042 - 0.090)	0.122* (0.088 - 0.159)	0.040 (0.025 - 0.062)	0.069* (0.039 - 0.099)
Zn	175 (163 - 197)	205* (182 - 222)	183 (155 - 223)	222* (204 - 243)

Data are expressed as median and the respective 25–75 percentile boundaries; * - The difference is significant at $p < 0.05$ in comparison to Type 1 schools.

compared with Type 1 schools. No significant group difference in hair K and P levels was observed both in girls and boys. For boys, the highest hair Na content was observed in Type 2 schools exceeding the corresponding values in Type 1 schools by a factor of more than two. However, no significant group difference in hair Na was observed in girls attending different types of schools.

3.4. Essential trace elements in hair

Further analysis of hair essential and conditionally essential trace element levels (Table 5) showed that only hair silicon and iodine content did not differ significantly among students from different types of schools. Hair B levels in children from Type 2 schools were characterized by 29% (boys) and 46% (girls) decrease when compared to the respective control values. It is shown that selenium content is higher in boys and girls from Type 2 schools by 17% and by 23% than that in the control schools, respectively.

In boys attending Type 2 schools hair Co, Cr, Cu, Fe, Li, Mn, V, and Zn content exceeded the corresponding values in Type 1 schools by 63, 36, 21, 114, 42, 72, 94, and 17%, respectively. In girls from Type 2 schools hair Cr, Cu, Fe, Mn, V, and Zn content was higher by 23, 14, 90, 54, 74, and 21% as compared to the control values. No significant group difference in Co and Li content was observed in girls' hair.

3.5. Hair toxic trace elements

In addition to essential elements, nutritional intervention in Tajik

schoolchildren also had a significant impact on hair toxic element levels (Table 5). It was shown that hair Pb, Ni, and Cd concentration did not differ significantly among students from different types of schools. Both in boys and girls nutritional intervention resulted in a significant more than 3 and 5-fold decrease in hair Hg level as compared to the control values, respectively. At the same time, hair Al, As, and Be content in boys from Type 1 schools was 30, 6, and 25% lower compared with the respective values in Type 2 schools. In girls the lowest hair tin content was found in Type 2 schools, being 14% lower compared with Type 1 schools. No significant group differences in Al, As, and Be hair levels were observed in girls, whereas boys were characterized by a nearly similar hair Ni levels.

4. Discussion

The obtained data demonstrate that introduction of trace element fortified products along with increasing food variability within WFP and governmental programs significantly increased intake as well as hair trace element content in Tajik schoolchildren. Surprisingly, using iodized salt significantly increased iodine intake but not have any valuable intake on hair iodine content.

Nutritional status of Tajik children has improved significantly during the last decades, although further efforts are required in order to provide an adequate micronutrient supply [30]. Particularly, an earlier study demonstrated that legume consumption in women of child-bearing age is considered as sufficient predisposing to adequate iron and folate intake [31]. However, the results of a recent study

demonstrated that the prevalence of iron deficiency anemia was estimated as 20% in children aged 25–60 months being unrelated to overweight and obesity [32]. A higher rate of childhood anemia is observed in Gorno-Badakhshan Autonomous Oblast of Tajikistan (41.4%) whereas the lowest was observed in Dushanbe (16.1%) [33]. These observations are in agreement with the lowest rate of soil irrigation in GBAO [34]. A study performed in South Tajikistan revealed mild-to-moderate iodine deficiency in schoolchildren with 46.6% being goiterous [23]. The lowest iodine intake was observed in children from GBAO as well as Dushanbe, whereas adequate intake was found only in Sughd as assessed by urinary iodine concentration [35]. In addition, analysis of street foods in Dushanbe (Tajikistan) demonstrated that the available foods are considered as nutritionally inadequate with respect to sodium and potassium content [36]. It is also notable that zinc and iron content of grains growing in Tajikistan is dependent on a particular location [37], being indicative of different nutritional adequacy in regions.

In addition to low intake of essential trace elements, toxic trace elements exposure may have a significant impact on population health due to an increasing rate of environmental pollution [38]. Former uranium ore mining sites may be considered as the sources of both radionuclide and heavy metal pollution [39]. Although no primary sources of lead pollution are present in Tajikistan, transboundary transfer of Pb-containing aerosols from other countries including China may also significantly contribute to the national lead exposure levels [40]. Earlier studies demonstrated increased levels of heavy metals in dust aerosols of the south-central part of Tajikistan [41].

Therefore, monitoring of micronutrient (including trace element) status, as well as metal exposure assessment, are essential tools for health assessment and control of efficiency of nutritional interventions in Tajik schoolchildren being characterized by a high risk of trace element imbalance.

The obtained data demonstrate that using fortified products had a significant impact on both trace element intake and hair levels. Generally, the observed elevation of hair essential trace elements and minerals in children consuming iron- and zinc-fortified wheat products corroborates earlier data. Enrichment of wheat flour with micronutrients including iron and zinc is considered as the valuable tool for increasing trace element supply [42]. Particularly, the administration of Zn-fortified bread significantly increases serum Zn and Fe levels in Zn-deficient Peruvian women [43]. Using fortified wheat flour was shown to have a positive impact on serum Zn levels, markers of iron status, as well as the incidence of iron deficiency anemia in both women and their children [44]. Experimental studies also demonstrate increased zinc and iron bioavailability from fortified bread [45]. Oppositely, another study registered reduced fractional Zn absorption from Zn fortified foods in Peruvian schoolchildren, although total intake was significantly increased [46]. However, a study in Indonesian children demonstrated a reduction in Fe absorption from foods cofortified with zinc sulfate, but not ZnO [47].

A similar effect was demonstrated for iron-fortified products. Particularly, fortification of wheat-based lunch in Indian schoolchildren resulted in a significant reduction in the prevalence of IDA together with the elevation of blood Hb, serum ferritin and transferrin receptor, as well as zinc protoporphyrin levels [48]. Iron fortification was also considered as a cost-effective tool for improvement of iron status in Brazilian children [49]. Iron fortification did not increase the total iron content of foods but also had a significant impact on iron bioavailability. In particular, iron-fortified wheat flour-based products were shown to have 27% higher iron bioavailability as compared to the control biscuits [50]. However, the results of other study demonstrated that only NaFeEDTA but not other commonly used iron compounds (ferrous lactate, ferrous fumarate, ferric pyrophosphate, carbonyl iron, ferrocenel, etc.) significantly increased iron dialyzability *in vitro* [51].

Salt iodination was shown to be an effective tool to increase the iodine status of the population [52]. Particularly, the consumption of

iodized salt has been shown to prevent the prevalence of goitre in children from iodine deficiency [53]. It is proposed that iodine may be used as the potential biomarker of iodine status [54], although urinary iodine concentration is considered as the golden standard of iodine intake assessment [55]. Using iodized salt significantly increased iodine excretion in numerous studies [56]. Surprisingly, despite a significant difference in iodine intake hair I content did not increase in children consuming iodinated salt. At the same time, the absence of significant group difference in hair iodine content generally corroborates the existing contradictions for UIC. Particularly, it was shown that iodine supplementation significantly reduced urinary iodine excretion [57]. However, no particular mechanism of the observed lack of increase in hair iodine in response to iodized salt consumption is unclear. Moreover, a detailed analysis of other markers of iodine status, as well as thyroid hormones, is strongly recommended.

The obtained data also revealed a significant increase in hair levels of other trace elements including both essential and some toxic ones. Given the lack of fortification, one can propose that increased dietary diversity in children involved in WFP and government programs may be considered as the additional source of trace elements. Particularly, it was demonstrated that dietary diversity score is associated with increased probability of adequate intake of zinc, iron, calcium, as well as vitamins [58,59]. Higher dietary diversity scores are associated with a lower risk of childhood stunting in developing countries [60] including Tajikistan [33].

Although some toxic trace elements (Al, As, Be) were shown to be increased in the hair of children involved in WFP and governmental programs, hair mercury levels were characterized by a significant decrease. These findings may hypothetically, antagonistic relationship between mercury and essential trace elements like zinc [61] or selenium [15] could have an impact on hair Hg levels.

At the same time, the present study has certain limitations. First, only trace element intake with school meals was estimated, whereas domestic intake of micronutrients was not monitored. Second, using other samples for assessment of trace element status (blood compartments, urine) could be beneficial in order to overcome the potential limitations of using hair as the substrate for trace element and mineral analysis. Moreover, a study of thyroid functioning biomarkers including thyroid-stimulating hormone (TSH), triiodothyronine (T_3), thyroxine (T_4), as well as thyroid autoantibodies may be considered as the beneficial approach to the estimation of iodine bioavailability. Finally, the present cross-sectional study demonstrated the difference in trace element intake and nutritional status of children, whereas their initial nutritional status before attending the schools was not registered.

5. Conclusions

The obtained data demonstrate that nutritional intervention within governmental and WFP programs resulted in a significant increase in both intake and hair content of essential trace elements and especially iron and zinc in Tajik schoolchildren. Improvement of school meals through the introduction of fortified products was also associated with improvement of anthropometric parameters of children. Despite a significant increase of iodine intake due to supplementation with iodized salt, no increase in hair iodine content was observed. Therefore, hair trace element analysis was demonstrated to be an effective tool for nutritional intervention efficiency assessment for the majority of trace elements (iron, zinc, etc.) except for iodine.

Because of the high rate of zinc, iodine, iron, and other trace element deficiency in Tajik schoolchildren, increased micronutrient supply within WFP and governmental programs may have a significant impact demographic parameters and economic outcome [62]. However, further studies including a detailed assessment of nutritional and health status with a special focus on iodine and thyroid functioning are required.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.jtemb.2019.06.018>.

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