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Sustainable Diet Optimization and Analysis Applied on the Hungarian Dietary Patterns

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Background and Aims

Introduction

The depletion of natural resources, peeking global population, and climate change all point toward one of the most challenging problems for humanity in the nearby future. To address this problem, the United Nations defined the Sustainable Development Goals, among which there are numerous aims at a sustainable food system and nutrition (United Nations, 2015). One of the approaches to release this global burden is the concept of sustainable nutrition that, by definition, includes holistic elements besides human health: economic, socio-cultural, and environmental dimensions (FAO and WHO, 2019; Fischer & Garnett, 2016). To realize the complex concept of sustainable nutrition, dietary or food-related environmental impact, health, socio-cultural and economic aspects have been put into the focus of research in this field. To study its comprehensive approach to sustainable nutrition, three main methodological approaches has been developed: (1) descriptive and correlative analyses between the metrics of sustainable nutrition, (2) dietary-scenarios analysis: the comparison of baseline and alternative dietary scenarios and their impact, (3) sustainable diet optimization (Hallström et al., 2015; Jones et al., 2016; Perignon et al., 2016; Gazan, Brouzes et al., 2018; van Dooren, 2018; Harris et al., 2020; Vettori et al., 2021). This dissertation focuses on food-related and dietary water footprint as environmental impact indicators, besides nutritional or dietary quality and cultural acceptability adapted at the Hungary population-level. The water footprint is of special importance since 70% of the total anthropogenic footprint is created by food production, besides, it is the main course of water pollution (FAO and WHO, 2019). Besides, in its latest country-specific recommendation, the EC urges Hungary to implement reforms and investments in sustainable water management (EC, 2022b). Furthermore, dietary risk factors are the second largest (after tobacco use) contributors to the development of Noncommunicable diseases (NCDs), which are the leading cause of death in the developed countries (IHM, 2019), thus a shift toward more sustainable diets would also be critically important regarding the issue of health, however, this dietary shift should also regard cultural acceptability.

Research questions summarized

RQ_1: How much dietary water footprint reduction is possible on the population-level?

RQ_2: What are the main contributors among food groups and sub-groups to the dietary water footprint on the population-level?

RQ_3: What are the health and dietary water footprint impact and their association with baseline and alternative dietary scenarios on the population-level?

RQ_4: What are the characteristics of dietary water-footprint-reduced and healthier diets at the population-level?

RQ_5: What are the associations of food-related water footprint and nutrient composition of the most consumed food items and categories on the population-level?

RQ_6: What is the association between dietary water footprint and dietary quality on the level of nutrients?

Aims

The aims of this research are threefold: (1) applying the state-of-the-art methods, to analyse and optimize the nutritional/dietary quality and food-related/dietary water footprint and their associations on the Hungarian population-level regarding its cultural aspects, (2) to provide evidence-based methods and information to nutritionist practitioners for the inclusion of dietary water footprint aspect in their counseling practice, and (3) to provide supporting evidence for the development of national FBDGs from the aspect of dietary water footprint. The aims were realized in 4 different studies (S_1-S_4) and in their fused conclusions.

Methods

The thesis composed of four studies that will be assigned as S_1-S_4 through methods and results and conclusions are based on the fusion of them. The included studies were based on three dimensions and their indicators and metrics of sustainable nutrition:

(1) socio-cultural dimension: cultural acceptability, sex

(2) ecological dimension: food-related or dietary water footprint

(3) health dimension: dietary / nutritional quality

S_1: Association of food-related water footprint and nutrient composition of the most commonly consumed foods and food categories (Tompa, Kiss, & Lakner, 2020)

The study design consists of the correlation analysis between the nutrient composition and green and blue water footprint of the most commonly consumed food items in Hungary (n = 44) and the classification of nutrients based on their association with food-related blue and green water footprint and population intake level.

S_2: Association of dietary water footprint and dietary quality of individual diets – an integrative and statistical analysis (Tompa, Kanalas, Kiss, Soós, & Lakner, 2021)

The study design included the common measurement of a nutritionist practice: diet analysis based on 3-day dietary records and body composition measurement with the addition of dietary water footprint analysis of diets (n = 25). It was aimed to identify the association between dietary quality, body composition – as health indicators – and the environmental impact of diets, besides, to identify sustainable dietary factors based on descriptive and correlative analyses.

S_3: Blue and green water footprint and dietary quality consequences of alternative diets – dietary scenarios analysis (Tompa, Lakner, Oláh, Popp, & Kiss, 2020)

The main concept of the study design was to evaluate the dietary quality (i.e. health) and the blue and green dietary water footprint impact of different dietary scenarios based on the observed population diet and its alternative scenarios. In this comprehensive work, blue and green dietary water footprint assessment and 2 types of dietary quality scores and their integrative score value was developed to evaluate the dietary quality of 6 different dietary scenarios: baseline, reduced meat, vegetarian, vegan, sustainable, cardio protective and ketogenic.

S_4: The design of the diet optimization model targeting water footprint reduction, while fulfilling nutritional adequacy and respecting cultural acceptability (Tompa et al., 2022).

A linear programming-based diet optimization model was designed to target stepwise dietary water footprint reduction while fulfilling nutritional adequacy and minimizing deviation from the typical population observed diet. In short about this diet optimization model, food sub-groups were included as decision variables, recommended dietary intake values, recommendations of food-based guidelines, population 10th and 90th intake as sociocultural metric and green and blue water footprint values as constraints. For objective function, minimizing total dietary water footprint (Equation 1.) was set at first step and minimizing relative deviation from observed diets (Equation 2.) was set for further steps reaching maximum water footprint reduction while satisfying the constraints.

Equation 1.:

$$minimize\ f = \sum_{i=1}^{35} Q_i W_i$$

where *i* represents the 35 food sub-groups, Q is the quantity of food sub-groups (g/day/capita), and W is the total water footprint (l/g) of food sub-groups.

Equation 2.:

$$minimize\ f = \sum_{i=1}^{35} ABS\left(\frac{Q_{opt,i} - Q_{obs,i}}{Q_{obs,i}}\right)$$

where *i* represents the 35 food sub-groups, ABS refers to the absolute value, Q_{opt} is the optimized quantity of food sub-groups, and Q_{obs} is the mean observed quantity of food sub-groups.

Figure 1. Shows the logical summary of the main methodological aspects.

Methodological approaches to study dietary/food-related water footprint and nutritional/dietary quality on the Hungarian population-level

	(1) Descriptive and correlative analyses		(2) Dietary scenarios analysis	(3) Diet optimization
	Association of food-related water footprint and nutrient composition of the most commonly consumed foods and food categoires**(S1)**	Association of dietary water footprint and dietary quality of individual diets – an integrative and statistical analysis **(S2)**	Water footprint and dietary quality consequences of alternative diets – dietary scenarios analysis **(S3)**	The design of the diet optimization model targeting water footprint reduction, while fulfilling nutritional adequacy and respecting cultural acceptability **(S4)**
Sample	Population-level, representative	Individual-level, not representative	Population-level, representative, separate analysis by sex	Population-level, representative, separate analysis by sex
Databases	Central Statistical Office, FAO Food Balance Sheet, Water Footprint network	Central Statistical Office, FAO Food Balance Sheet, Barilla Center for Food & Nutrition, 3-day dietary records,	Hungarian Diet and Nutritional Status Survey 2014, FAO Food Balance Sheet, Central Statistical Office, Water Footprint Network	Hungarian Diet and Nutritional Status Survey 2014, FAO Food Balance Sheet, Central Statistical Office, Water Footprint Network
Dietary level of analysis	Foods	Diets	Diets	Diets
Dietary data	Commonly consumed foods and food categories (n =44)	Random sample, indivdiual diets (n =25)	Population mean dietary intake in kcal/day/capita of the main food groups (n = 854)	Population mean dietary intake in g/day/capita of the food sub-groups (n = 854)
Water footprint	Blue and green	Total (blue, green and grey)	Blue and green	Total (blue, green and grey)
Cultural acceptability	Foods consumed in the greatest quantity on the population-level	NA*	Foods consumed in the greatest quantity in the population (main food groups weighted by the national supply amount of foods)	Objective function is to minimize devitaion from the population observed diets in the model
Nutritional/dietary quality and other health indictors	Foods nutrient composition	Quality indicator nutrients, dietary quality score, body composition	Dietary quality score	Nutrient recommended intake values as constraints and specific contsraints on foods based on recommendations in the model
Study design	Correlation analyses and classification of nutrients	Descriptive and correlative analyses of individual diets (water footprint and dietary quality) and body composition, classification of nutrients	Water footprint and health impact (dietary quality) evaluation of population baseline and alternative dietary scenarios	Diet optimization targeting water footprint reduction while nutritionally adequate and cultural-acceptability-focused
Analyses and/or evaluations	Correlation between the food-related water footprint and nutrient density of foods, classification of nutrients based on correlation with water footprint and level of population intake	Calculation of dietary water footprint and dietary quality of observed individual diets, correlation analyses between dietary quality, nutrient density, meat intake and body composition, classification of nutrients based on their association with water footprint and health-related impact	Integrative comparison of baseline and alternative scenarios based on their blue and green water footprint and dietary quality	Description of the water footprint of population observed and optimized diets, calculation of major contributors to dietary water footprint among main and sub-food groups, description of dietary shift towards the optimized diets, identification if binding nutrients
Softwares and devices	IBM SPSS Statistics® v. 25	NutriComp DietCAD, Jamovi statistical software, InBody770® body composition measurement	Excel 2016 software	R programming (Tidyverse and ROI lpSolve packages)

*NA: not applicable

Figure 1.: Summary table of the main methodgloical aspects that provides the base for the studies

Results and Discussion

(S$_1$) Based on the blue and green water footprint and nutrient composition of the most consumed foods and food categories as variables, Spearman rank-correlation proved association in several cases ($p < 0.05$). Notably, there was a significant positive correlation found between the following nutrient composition and food-related WFP of energy, total protein, cholesterol, total fats, SFA, riboflavin, and vitamin B_{12} among which, energy, total fats, SFA, cholesterol population intake is higher than recommended, hence foods with a high content of these nutrients should be limited in the water footprint friendly and healthier diets. On the other hand, a negative significant correlation was proved in the case of total carbohydrates, dietary fibers, folic acid, and vitamin C among which the population intake of total carbohydrates, dietary fibers, and folic acid are lower than recommended, thus the foods with high content of these nutrients should be promoted in water footprint friendly, healthier diets. Protein was found as an important indicator in a positive significant relationship with water footprint, however, the population intake is adequate, hence the source of intake should be considered: more animal-based and less plant-based foods (Table 1.).

Table 1.: Classification of nutrients based on correlation with the most commonly consumed foods-related blue and green water footprint and population intake level

Type of nutrient	Type and direction of the correlation		
(1) The average intake of the Hungarian population is higher than the RDI	energy^{g}, total fats^{b,g}, SFA^{,g}, cholesterol^{b,g},vitamin-B_{12}^{b,g},	vitamin-C^{g}	niacin, vitamin-$B_{6,}$ vitamin-E (men), sodium, magnesium, phosphorus, iron (men)
(2) The average intake of the Hungarian population meets the RDI	total protein^{b,g,}		thiamin,
(3) The average intake of the Hungarian population is lower than the RDI	riboflavin^{g}	total carbohydrates^{g}, dietary fibers^{g}, folic acid^{g}	vitamin-A, vitamin-E (women), potassium, calcium, iron (women), zinc
	(a)significant (+) correlation with water footprint	(b)significant (–) correlation with water footprint	(c) no significant correlation

RDI: Recommended intake value

SFA: saturated fatty acids

b: blue water footprint

g: green water footprint

Based on the classification of Table 1., group 1a includes nutrients that are overconsumed and have a strong association with green and/or blue water footprint, in general, they are typically high in animal-based foods. Group 3b includes nutrients that are under-consumed and have a weak association with GWP, in general, they are typically high in plant-based foods. Group 1b includes vitamin C which is somehow a controversial result, because nutrients that are typically high in vegetables and fruits and negatively correlate with green water footprint and have lower than optimal population intake, however, the average intake of vitamin C of the Hungarian population exceeds the RDI. In fact, fruits have a relatively high value of blue water footprint (Meier & Christen, 2012; Scheelbeek et al., 2020; Tompa, Lakner, et al., 2020), and they are on of the main sources of vitamin C but this analysis didn't show a positive correlation with blue water footprint. Group 2a includes protein, meaning that its intake meets with the RDI and has a high correlation to both blue and green water footprint. Since protein shows a strong correlation with dietary or food-related environmental impact (Saarinen et al., 2017; van Dooren et al., 2017) as well as usually classified as an advantageous nutrient (Hallström, 2018), it could play a key role in the shift to more sustainable food consumption by optimization the quality and quantity of dietary proteins, especially considering the question the animal- and plant-based sources.

(S_2) By analysing 25 individual diets and body composition, spearman correlation analysis ($p < 0.0.5$) proved a positive significant association between total dietary WFP and energy, SFA, protein, sodium, and total meat intake, while negative significant relationship between total dietary WFP and DQS, DQS also showed negative significant association with meat intake (Figure 2.). There was no significant correlation between body composition and other variables. These results suggest that dietary intervention in nutritionist practice (lower meat consumption, more diverse protein sources, lowering the non-beneficial nutrients (i.e. sodium, SFA), elevating the beneficial nutrients (i.e. dietary fibers)) could have a double benefit: water-footprint friendly and healthier.

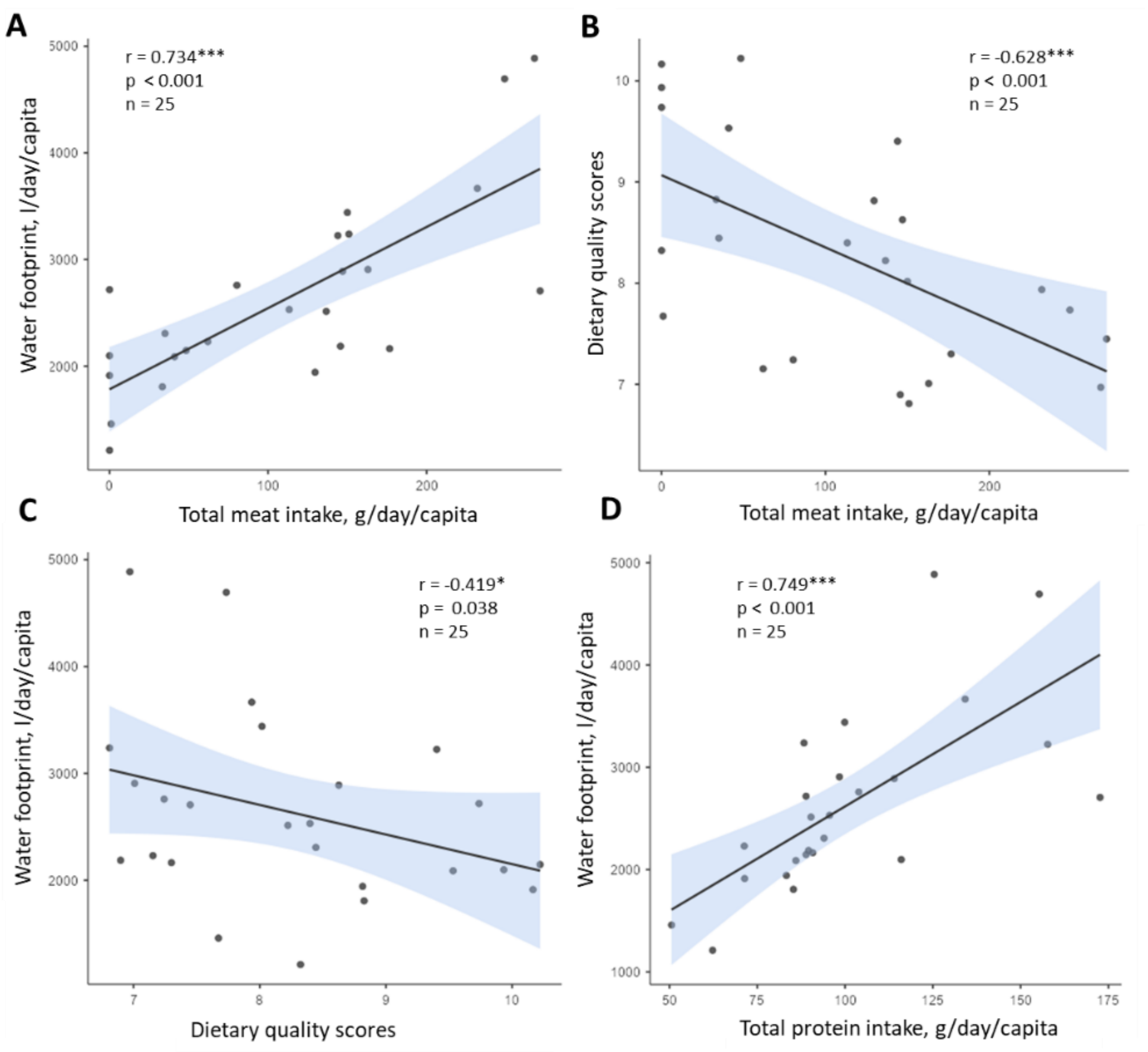

Figure 1.: Correlation between dietary water footprint and dietary quality indicators (Tompa et al., 2021)

There was an inverse correlation between the DQS and dietary water footprint that suggests that the improvement of dietary quality would simultaneously decrease the dietary water footprint (Figure 2C). Also, dietary water footprint was a positive correlation with total meat intake (Figure 2A) which is not surprising regarding that meats have the greatest contribution to the total dietary WFP (Harris et al., 2020). Based on these results, it would be reasonable lowering the meat intake, while slightly increasing the intake of other animal- and dominantly the plant-based protein sources to keep up the adequate dietary protein intake. Furthermore, the DQS and total meat intake also showed an inverse correlation (Figure 2B) that suggests that diets higher in meat content could be lower in dietary quality.

(S3) Based on the health and water footprint impact assessment of baseline and alternative dietary scenarios on the population-level, the "sustainable scenario" was regarded as the most beneficial in these aspects (+9% in dietary quality, −41.7% in green water footprint, and −28.9% in blue water footprint) compared to the populational observed diets on average of both sexes. The sustainable scenario was adapted to the Hungarian population from the EAT–Lancet Commission's publications (planetary healthy diet) (Willett et al., 2019) and is characterized by − in comparison with the observed diets in the population −: more diverse intake sources of proteins, lower intake of meat and milk and diaries, higher intake of plant-based proteins, vegetables and fruits and similar grains, fats and oils content (with the preference of vegetable oils over animal fats), sweets and alcohols were standardized close to the observed level since there was no quantified recommendation for them besides the "as low as possible" principle.

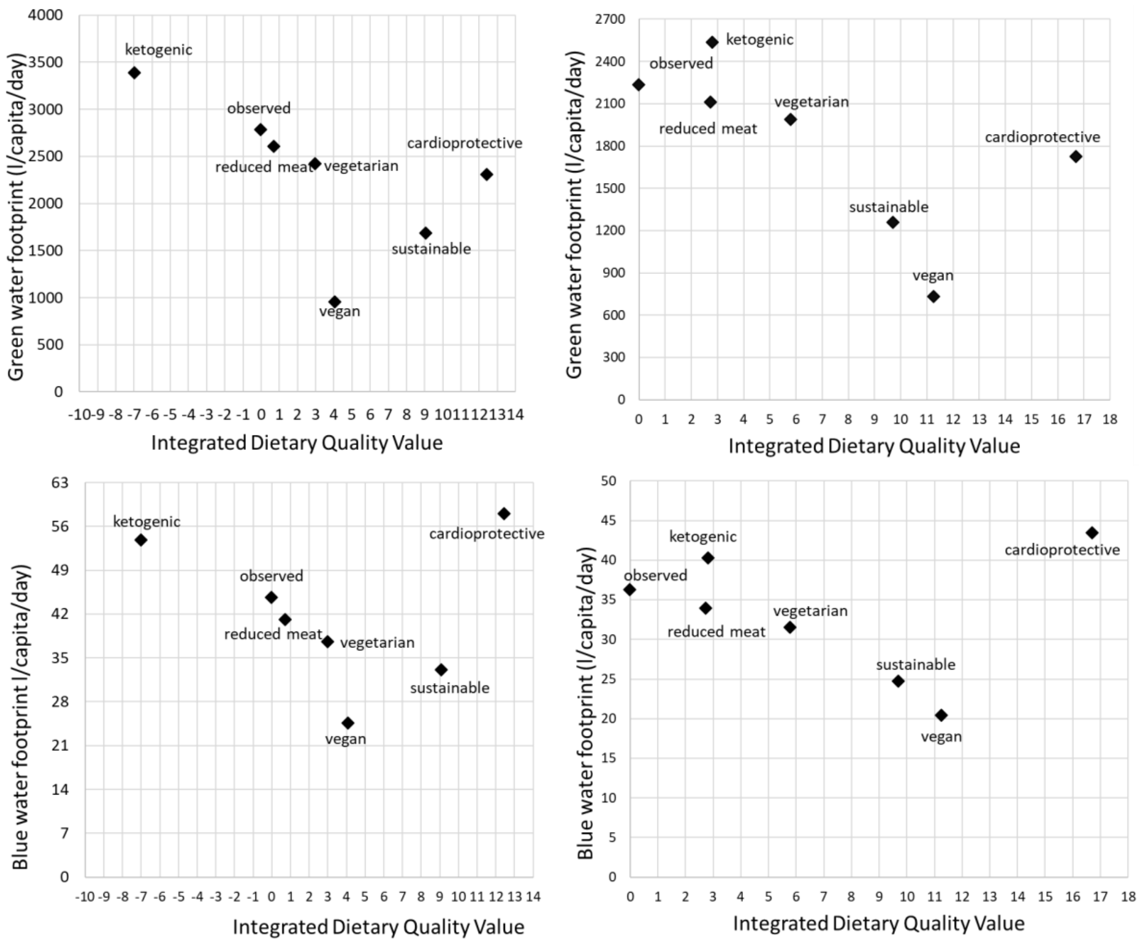

Figure 3.: Blue and green water footprint impact, dietary quality and their associations of baseline and alternative dietary scenarios (Tompa, Lakner, et al., 2020)

(S_4) Dietary water footprint of observed and optimized diets and their main contributors among main food groups and sub-groups

The observed total dietary water footprint was 3094.7 l/d/c (green WFP: 2710.3; blue WFP: 62.0 l/d/c) for women and 3874.4 l/d/c (green WFP: 3367.7; blue WFP: 78.4 l/d/c) for men that is by averaging the values of the two sexes result in 3484 l/d/c (Figure 4.). Harris et al. (2020) meta-analysis estimated a rough range of 2873-3792 l/capita/day for European countries (with or without the inclusion of grey water footprint). Consequently, the estimated total dietary water footprint of Hungary is in the upper range of the European average. The proportion of green dietary water footprint makes the majority up of total (86-87%) and the proportion of blue water footprint is (2-3%) that is typical for this geographical region and require special considerations due to the climate change and its effect on water-management. The evaluation of the dietary water footprint of the observed diets on the population-level showed the following results: milk and dairies (men: 1125.9; women: 1050.3 l/d/c) and meats and meat products (men: 1195.8; women: 772.6 l/d/c) contributed the most to the total dietary water footprint, followed by grains for (men: 415.3, women 311 l/d/c) and fruits and products (men: 218.2, women: 242.9 l/d/c). On the food sub-group level milk and milk-based drinks (women: 461.3; men: 501.9 l/d/c), cheese (women: 265.1; men: 303.5 l/d/c), meat products (women: 239.3; men: 457.1 l/d/c), pork meat (women: 233.1; men: 354.9 l/d/c) and fresh and frozen fruits (women: 212.8; men: 192.8 l/d/c) were the major contributors to the dietary water footprint in the observed diet on the population-level.That in part agree with the international results (Gibin et al., 2022; Harris et al., 2020; Jalava et al., 2014; Lares-Michel et al., 2021; Steenson & Buttriss, 2021), however, the role of dairies and milk, especially among women should be in focus in the dietary shift towards more sustainable diet.

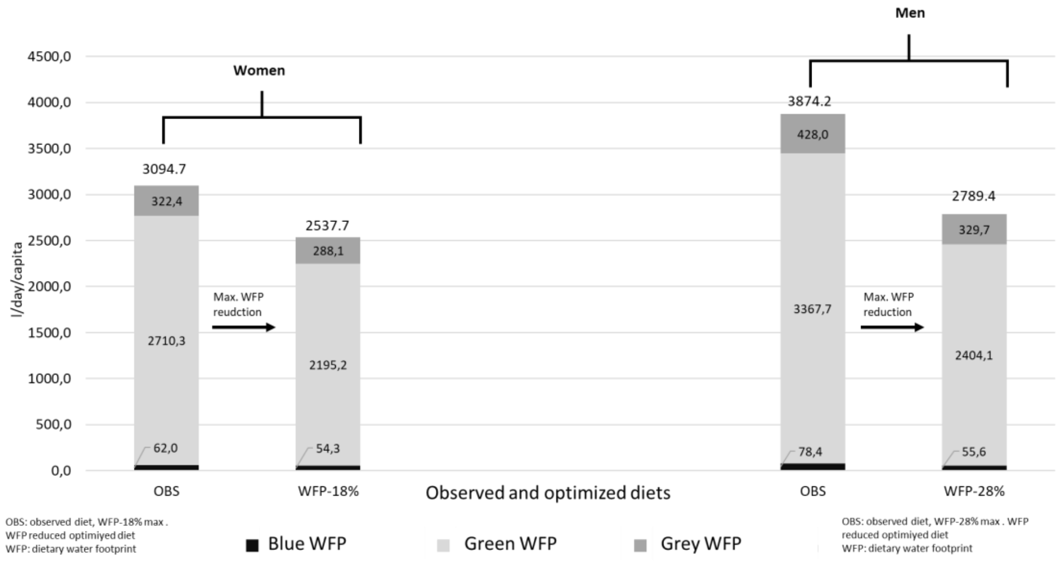

Figure 4.: Dietary water footprint of the observed and optimized diets, by sex (Tompa et al., 2022)

(S_4) Dietary shift towards water-footprint-reduced, nutritionally adequate and cultural-acceptability focused diets

The dietary shift from the observed to the optimized diets on the population-level was estimated by a sustainable diet optimization model designed to be nutritionally adequate, water footprint-reduced, and cultural acceptability-focused. From the results, the conclusion can be drawn that the dietary shift at the food levels is not as simple as more plant-based foods and less animal-based foods, but more sophisticated details were revealed at the maximum dietary water footprint reduction level. The key funding about the dietary shift is that, among meats and milk and dairies, the ultra-processed and fatty products should be limited (e.g. sausages and cheese), while the lean and low-level processed products (e.g. fermented dairies and poultry meat) should be increased in the diet instead. Besides, a clear disadvantage of alcoholic and non-alcoholic drinks was proven: while the necessity to limit alcoholic drinks seems obvious regarding the their status as behavioral risks of NCDs (IHM, 2019), the same is not true about non-alcoholic drinks. The disadvantage of drinks lies in the high fruit content of juices that are the “hidden” but great contributors to dietary water footprint (Lares-Michel et al., 2021) due to their high blue footprint of them in addition to that they have no advantage versus fresh fruits in the aspect of health in general. Furthermore, drinks often contain a high amount of added sugars, which is another identified dietary contributor to NCDs (IHM, 2019). Other food sub-groups high in added sugars should be limited (bakery products, pastries, and sweets, honey and sugars, jams, and carbonated soft drinks). Vegetables and grains and cereals showed a beneficial picture in general, proving their place as the base of the dietary pyramid for the population in the healthier and water footprint friendly diets as well and should be consumed in higher amount – especially – because of the dietary fibers content. Besides, eggs, nuts and legumes should be recommended to increase in the diet, since – in the adequate proportion – they are good sources of dietary protein, making the diet more diverse in that aspect and beneficial in the means of dietary water footprint (Figures 5-6.).

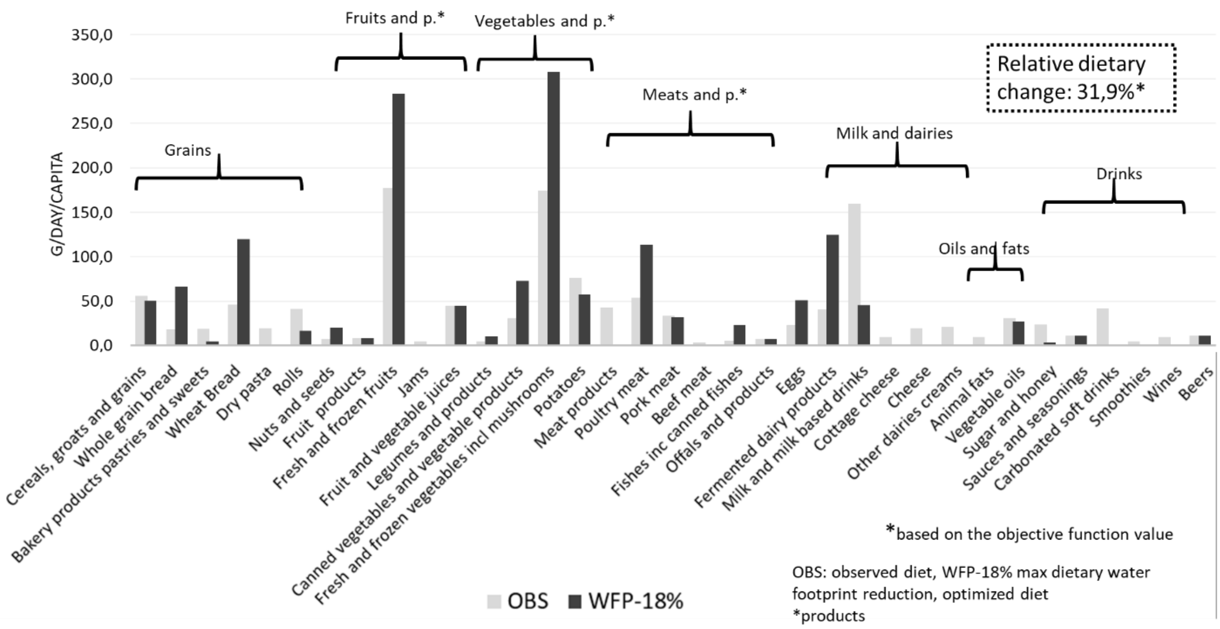

Figure 5.: Dietary shift towards the water footprint-reduced, nutritionally adequate and cultural-acceptnaility focused diets, women (Tompa et al., 2022)

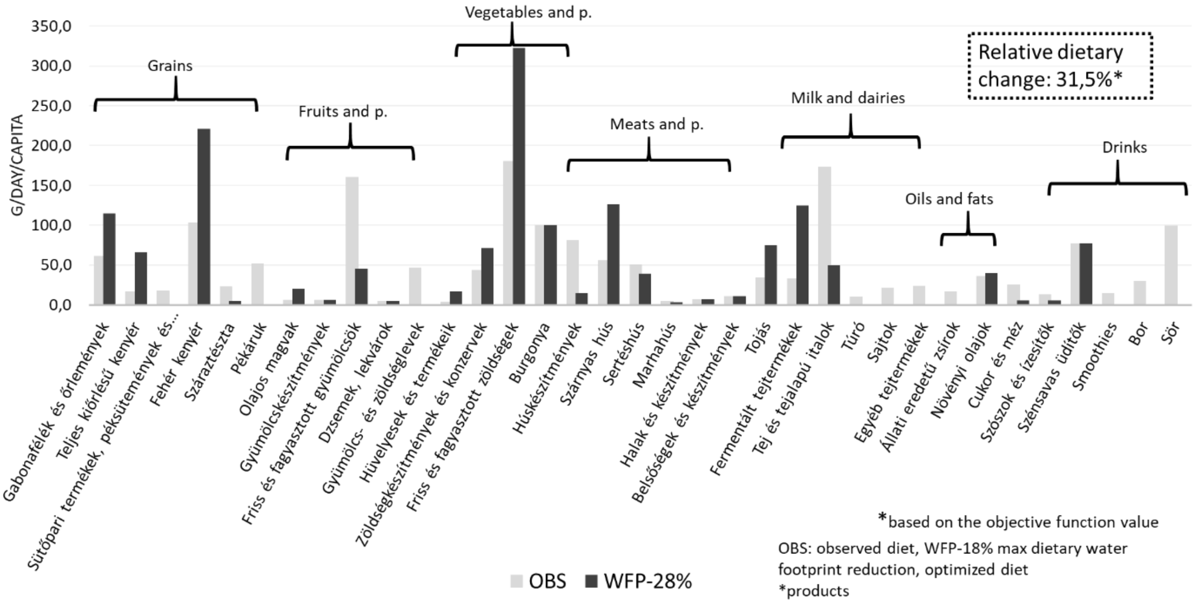

Figure 5.: Dietary shift towards the water footprint-reduced, nutritionally adequate and culutral-acceptnaility focused diets, men (Tompa et al., 2022)

(S4) Binding nutrients in the diet optimization models: considerations at the population-level

The maximum energy constraint was problematic in each model, which could be because energy and nutrient-dense foods are advantageous in the models. Comparing the two sexes, a greater reduction of the total dietary water footprint was possible for men (women: 18% and men: 28%), since the higher energy range (2300–2600 kcal versus 1700–2000 kcal for women) of diets provided more space for a feasible solution. Besides, the minimum constraint on dietary fibers and the maximum on sodium were also binding in each model for both sexes, which is in agreement with the Hungarian population intake, which is typically low in dietary fibers and high in sodium (Sarkadi Nagy et al., 2016). For women, the minimum limit for vitamin B12 in each model and potassium, iron, and zinc in WFP-18% were binding constraints, demonstrating that the greater the reduction in the dietary water footprint, the more binding the nutrients. The potassium, zinc, and iron intake of women is indeed a problem on the population-level, but the B12 intake is adequate (Sarkadi Nagy et al., 2016). The reason for this could be that otherwise nutritionally and/or environmentally non-beneficial food groups (e.g., meat products, offals, cheese) were limited or decreased in the models that are a common source of the intake of vitamin B12. For men, the minimum constraint of vitamin D (WFP-28%) and zinc (WFP_OBS and WFP-28%) and the maximum for total fat (WFP-28%) were limiting factors. The population intake is problematic in the case of each nutrient, and, again, the step 2 reduction in the dietary water footprint meant that the limit in nutrient constraints was reached.

Conclusions and recommendations

The conclusions are valid for (1) food related/dietary water footprint, (2) nutritional/dietary quality and (3) cultural acceptability among the sustainable nutrition dimensions, besides, they are representative for the Hungarian population.

The observed total dietary water footprint was 3484 l/day/capita (green: 3039 l/day/capita and blue: 70.2 l/day/capita) among the Hungarian population averaged for the two sexes. The proportion of green dietary water footprint makes the majority up of total (86-87%) and the proportion of blue water footprint is (2-3%) that is typical for this geographical region and require special considerations due to the climate change and its effect on water-management With a well-designed sustainable diet optimization considerable reduction is possible from total dietary water footprint (~23.9%), while nutritionally adequate and cultural-acceptability-focused the diets are, without the pre-exclusion of animal-based foods. The dietary blue water footprint should be analyzed and interpreted separately given its significant importance and different impact from other environmental impact categories, including green water. The main dietary water footprint contributors of the observed diets are the milk and dairies and meats, however, the quality change (preference for low fat and low processed products over high fat and highly processed products) of them would be just as important as the total quantity change in the main food group intake. More water footprint-friendly and healthier diets that respect the traditional dietary patterns could be described the simplest as "reduced animal-based foods" diets, especially reduced in highly processed and high fat meats and dairies, however, without the elimination of main food groups. Besides, it contains an elevated amount of vegetables and grains, while among fruits and products, the fresh and non-processed ones should be preferred over high processed products and added sugar content, since they heavily impact the dietary blue water footprint. The source of protein could be a key factor in the water footprint friendly and healthier diets since it strongly correlates with water footprint (in plant-based food also) but the population intake is adequate: the more diverse (including less animal- and more plant-based foods) source of the intake the better, while over-consumption should be avoided. Besides, energy, saturated fatty acids, dietary fibers, calcium, vitamin-B_{12}, vitamin-C, sodium, vitamin-D, iron, zinc, and potassium were identified as problematic nutrients to reach minimum adequate intake or not exceed the maximum recommended intake value when dietary water-footprint reduction is targeted, and nutritional adequacy should be ensured on the population-level.

New scientific results

NSR_1: With sustainable diet optimization – based on linear programming – I estimated the possible total dietary water footprint (green, blue, and grey) reduction (– 18% for women and – 28% for men) in optimized diets designed to be nutritionally adequate and cultural-acceptability-focused (dietary shift: ~ 32%) on the Hungarian population-level.

NSR_2: I estimated the major total (green, blue, and grey) dietary water footprint contributors to the observed and optimized (water footprint reduced, nutritionally adequate, and cultural-acceptability-focused) diets among main food groups and food sub-groups separately for men and women on the Hungarian population-level.

NSR_3: Based on the health and blue and green water footprint impact analysis of baseline (observed diet) and alternative dietary scenarios, I identified that the "sustainable scenario" (adapted from the "planetary healthy diet" (Willet et al. (2019) to the Hungarian population) as the most advantageous dietary scenario to shift towards (+9% in dietary quality, −41.7% in green water footprint, and −28.9% in blue water footprint).

NSR_4: With sustainable diet optimization – based on linear programming – I described the possible dietary shift towards the dietary water footprint-reduced, nutritionally adequate and cultural-acceptability-focused diets by identifying the main food groups and sub-groups to be limited or increased compared to the observed, representative Hungarian diets, separately for both sexes.

NSR_5: Based on the most consumed foods and food categories in Hungary, I identified the association between nutrition composition and food-related blue and green water footprint, furthermore, I identified nutrients as indicators based on their food-related water footprint and inadequate or excessive intake level on the population-level.

NSR_6: I identified nutrients at risk for deficiency or excess intake on the population-level in the case of the dietary shift towards dietary water footprint-reduced, nutritionally adequate, and culturally acceptably diets, separately for both sexes.

Most important references

1. EC, European Commission. (2022b). *COUNCIL RECOMMENDATION on the 2022 National Reform Programme of Hungary and delivering a Council opinion on the 2022 Convergence Programme of Hungary* (Vol. 4). Available at: https://eur-lex.europa.eu/search.html?name=collection%3Aeu-law-pre-acts-com&type=named&qid=1653353289484&DD_YEAR=2022 (last accessed: 02.06.2022.)
2. FAO and WHO., Food and Agricultural Organization of the United Nations and World Health Organization (2019). *Sustainable healthy diets – Guiding principles.* Roma, Available at: https://www.who.int/publications/i/item/978924151664 Fischer, C.G. and
3. Garnett, T. (2016). *Plates, pyramids and planets: developments in national healthy and sustainable dietary guidelines: a state of play assessment*. FAO, Roma; FCRN, University of Oxford, Oxford. p. 71. Available at: http://www.fao.org/3/i5640e/I5640E.pdf (last accessed: 02.06.2022)
4. Gazan, R., Brouzes C. MC., Vieux, F., Maillot, M., Lluch, A., & Darmon, N. (2018). Mathematical Optimization to Explore Tomorrow's Sustainable Diets: A Narrative Review. *Advances in Nutrition*, *9*(5), 602–616. https://doi.org/10.1093/advances/nmy049

   Gibin, D., Simonetto, A., Zanini, B., & Gilioli, G. (2022). A framework assessing the footprints of food consumption. An application on water footprint in Europe. *Environmental Impact Assessment Review, 93*(January), 106735. https://doi.org/10.1016/j.eiar.2022.106735

   Hallström, E., Carlsson-Kanyama, A., & Börjesson, P. (2015). Environmental impact of dietary change: A systematic review. *Journal of Cleaner Production*, *91*, 1–11. https://doi.org/10.1016/j.jclepro.2014.12.008
5. Hallström, E., Davis, J., Woodhouse, A., & Sonesson, U. (2018). Using dietary quality scores to assess sustainability of food products and human diets: A systematic review. *Ecological Indicators*, *93*(May), 219–230. https://doi.org/10.1016/j.ecolind.2018.04.071
6. Harris, F., Moss, C., Joy, E. J. M., Quinn, R., Scheelbeek, P. F. D., Dangour, A. D., & Green, R. (2020). The Water Footprint of Diets: A Global Systematic Review and Meta-analysis. *Advances in Nutrition*, *11*(2), 375–386. https://doi.org/10.1093/advances/nmz091
7. IHM, Institute for Health Metrics and Evaluation. (2019). *Global Burden of Disease (GBD): Cause of death in both sexes at all ages and related risk factors in Hungary*, University of Washington, Retrieved from: https://vizhub.healthdata.org/gbd-compare/ (last accessed: 02.06.2022.)
8. Jalava, M., Kummu, M., Porkka, M., Siebert, S., & Varis, O. (2014). Diet change - A solution to reduce water use? *Environmental Research Letters*, *9* 074016. https://doi.org/10.1088/1748-9326/9/7/074016
9. Jones, A. D., Hoey, L., Blesh, J., Miller, L., Green, A., & Shapiro, L. F. (2016). A Systematic Review of the Measurement of Sustainable Diets. *Advances in Nutrition: An International Review Journal*, *7*(4), 641–664. https://doi.org/10.3945/an.115.011015
10. Lares-Michel, M., Housni, F. E., Aguilera Cervantes, V. G., Carrillo, P., Michel Nava, R. M., & Llanes Cañedo, C. (2021). Eat Well to Fight Obesity… and Save Water: The Water Footprint of Different Diets and Caloric Intake and Its Relationship With Adiposity. *Frontiers in Nutrition*, *8*(July). https://doi.org/10.3389/fnut.2021.694775
11. Meier, T., & Christen, O. (2012). Gender as a factor in an environmental assessment of the consumption of animal and plant-based foods in Germany. *International Journal of Life Cycle Assessment*, *17*(5), 550–564. https://doi.org/10.1007/s11367-012-0387-x
12. Perignon, M., Masset, G., Ferrari, G., Barré, T., Vieux, F., Maillot, M., … Darmon, N. (2016a). How low can dietary greenhouse gas emissions be reduced without impairing nutritional adequacy, affordability and acceptability of the diet? A modelling study to guide sustainable food choices. *Public Health Nutrition*, *19*(14), 2662–2674.
13. Saarinen, M., Fogelholm, M., Tahvonen, R., & Kurppa, S. (2017). Taking nutrition into account within the life cycle assessment of food products. *Journal of Cleaner Production*, *149*, 828–844. https://doi.org/10.1016/j.jclepro.2017.02.062
14. Sarkadi Nagy, E., Bakacs M., Illés É., Varga A & Martos É. (2016). HDNSS. *Az Országos Táplálkozás és Tápláltsági Állapot Vizsgálat OTÁP 2014 főbb eredményei – előadás [Main results of the Hungarian Dietary and Nutritional Status Survey 2014 – presentation]* Available at: https://ogyei.gov.hu/dynamic/5_sarkadi_otap2014_makrotap.pdf (last accessed:02.06.2022.)
15. Scheelbeek, P., Green, R., Papier, K., Knuppel, A., Alae-Carew, C., Balkwill, A., … Dangour, A. D. (2020). Health impacts and environmental footprints of diets that meet the Eatwell Guide recommendations: analyses of multiple UK studies. *BMJ Open, 10*(8), e037554. https://doi.org/10.1136/bmjopen-2020-037554

Steenson, S., & Buttriss, J. L. (2021). Healthier and more sustainable diets: What changes are needed in high-income countries? *Nutrition Bulletin*, *46*(3), 279–309. https://doi.org/10.1111/nbu.12518

16. UN, United Nations. (2015). *Sustainable Development Goals (SDGs)*. Available at: https://sdgs.un.org/goals (last accessed: 02.06.2022.)
17. van Dooren, C., (2018). A Review of the Use of Linear Programming to Optimize Diets, Nutritiously, Economically and Environmentally. *Frontiers in Nutrition*, *5*(June). https://doi.org/10.3389/fnut.2018.00048
18. van Dooren, C., Douma, A., Aiking, H., & Vellinga, P. (2017). Proposing a Novel Index Reflecting Both Climate Impact and Nutritional Impact of Food Products. *Ecological Economics*, *131*, 389–398. https://doi.org/10.1016/j.ecolecon.2016.08.029
19. Vettori, V., Bronzi, B., Lorini, C., Cavallo, G., & Bonaccorsi, G. (2021). Widespread dietary patterns (Healthy and balanced diet, western diet, and vegan and vegetarian diets) compared for water consumption: Which is the winner? *Sustainability (Switzerland)*, *13*(21). https://doi.org/10.3390/su132111946
20. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., … Murray, C. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet*, *6736*(18), 3–49. https://doi.org/10.1016/S0140-6736(18)31788-4

List of publications in the field of studies

International IF journal articles

Tompa, O., Kiss, A., Maillot, M., Nagy, E. S.,Temesi, Á. & Lakner Z.(2022). Sustainable Diet Optimization Targeting Dietary Water Footprint Reduction — A Country-Specific Study. *Sustainability*, 14(4), 2309; https://doi.org/10.3390/su14042309, **IF: 4.17, Q1**

Tompa, O., Kanalas O., Kiss, A., Soós S., & Lakner, Z. (2021). Integrative analysis of dietary water footprint and dietary quality – Towards the practical application of sustainable nutrition. *Acta Alimentaria*. https://doi.org/10.1556/066.2021.00070, **IF: 0.65, Q3**

Tompa, O., Lakner, Z., Oláh J., Popp J., & Kiss, A., (2020). Is the Sustainable Choice a Healthy Choice?—Water Footprint Consequence of Changing Dietary Patterns. *Nutrients*, 12(9), 1–19. https://doi.org/10.3390/nu12092578, **IF: 5.43, Q1**

Tompa, O., Kiss, A., & Lakner, Z. (2020). Towards the sustainable food consumption in central Europe: Stochastic relationship between water footprint and nutrition. *Acta Alimentaria*, 49(1), 86–92. https://doi.org/10.1556/066.2020.49.1.11, **IF: 0.65, Q3**

International conference presentations

Tompa O., Kanalas O., Plasek, B.; Anna, Kiss, Analysis of the association between the healthiness and ecological footprint of nutrition and body composition - a methodological approach In: Fodor, Marietta; Bodor-Pesti, Péter; Deák, Tamás (eds.) SZIEntific Meeting for Young Researchers 2020 : ITT Ifjú Tehetségek Találkozója 2020, Bp, Hungary : SZIE Budai Campus (2021) 437 p. pp. 416-419. , 4 p., lecture

Tompa, O., Kiss A., Lakner, Z., Lecture: Association of the Hungarian Food Consumption Structure and Water Footprint, Tavaszi Szél Konferencia 2019, Nemzetközi Multidiszciplináris Konferencia, Doktoranduszok Országos Szövetsége, 2019.05.03-05., ISBN 978-615-5586-42-2, pp 89-90.,

Tompa, O., Kiss A., Lakner, Z., Lecutre: Analysis of different dietary scenarios based on the Hungarian nutrition from the aspect of health and sustainability, 19th International Nutrition & Diagnostics Conference (INDC) 2019.10.15-18., Prague, pp 39.

International conference full papers

Tompa O.; Kanalas O., Plasek, B.; Anna, Kiss, Analysis of the association between the healthiness and ecological footprint of nutrition and body composition - a methodological approachIn: Fodor, Marietta; Bodor-Pesti, Péter; Deák, Tamás (eds.) SZIEntific Meeting for Young Researchers 2020 : ITT Ifjú Tehetségek Találkozója 2020, Bp, Hungary : SZIE Budai Campus (2021) 437 p. pp. 416-419. , 4 p., conference paper

Hungarian conference presentations

Tompa, O., Lakner, Z., Fenntartható táplálkozás a fejlődő országokban: az élelmiszer-fogyasztás optimalizálása, Magyar Tudományos Akadémia, Kertészeti és Élelmiszertudományi Bizottság, Élelmiszertudományi Albizottság, 2018.12.06., ISBN: 978-963-508-900-0, pp 21.

Tompa, O., Kiss A., Lakner, Z., Hivatalos, élelmiszeralapú, fenntartható táplálkozási ajánlások összehasonlító elemzése, I. Országos Táplálkozástudományi Szakemberek Konferenciája, Debrecen, 2019.03.09., ISBN 978-963-490-075-7, 99 17., pp 18.

Tompa, O., Kiss A., Lakner, Z., Különböző étrendi szcenáriók elemzése fenntarthatósági és egészségességi szempontok alapján, Magyar Táplálkozástudományi Társaság XLIV. Vándorgyűlése, Székesfehérvár, 2019.03-05., ISBN 978-615-5606-09-0, pp 50.

Kiss, A., **Tompa, O**., Fenntarthatóság a sporttáplálkozásban? A rekreáció sokszínűsége” c. Leisure konferencia, 2019.10.15.. Miskolc

International poster presentations

Tompa, O., Kiss A., Lakner, Z., Poster presentation: Analysis and optimization of the structure of food supply in Ethiopia, Africa and Europe Moving Forward - Evidence-based Solutions for African Development, 2019.01.24-26., Lüneburg, Leuphana University

Kiss, A., **Tompa, O**., Lakner, Z., Poster presentation: Future of food supply in Africa-a system dynamic, network-based approach, Africa and Europe Moving Forward - Evidence-based Solutions for African Development, 2019.01.24-26., Lüneburg, Leuphana University

Tompa, O., Kiss A., Lakner, Z., Poster presentation: Estimation of food and nutrient intake based on the two opposite extemities – an experimental approach in case of Hungary, 19th International Nutrition & Diagnostics Conference (INDC) 2019.10.15-18., Prague, pp 119.