How to meet nutritional recommendations and reduce diet environmental impact in the Mediterranean region? An optimization study to identify more sustainable diets in Tunisia

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Abstract

Tunisia is a typical country of the Mediterranean region where high prevalence of overweight, obesity and non-communicable diseases co-exist with some micronutrient deficiencies, and diet-related environmental issues must be addressed. Individual food choices may influence both health and environment. The aim of this study was to identify diets that are nutritionally adequate, culturally acceptable, and with low environmental impact for Tunisian adults.

Individual dietary data from a national Tunisian survey on food consumption (n=7209, 35-70 years) and the national food composition table were used to estimate the food and nutritional content of the mean observed (OBS) diet. The diet environmental impact was assessed through seven metrics: water deprivation, land-use, land-use potential impacts on biodiversity loss, erosion resistance, mechanical filtration, groundwater replenishment, and biotic production. Quadratic optimization models were implemented to obtain diets that met the nutritional recommendations, and concomitantly respected increasingly stringent environmental constraints and minimized the departure from the OBS diet.

Without environmental constraints, the nutritional recommendations were met by increasing the amount of dairy, starch and vegetables, and decreasing foods high in fat/salt/sugar (HFSS) and added fat. Compared with the OBS diet, the environmental impact of this diet increased: +32 % for water deprivation and +46-48 % for land use and its impacts.

When a moderate environmental impact reduction (≤30%) was added to the nutritional constraints, the dietary changes at the food group level were similar to those required to reach nutritional adequacy, except for a progressive decrease in meat/fish/egg quantities. Animal-based product contributions to the total energy and protein content were close or slightly lower than in OBS diet, but a redistribution of sources was required: less meat in favor of dairy, egg and fish products. Stronger reductions (≥40%) required substantial changes that might compromise the optimized diet acceptability.

Targeting a nutritionally adequate diet without considering its environmental impact might increase water deprivation, land use and its impacts on biodiversity and soil quality. In Tunisia, moving towards healthy diets with lower environmental impact relied more on redistributing the sources of animal-based products rather than on reducing their total contribution, together with a decrease of HFSS and added fats, and an increase of vegetables. Actions to favor the adoption of such dietary changes by consumers should be explored to promote more sustainable diets in the Mediterranean region.

Keywords: nutrition; sustainability; diet; optimization; mathematical programming; multi-criteria analysis; Tunisia; water footprint; biodiversity; land-use; food consumption; dietary shifts; Mediterranean region

1 Introduction

During the last decades, several countries in the Mediterranean region underwent an epidemiological and nutritional transition that has resulted in a major increase of the prevalence of overweight, obesity and non-communicable diseases (NCD), while some micronutrient deficiencies persist (Gartner et al., 2014; NCD Risk Factor Collaboration (NCD-RisC), 2016a, 2016b). Besides these public health challenges, the Mediterranean area is also facing climate and environmental issues, especially water deprivation and biodiversity loss, particularly in the Near East and North Africa (CIHEAM/FAO, 2015). The current food system has a major environmental impact by contributing between 19-29% of global greenhouse gas emissions (GHGE) (Vermeulen et al., 2012) and by representing ~70% of global freshwater use (Whitmee et al., 2015). Therefore, changes in food consumption and production patterns are needed to ensure more sustainable food systems and achieve food and nutrition security in the Mediterranean region. As individual food choices can influence public health and also the environment, there is an urgent need to promote sustainable diets, defined by the Food and Agriculture Organization (FAO) as nutritionally adequate, safe and healthy, culturally acceptable, financially affordable, and with low environmental impacts (Food and Agriculture Organization, 2010).

Previous studies have explored the potential of dietary shifts towards more sustainability by assessing the environmental impact of the existing diets (Perignon et al., 2017) or of dietary scenarios, such as the Mediterranean-type diet, New Nordic diet, and diets with reduced levels of animal products, compared with the national average diet (Berners-Lee et al., 2012; Risku-Norja et al., 2009; Sáez-Almendros et al., 2013; Saxe et al., 2013; Temme et al., 2013; van Dooren et al., 2014). However, these approaches do not allow identifying diets that improve simultaneously all dimensions of diet sustainability. Indeed, high nutritional quality is not necessarily associated with affordability or lower environmental impact (Biesbroek et al., 2017;

Perignon et al., 2017; Vieux et al., 2013). Moreover, some dietary scenarios may be too different from the dietary habits in the studied countries, which limits their acceptability. Mathematical diet optimization (herein referred as “diet optimization”) can be used to find the optimal combination of foods to fulfil a set of constraints, and is a unique and powerful tool for studying simultaneously the multiple dimensions of diet sustainability (Gazan et al., 2018). For instance, when applied to study sustainability issues, diet optimization can be used to meet nutrient recommendations and reduce environmental impacts, while maximizing the similarity with the current diets.

Moreover, previous studies essentially assessed the environmental impact in terms of GHGE (Payne et al., 2016; Perignon et al., 2017). However, it is well known that GHGE are not a proxy for the full range of environmental impacts associated with a diet. Indeed, among the 169 targets of the Sustainable Development Goals, water deprivation, land degradation, and biodiversity loss have been identified as environmental areas of concerns that need to be addressed (IPBES, 2019; Ridoutt et al., 2017; United Nations General Assembly, 2015). Yet, a recent review reported that very few studies investigated dietary changes to reduce these impacts by using metrics that can be applied in a life cycle context (Ridoutt et al., 2017). The authors concluded that the available evidence on dietary patterns and water deprivation, land degradation and biodiversity loss is very limited, and did not identify generalizable findings. In addition, the few existing studies were all conducted in Europe, and only one explored the effect of shifting to a healthier diet on water deprivation (Hess et al., 2015). Therefore, more analyses of the compatibility between nutritional and environmental goals using appropriate metrics are needed, especially in the Mediterranean region where water deprivation is critical.

Tunisia is a typical country of the Mediterranean region that is undergoing a nutrition transition and where high prevalence of overweight, obesity and NCD co-exist with some micronutrient deficiencies (Atek et al., 2013; Traissac et al., 2016). Tunisia has a marked climatic north-south gradient, from a Mediterranean region in the north to a semi-arid and then desert area in the south. This puts the country especially at risk to climate change effects on land, coastal zones, water, and agriculture (Thiébault et al., 2016; Verner and World Bank. Middle East and North Africa Region. Sustainable Development., 2013).

The objective of the present study was to identify, using diet optimization models, the dietary changes that allow fulfilling the World Health Organization (WHO) nutritional recommendations, reducing the diet environmental impact, and respecting the Tunisian population’s dietary habits.

2 Methods

2.1 Dietary and food composition data

Dietary data were derived from a nationally representative cross-sectional survey performed among 35-70-year-old adults of both sexes in Tunisia in 2005, as part of the Transition and Health Impact in North Africa (TAHINA) project (Atek et al., 2013). This survey collected retrospective data on food consumption during one month using a validated semi-quantitative food frequency questionnaire (El Ati et al., 2004). For the purpose of our study, the 138 food items declared to be consumed by the participants were classified in 8 food groups [fruits & vegetables, starch, meat/fish/eggs (MFE), dairy, foods high in fat/salt/sugar (HFSS), mixed dishes, added fat & seasoning, drinks], and 23 food sub-groups (Supplemental Table 1). A specific Tunisian food composition database (El Ati et al., 2007), completed by the USDA table (US Department of Agriculture, 2008), additional laboratory analyses and the Food Processor software, version 8.3 (ESHA-Research-Inc, 2003) were used to estimate the energy and nutritional content (macro- and micronutrients) of the identified food items and diets.

The 138 food items were also classified as animal- or plant-based products to estimate the animal-based product contributions to the diet total energy and protein content.

Energy intake under-reporters were identified using Black's equations (Black, 2000). As the prevalence of overweight and obesity was high in the studied population (71% and 37% among women) (Atek et al., 2013), the basal metabolic rates used to calculate Black's cutoffs were estimated using Mifflin equation (Mifflin et al., 1990). The mean observed (OBS) diet was estimated using data from a final sample that included 6279 adults, aged 49.2 ± 9.5 years, among whom 52.9 % were women.

2.2 Environmental impact of diets

The environmental impact of food items was estimated using seven metrics: water deprivation, land use, land use potential impacts on erosion resistance, mechanical filtration, groundwater replenishment, biotic production, and biodiversity. Impacts were computed with a life cycle vision using a hybrid method that combined trade statistics and production data, in order to estimate the impact in the countries of production (Tunisia and/or other countries, if imported) of the food items consumed in Tunisia. The methodology used to estimate the seven metrics (expressed by kg of food) for each of the 138 foods declared to be consumed by the Tunisian population in the nationally representative cross-sectional study has been described elsewhere (Sinfort et al., 2019). Briefly, national dietary survey data were matched with the UNComtrade and the FAOstat databases to obtain the quantity of food produced per production country, for each food item consumed in Tunisia. Yield per crop and per country were used to compute the occupied surfaces, and blue water consumption was extracted from the Water Footprint Network datasets. The potential impacts were then obtained by multiplying the amounts of consumed water and land use surface with characterization factors. The characterization factor used to estimate water deprivation impacts was the Water Stress Indicator provided by Pfister et al. for each country (Pfister et al., 2009). Land use impacts were computed from the occupied surface (including land occupied by animal feed crops), from land use types, and from the main biome of the production country. Then LANCA characterization factors (Beck et al., 2011; Bos et al., n.d.) were used to compute land use potential impacts. The land use impacts on biodiversity were calculated using country-specific global characterization factors estimated by Chaudhary et al. with the countryside species−area relationships (SAR) model and average approach (Chaudhary et al., 2015). The developed methodology assessed the impact at a global scale, which is necessary when studying complete diets that include food items from many countries.

The environmental impact of the OBS and optimized diets was then estimated for each metric by summing the impact of all food items weighed by their quantity in the diet. For each metric, a positive value indicates a detrimental impact, and a negative value a beneficial impact.

2.3 Diet optimization

Quadratic optimization models were used to obtain nutritionally adequate diets that departed the least from the food content of the OBS diet. The model variables were the 138 food items consumed by the population. For each model, the objective function to be minimized was the quadratic deviation from the mean observed intake for each food item and food group, in order to promote minimal variations on all foods and penalize large variations in the diet composition. The objective function was expressed as follows:

$$Minimize\ f = \frac{1}{138}\sum_{i=1}^{138}\left(\frac{Q_i^{opt} - Q_i^{obs}}{Q_i^{obs}}\right)^2 + \frac{1}{8}\sum_{j=1}^{8}\left(\frac{Q_j^{opt} - Q_j^{obs}}{Q_j^{obs}}\right)^2$$

where i represents the 138 food items and j the eight food groups (starch, vegetables; fruits; MFE, dairy, mixed dishes, added fat & seasoning, and drinks), Q^{obs} is the mean observed quantity, and Q^{opt} the optimized quantity. The minimization function was applied at the food item level to deviate as little as possible from the OBS diet, but also at the food group level to respect the meal structure habits and favor substitutions by foods from the same meal component.

The total energy intake of the OBS diet was imposed in all models, as well as nutritional constraints in order to meet the WHO recommendations for 30 nutrients (list of nutritional constraints in **Table 1**). In addition, the fish subgroup was constrained to a maximum intake of two portions per week, to avoid high exposure to contaminants (ANSES, 2010).

Models with increasingly stringent environmental constraints were defined: a model without constraints on the environmental metrics (Nut-Env$_{free}$ model), a model with constraints that limited the environmental metrics to the observed level (Nut-Env$_{obs}$), and models with constraints to decrease the environmental indicators by 10% at each step (Nut-Env$_{-10}$, Nut-Env$_{-20}$, etc… until mathematical infeasibility).

Finally, realism constraints were included in all models to avoid implausible changes relative to the diet consumed by the general Tunisian adult population. Specifically, the total diet weight could vary only by ±20% relative to the mean observed intake. Moreover, the quantities of food items, groups and subgroups could range between the 5th and 95th percentiles of the observed intakes (percentiles were calculated for consumers in the case of food items, and for the whole population in the case of food groups and subgroups). All models were run using the GAMS software package (version 23.8.2).

3 Results

The food group and subgroup quantities in the OBS diet and in the optimized diets are detailed in Supplemental Table 2.

3.1 Food composition, nutritional content, and environmental impact of the mean observed diet

The food group composition and nutritional content of the OBS diet are presented in **Figure 1** and **Table 1,** respectively. The OBS diet did not meet the nutritional constraints for calcium, copper, iron, magnesium, potassium, vitamin D, and vitamin E (all below the WHO recommendations), as well as sodium and total fat (both above the WHO recommendations). Animal products represented 15.4% of the total energy, and 42% of the total proteins.

The environmental impacts (per person and per day) of the OBS diet were 0.32 m^3 eq of water deprivation (**Figure 2A**), 262 m^2 of land use (**Figure 2B**), 16538 m^3 of water infiltration loss from land occupation (**Figure 2C**), 2.6 m^3 of groundwater regeneration loss from land occupation (**Figure 2D**), and 2.2.10^{-13} species lost due to land use (**Figure 2E**). The impact was beneficial for two metrics: -274.3 kg of soil loss due to erosion from land occupation and -139.5 kg of biotic production loss from land occupation (data not shown). Therefore, the subsequent analyses focused on the five environmental metrics that showed a detrimental impact of the diet on the environment.

3.2 Dietary changes needed to reach nutritional adequacy and consequences on the diet environmental impact (Nut-Env$_{free}$ vs. OBS diets)

Compared with the OBS diet, dairy (+98%), fruit (+13%), vegetables (+23%), and starch (+33%) quantities were increased, and HFSS (-58%), and added fat & seasoning (-21%) were reduced in the Nut-Env$_{free}$ diet (**Figure 1A**). The total MFE quantity did not change between OBS and Nut-Env$_{free}$ diets, but intra-group substitutions occurred (**Figure 1B**): the quantity of eggs (+49%), red meat (+47%), fish/seafood (+15%) and offal (+13%) increased, while poultry decreased (-72%).

All five environmental metrics that showed a detrimental impact increased in the Nut-Env$_{free}$ diet compared with the OBS diet (**Figure 2**): water deprivation (+32 %), land use (+46%), biodiversity loss (+48%), groundwater regeneration loss (+47%), and mechanical filtration (+47%).

3.3 Dietary changes needed to reduce the diet environmental impact and reach nutritional adequacy (Nut-Env$_{free}$ vs Nut-Env$_{-10, \ldots}$ diets)

At the food group level, reducing by up to 30% each of the environmental metrics (Nut-Env$_{-10,}$ Nut-Env$_{-20,}$ and Nut-Env$_{-30}$ models) did not require any additional change in food group quantities than those present in the Nut-Env$_{free}$ diet, except for a progressive decrease in MFE quantities (**Figure 1A,** "moderate impact reductions" section). Conversely, for reducing the environmental impact by more than 40% (Nut-Env$_{-40}$ to Nut-Env$_{-70}$ models), major changes in food group quantities were needed (**Figure 1A**, "strong impact reductions" section): higher vegetable and fruit quantities, and progressive reduction of the amount of starch and dairy.

Thereafter, “moderate impact reductions” and “strong impact reductions” will be used to define environmental impact reductions up to 30% and equal/higher than 40%, respectively.

At the food subgroup level, the changes within the MFE group were different from those induced by the Nut-Env$_{free}$ model when the environmental impact constraints were imposed **(Figure 1B**). Specifically, red meat quantity was increased in the Nut-Env$_{free}$ diet (+47% vs. OBS diet), whereas it was reduced by 50% in the Nut-Env$_{obs}$ diet (vs. OBS diet) and even more for moderate impact reductions. For stronger impact reductions, red meat was nearly (impact reductions of 40%) or totally suppressed (impact reductions ≥50%). Egg quantity increased for moderate impact reductions (≤30%), whereas it progressively decreased for stronger reductions (≥40%).

In terms of dietary energy content (**Figure 1C**), moderate impact reductions (≤30%) required a decrease of meat contribution to the total energy that was compensated by a progressive increase of the egg and starch contributions. For strong impact reductions (≥40%), the energy contributions of dairy products and egg decreased, and were balanced by higher contributions of fruits and starch.

The greatest achievable environmental impact reduction while respecting all nutritional recommendations was 70%. For 80% reduction, there was no feasible solution (i.e., no combination of foods) to fulfill the whole set of nutritional and realism constraints. The constraints on vitamin D and calcium made not feasible the diet optimization associated with 80% reduction of the environmental impact. Although mathematically possible, reaching nutritional adequacy while reducing by 70% the environmental impact required an extreme shift from the OBS diet (**Figure 1**), particularly very high intakes of fruits and vegetables (almost 1.1 kg/day). Considering that vitamin D can primarily be obtained from sun exposure, sensitivity analyses were performed with the constraint that vitamin D level should not be reduced relative to the level in the OBS diet (~3 µg/day), instead of imposing to fulfill the recommendation of 5 µg/day (data not shown). With this new constraint, changes in food group quantities were very similar, except for the model with the highest environmental impact reduction (Nut-Env$_{-70}$). In the Nut-Env$_{-70}$ diet with the new constraint on vitamin D, the quantity of eggs (an important contributor to vitamin D content) did not increase, unlike in the Nut-Env$_{-70}$ model with the vitamin D >5 µg/d constraint (**Figure 1B**), while that of vegetables increased to compensate for the egg contribution to vitamin A.

3.4 Changes in animal-based product contributions

Reaching nutritional adequacy (Nut-Env$_{free}$) induced an increase of the animal-based product contribution to the total energy (from 15.4% in the OBS diet to 18.5% in the Nut-Env$_{free}$ diet) (**Figure 3A**). The share of proteins from animal origin was 42% in the OBS diet and 40% in the Nut-Env$_{free}$ diet (**Figure 3B**).

When moderate environmental impact reductions (≤30%) were added to the nutritional constraints, the total contribution of animal products to the dietary energy (approximately 1/6 of the total energy) remained similar, but the fraction of animal proteins was lower (approximately one third of the total protein content), compared with the OBS diet. For stronger environmental impact reductions (>40%), the total contribution of animal products to dietary energy and protein content progressively decreased.

Beyond the total contribution, the contribution of each animal-based product changed. For moderate environmental impact reductions (≤30%), the contribution of the dairy and egg subgroups to the total energy and protein content increased, while that of red meat and poultry decreased compared with the OBS diet. For stronger reductions (>40%), the meat contribution was <0.5% and the dairy group contribution progressively decreased.

4 Discussion

Based on individual dietary data from a national survey, the present study i) estimated the environmental impact (water deprivation, land use, land use potential impacts on biodiversity, erosion resistance, mechanical filtration, groundwater replenishment, and biotic production) of the average diet consumed by the adult Tunisian population, and ii) identified the main dietary shifts required to meet the nutritional recommendations, and concomitantly reduce the environmental impact and minimize the departure from the observed average diet for respecting eating habits and cultural acceptability.

We estimated the water deprivation impact of the average Tunisian diet to 316 L eq/person per day. This value is twice higher than the 160 L/person per day estimated for the current UK food consumption (Hess et al., 2015). We did not find any literature data to compare the biodiversity impact due to land use. Our study revealed that the soil impact related to land occupation was beneficial, for two of the four indicators. This highlights the complexity of land use impact on the environment, especially in semi-arid regions, such as the south of Tunisia. Indeed, land-saving measures are needed to reduce biodiversity loss and protect ecosystem services (Foley et al., 2011). On the other hand, developing farming in semi-arid areas could be beneficial in terms of biomass production and resistance to erosion, if livestock management is adequate. However, the land use impact estimations should be interpreted with caution because they are computed from annual and country-level averages that do not take into account local specificities.

We showed that fulfilling the WHO nutritional recommendations induced an increase of the diet environmental impact: by approximately 30% for water deprivation and by nearly 50% for indicators of land use impact, particularly biodiversity loss. A previous study reported that the dietary scenario designed to conform with the “Eatwell plate” guidelines led to a modest change in the water-scarcity footprint of UK food consumption (-3%), with a large impact variability depending on the production countries (from -18% for the impact in Belgium to +30% for the impact in Pakistan) (Hess et al., 2015). Our results are consistent with the study by Tom et al. (Tom et al., 2015) who found that the blue water footprint increased by 16% when shifting from the current US diet to a healthier diet. The increased environmental impacts found in our study were primarily driven by the increase in dairy products (for water footprint and land use) and starch and fruits (for water footprint). This diet change was probably driven by the low intake of calcium, vitamin D and magnesium in the mean observed diet. Our results highlight the challenge of developing more sustainable diets, with trade-offs between health and environmental goals. Similarly, previous studies observed that healthier diets were associated with higher GHGE (Biesbroek et al., 2017; Perignon et al., 2016; Vieux et al., 2018). However, our diet optimization study also showed that some dietary shifts (increasing the amount of vegetables, dairy and starch products, decreasing HFSS and fats, and reducing meat in favor of fish and eggs) could reconcile nutritional adequacy and a lower environmental impact, while minimizing the departure from the average Tunisian diet. For a 30% reduction of the environmental impact, the magnitude of dietary changes was similar to that required to reach nutritional adequacy alone. However, for higher environmental impact reductions (≥40%), more substantial dietary shifts are required that might compromise the cultural acceptability of such optimized diets.

Reaching nutritional adequacy induced an increase of animal-based products (from approximately 1/6 of the total energy in the observed diet to 1/5 in the optimized diets). When environmental impact reductions were imposed in addition to the nutritional adequacy goal, their energy contribution was decreased to similar levels as in the mean observed diet, but a redistribution within animal-based products occurred with a reduction of meat contribution in favor of dairy products, fish and eggs. Therefore, although reducing the consumption of animal products is often suggested as a key strategy to lessen the environmental impact of diet (Ridoutt et al., 2017), recommendations targeting total animal products may not be appropriate in some Mediterranean countries where the current intake of animal-based products can be, in some contexts, already low. Our optimization study showed that in Tunisia, moving towards a more sustainable diet relied more on redistributing the sources of animal-based products (increase in dairy, fish and eggs vs. reduction of meat products) rather than on reducing their total contribution. Our results underline the importance of context-specific recommendations and confirm that the regional realities need to be carefully considered when examining the role of animal-source foods in achieving more sustainable diets (Willett et al., 2019).

The first strength of our study is the assessment of the diet environmental impact based on several water and land use indicators, and estimated using a life cycle approach that considers the impacts in the food-producing countries. By taking into account international trade and weighing water use with Water Stress Index factors and land use with country-specific characterization factors, the present study assessed sustainability concerns on a global scale. Moreover, our study is based on dietary data from a national survey using a specific and validated food frequency questionnaire, and a Tunisian food composition table. Moreover, our study took into account simultaneously several dimensions of diet sustainability (nutrition, environment, and cultural acceptability) using diet optimization. Accordingly, our study identified not only the dietary shifts required to reach a healthy diet that fulfils a whole set of nutritional recommendations, but also the shifts needed to move towards a healthy diet with a lower environmental impact. Furthermore, by minimizing the changes from the observed diet, the optimized diets were more realistic and potentially culturally acceptable (Gazan et al., 2018).

The present study has some limitations. It could be improved by taking into account the bioavailability of key nutrients, such as iron and zinc, that is influenced by the presence of absorption enhancers and inhibitors in the diet (Barré et al., 2018). Moreover, fish consumption has important effects on biodiversity that are not taken into account in this study due to the lack of data. The studied population (35-70 years) did not include younger adults and this can also be seen as a limitation. In addition, using an individual diet optimization approach (rather than optimizing the population diet as done in the present study) would better integrate individual food preferences and eating habits (Gazan et al., 2018). Moreover, although several sustainability dimensions were taken into account, this study could be improved by integrating the diet cost in the models. Finally, although minimizing the departure from the observed diet and introducing realism constraints allowed avoiding extremely theoretical diets, such method cannot guarantee that the resulting dietary shifts would be acceptable to the consumer.

5 Conclusion

This diet optimization study showed that designing a nutritionally adequate diet without considering its environmental impact might increase diet-related land use, water deprivation, and land use impacts on biodiversity and soil quality. However, nutritional adequacy and moderate reductions of the environmental impacts (-30%) might be achieved through dietary shifts different in type but of similar magnitude than those required to meet the nutritional recommendations alone. In Tunisia, moving towards healthy diets with lower environmental impact relied more on redistributing the sources of animal-based products rather than on reducing their total contribution (less meat in favor of dairy, egg and fish products), together with an increase of vegetables and a decrease of fat and sweet products. The dietary changes identified in this study can be translated into action proposals to target food consumption and production in order to promote more sustainable diets in the Mediterranean region. The implementation of actions to favor the adoption of the identified dietary changes by consumers should be investigated.

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8 Tables and Figures

Table 1: Nutritional constraints implemented in the diet optimization models, and nutrient content in the mean observed diet.

Nutrient	Constraint applied in the modeled diets[1]	Content in the mean observed diet[2]
Proteins (g*kg of body weight[3]/d)	> 0.83 (WHO/FAO/UNU, 2007)	83.7
Carbohydrates (%E)	[50-75] (FAO/WHO, 2007)	50.7
Total fat (%E)	[15-35] (FAO, 2010)	**35.6**
Saturated fatty acids (%E)	< 10 (FAO, 2010)	7.4
Total PUFA[4] (%E)	[6-11] (FAO, 2010)	9.4
n-6 PUFA (%E)	[2.5-9] (FAO, 2010)	8.0
n-3 PUFA (%E)	[0.5-2] (FAO, 2010)	1.1
Cholesterol (mg/d)	<300 (WHO-FAO, 2003)	237.5
Fibers (g/d)	> 25 (WHO-FAO, 2003)	31.8
Free sugars (%E)	< 10 (WHO-FAO, 2003)	6.7
Vitamin A (µg RE/d)	[550-3000] (WHO-FAO, 2004)	751.6
Vitamin B1 (mg/d)	> 1.15 (WHO-FAO, 2004)	2.4
Vitamin B2 (mg/d)	> 1.2 (WHO-FAO, 2004)	2.2
Vitamin B3 (mg/d)	[15-35] (WHO-FAO, 2004)	27.7
Vitamin B5 (mg/d)	> 5 (WHO-FAO, 2004)	5.0
Vitamin B6 (mg/d)	[1.3-100] (WHO-FAO, 2004)	1.9
Folates (µg DFE/d)	[400-1000] (WHO-FAO, 2004)	706.3
Vitamin B12 (µg/d)	> 2.4 (WHO-FAO, 2004)	5.0
Vitamin E (mg α-tocopherol/d)	> 15 (WHO-FAO, 2004)	**10.5**
Vitamin C (mg/d)	[45-1000] (WHO-FAO, 2004)	168.3
Vitamin D (µg/d)	[5-50] (WHO-FAO, 2004)	**3.1**
Calcium (mg/d)	[1000-3000] (WHO-FAO, 2004)	**723.6**
Magnesium (mg/d)	[242-350] (WHO-FAO, 2004)	**206.9**
Zinc (mg/d)	[5.95-45] (WHO-FAO, 2004)	9.7
Selenium (µg/d)	[30-400] (WHO-FAO, 2004)	122.5
Iron (mg/d)	[21.5-45] (WHO-FAO, 2004)	**18.2**
Sodium (g/d)	< 2 (WHO, 2012)	**4.7**
Copper (mg/d)	[1.25-11] (WHO, 1996)	**1.0**
Potassium (mg/d)	> 3510 (WHO, 2011)	**3146.8**
Phosphorus (mg/d)	[700-4000] (Institute of Medicine, 1997)	1147.4
Total energy (kcal/d)	Equal to the total energy of the mean observed diet	2702

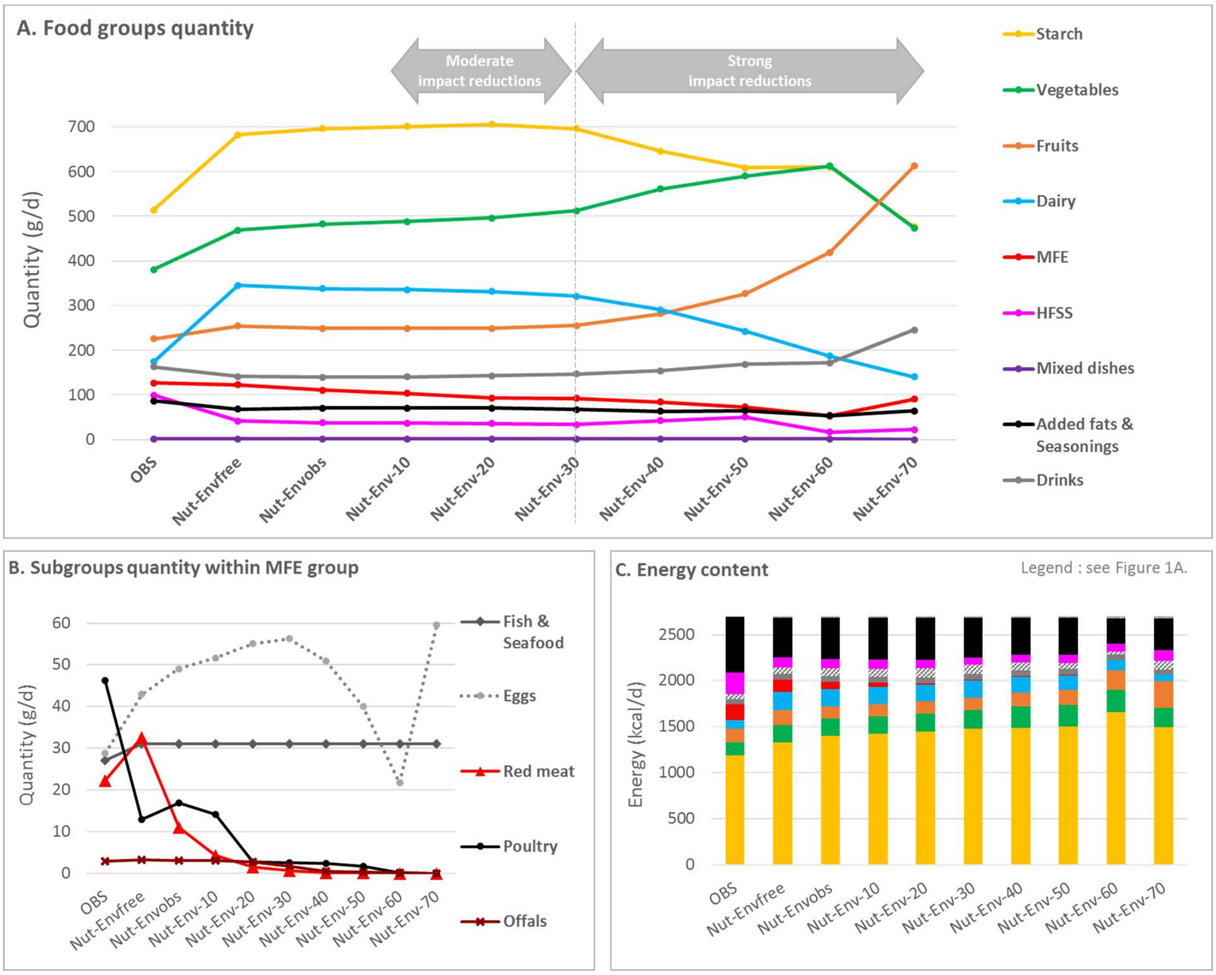
[1]Mean of the recommended dietary allowances for men and women

[2]Bold values indicate when a nutrient content does not fulfill the constraint.

[3]Mean body weight was estimated using national Tunisian dietary survey data

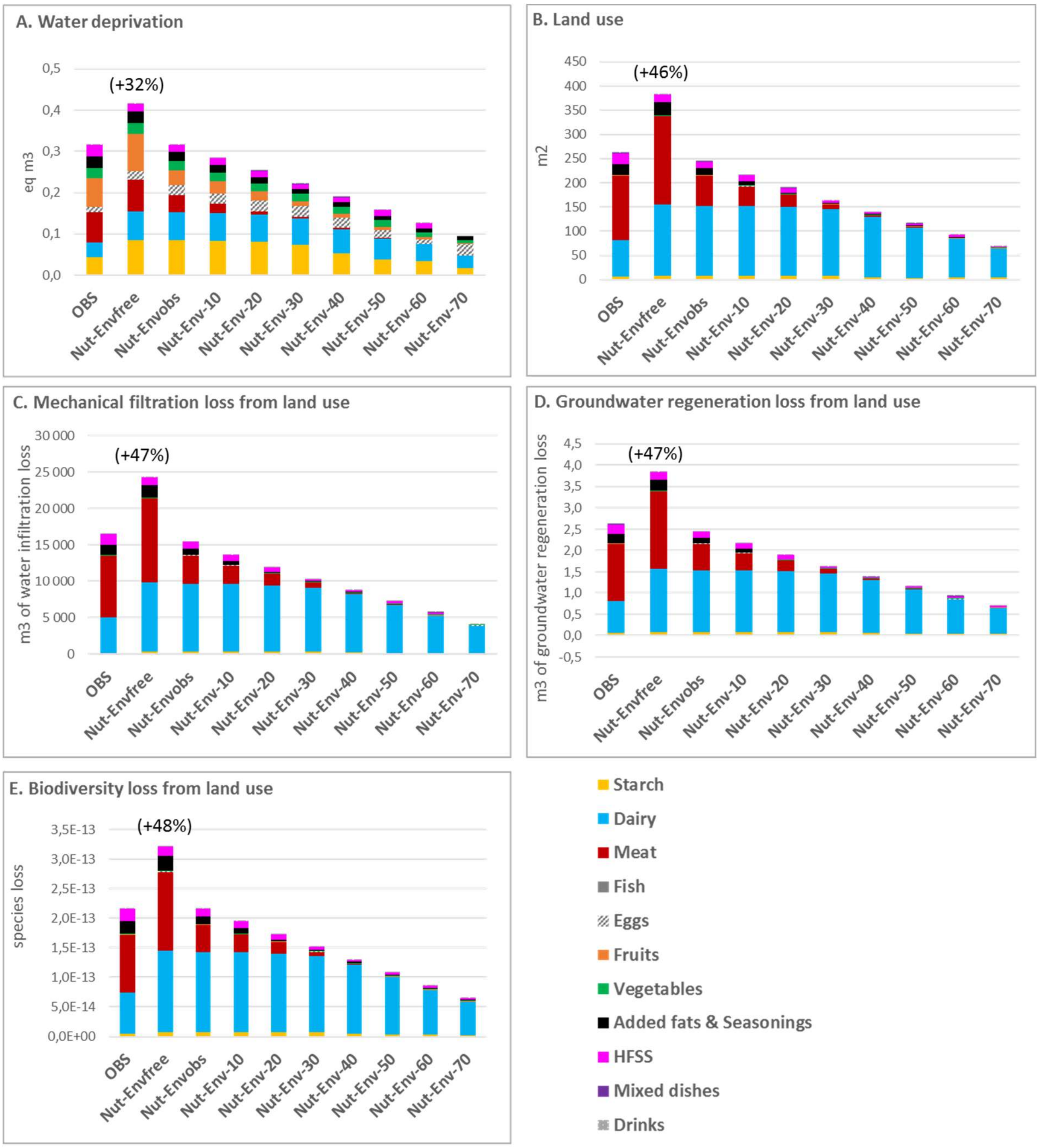
[4]Polyunsaturated fatty acids

Figure 1: **Food groups quantity (A), Subgroup quantity within the Meat/Fish/Egg group (B), and Energy content (C) in the observed and optimized diets.**



MFE: Meat/Fish/Egg; OBS: observed diet; Nut-Env$_{free}$: model without environmental constraints; Nut-Env$_{obs}$: model with constraints limiting the environmental metrics to the observed level; Nut-Env$_{-10}$, Nut-Env$_{-20, \ldots}$ etc: models with constraints imposing a 10% decrease of the environmental indicators at each step.

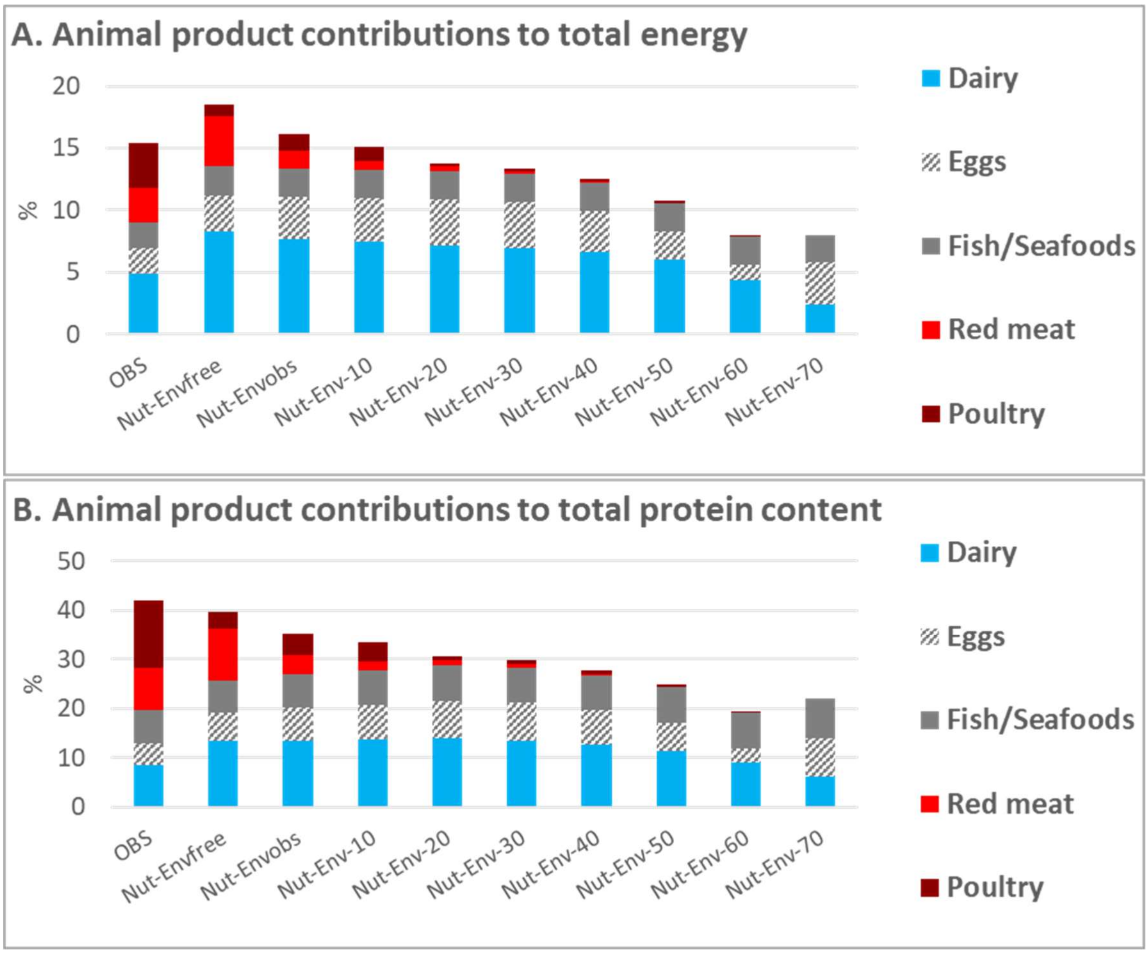
Figure 2: Food group contributions to water deprivation (A), land use (B), land use impacts on mechanical filtration (C), groundwater regeneration (D), and biodiversity (E) in the observed and optimized diets [1].



[1] Percentages between brackets show the increase of the Nut-Env$_{free}$ diet impact (vs. impact of the observed diet). HFSS: foods high in fat/salt/sugar; OBS: observed diet; Nut-Env$_{free}$: model

without environmental constraints; Nut-Env$_{obs}$: model with constraints limiting the environmental metrics to the observed level; Nut-Env$_{-10}$, Nut-Env$_{-20}$, ... etc: models with constraints imposing a 10% decrease of the environmental indicators at each step.

Figure 3: Animal-based product contributions to total energy (A), and total protein content (B) in the observed and optimized diets.



OBS: observed diet; Nut-Env$_{free}$: model without environmental constraints; Nut-Env$_{obs}$: model with constraints limiting the environmental metrics to the observed level; Nut-Env$_{-10}$, Nut-Env$_{-20, \ldots}$ etc: models with constraints imposing a 10% decrease of the environmental indicators at each step