Nutrient profiling and linear programming diet modelling: an analysis of the differences between the outcomes

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The primary purpose of this study is to determine what the difference of the outcomes of nutrient profiling and linear programming diet modelling are. The aim of both methods is to compose a healthy diet. Nutrient profiling determines the quality of a diet by examining the nutrient density of foods. A food is called nutrient dense when it contains many nutrients and fewer calories. The specific nutrient profiling system that is used in this research is the nutrient rich foods index (NRF). The index encourages 9 nutrients and limits 3. Linear programming diet modelling on the other hand is a mathematical way of composing a healthy diet. To compare the two methods, the nutrient profiling scores of foods that are included in the LP-diet model are calculated. The foods of the LP-diet model are divided within groups and the nutrient profiling scores of foods within one group are compared. After this, different versions of the LP-diet model are runned to see how adjustments on the model influence the foods and their corresponding nutrient profiling score that are selected by the model. On the basis of these experiments, it can be concluded that LP-diet modelling does not always recommend the same foods as a nutrient profiling system would. It became clear that the problem is in the reference intake of nutrients that are profitable for health. Either the LP-diet model has nutrient intakes that are too strict, or a diet composed with nutrient profiling contains too many encouraged nutrients.

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1. Introduction

Nowadays, many food, nutrition and health challenges exists. Obesity is one of the greatest health problems while on the other, too many people still go to bed hungry (Foresight, 2011). It is proven that the right diets and foods contribute to a healthy life, prevents chronic diseases and are solutions to problems like obesity (WHO Report, 2004). Luckily, more and more consumers are aware of the implications of healthy eating and how a healthy diet looks like (Croll, Neumark-Sztainer, & Story, 2001). They are, for example, trying to choose the right foods with the help of health claims on food packages (Scarborough, Boxer, Rayner, & Stockley, 2007). Not only the consumers but also governments are also trying to encourage healthy eating among their inhabitants through policies that promote healthy eating (Capacci et al., 2012). All together, we can state that healthy eating is a subject that is important among people and it receives greater attention than before (WHO Report, 2004). Healthy diets contribute to a more healthy lifestyle and since there is more attention for health, more and more consumers are willing to adapt their eating patterns to a specific diet. But how to compose such a healthy diet? Nutrient profiling and diet modelling with linear programming are two ways of composing healthy diets that are highlighted in this research.

Nutrient profiling is a quantitative method for categorising foods according to their nutritional quality which is determined by the nutrition density of foods. A food that is nutrition dense contains many nutrients and fewer calories (Drewnowski & Fulgoni, 2008). In the end, there is a score calculated for a food. A high score refers to a healthy food and a lower score refers to a foot that is less healthy. The development of nutrient profiling is a desirable step in tackling obesity and other diseases (Lobstein & Davies, 2009) but nutrient profiling has many more applications. Nutrient profiling is useful in consumer education, dietary guidance, nutrition labelling or in the regulation of health claims (Drewnowski & Fulgoni, 2008). There are multiple types of nutrient profiling systems. For all of those systems, it is important to determine which nutrients in the foods are examined. There are nutrient profiling systems that encourage nutrients, systems that limit nutrients or systems that apply a combination of both. The specific nutrient profiling system that is used in this research is the Nutrient Rich Foods index (NRF) that both encourages and limits nutrients (Drewnowski, 2010).

The outcomes of profiling will be compared to diet modelling with linear programming (LP). LP-diet modelling is a way of mathematical modelling and used to optimize diets. According to Butriss (2014) the definition of mathematical modelling can be defined as: “the use of mathematical techniques to formulate and optimise diets.” LP-diet models are typical resource optimisation problems and they select foods that should be in a healthy diet. The basis of an LP-diet model is that there are multiple constraints, set up in equations. These constraints say something about the minimum and maximum intake values of different nutrients or something about the palatability of a diet. Furthermore, one objective is set that should be maximised or minimised. The objective can be, for example, to minimise costs or to maximise nutrient intake (Butriss et al., 2014).

Problem statement

Both nutrient profiling as well as linear programming diet modelling are both scientific methods to compose a diet (Scarborough et al., 2007) (Lobstein & Davies, 2009). However, there is little research that compares nutrient profiling with LP-diet modelling, so we don't know if a diet that is composed with LP-diet modelling is similar to a diet that is composed with nutrient profiling.

Research objective

The goal of this research is to investigate the differences between diets that are composed with LP-diet modelling and nutrient profiling. There will be analyzed why certain diets are chosen and what the cause is of differences in recommendations.

Research question

Main-question

What are the differences in outcomes between LP-diet modelling and nutrient profiling?

Sub-questions

1. What is nutrient profiling and which foods does the method recommend?
2. What is LP-diet modelling and which specific LP-diet model is used?
3. What are the NRF9.3 indexes of the foods in the LP-diet model?
4. Is the LP-diet model feasible when foods with high NRF scores are used?
5. Are foods with a higher NRF score selected when another objective function is used?
6. Are foods with a higher NRF score selected when 12 nutrients of the NRF are included in the LP-diet model?

Method

The goal of this research is to check whether diets that are composed with the help of nutrient profiling are similar to diets that are composed with linear programming. The first step in this research is to check what nutrient profiling is, which foods the system recommends and which foods not. All these questions will be tackled with the help of literature study. The questions about what LP-diet modelling is will also be answered with literature study. To find out which foods an LP-diet model would recommend, a specific model is needed. The LP-diet model that is used in this research is a reduced version of the model of Gerdessen & de Vries (2015). The model will be runned to see which foods it selects.

Further data for this research is collected by assembling nutritional information about foods and by running different versions of the small diet model in FicoXpress. Multiple experiments will be done.

First of all**,** the NRF scores of all the foods used in the LP-diet model will be calculated, after which the scores of the foods will be ranked from a high to a low score. The NRF values are calculated conform the paper of Drewnowski (2010) that sums the percentages of daily values of the 9 nutrients to encourage, and subtracts the sum of the percentage of the daily values of the 3 nutrients that must be limited (Drewnowski, 2010).

After calculating NRF scores, the LP-diet model will be runned to see which foods it selects. Additionally, the foods are subdivided into groups. Groups are based on the function of a food in the diet model. All together, there are 15 groups in the model. A palatable human diet should contain at least one, but sometimes more foods of one food group. After separating the foods into groups, the experiment consist of two parts.

The first part of the experiment, the scores of the foods that are in the optimal solution of the model will be compared to the foods that are not. The expectation is that the NRF scores of these foods will be higher than the other foods, since LP-diet modelling and nutrient profiling both aim to reach an optimal and healthy diet.

The second part of the experiment is to do it the other way around. Foods with the highest NRF9.3 score among their group will be included in the LP-diet model, while all the other foods are excluded. There will be tested whether the model is feasible with these foods. Since the groups are set up according to the palatability constraints, and for each group at least one food is used, palatability constraints can't be a problem. Nevertheless, nutrient constraints could make the model infeasible. If they are indeed problematic, there will be tested whether the model is feasible when the reference intake of only one nutrient is included. By doing this, there will be checked whether one specific nutrient is problematic. Moreover, there will be checked which combination of constraints is problematic for the model by inserting back all the nutrient constraints in the model one by one.

After doing this experiment, the model will be runned with another objective function to see whether foods with a higher NRF score are selected.

The last experiment that is executed, is to use the 12 nutrients for the nutrient profiling system in the LP-diet model. There will be tested whether the model is feasible when including the 12 nutrients and their upper and lower bounds while the objective function is to maximize the intake of the encouraged nutrients and minimize intake of limited nutrients.

2. Nutrient profiling and the NRF9.3 index

In this chapter, we will discuss research question one: what is nutrient profiling exactly, and which foods does the method recommend?

Nutrient Profiling can be defined as the science of classifying or ranking foods according to their nutritional composition. (WHO, 2010) The nutrient profiling system is developed for promoting health and preventing diseases. The introduction of health claims is an example of a tool where nutrient profiling is used. A health claim helps people make food choices based on nutritional information of a specific food. Foods with enough good nutrients got health claims while foods that contained too many bad nutrients were disqualified (Drewnowski & Fulgoni, 2008).

Nutrient profiling is an unique tool to measure quality of diets since it applies to only one food (Miller et al., 2009). There are multiple nutrient profiling systems of which the Nutrient Rich Foods index (NRF) is one of them. There are also multiple versions of the NRF developed, but all of them are set up with the same scientific rules. In every NRF, nutrients must be selected that are measured in foods. To measure these nutrients, maximum and reference daily intake values must be set. Furthermore, it is important that there is an appropriate algorithm and that the model is validated against some objective measure of a healthy diet (Drewnowski & Fulgoni, 2008). But how to select these index nutrients? There are multiple options for this. First of all, a NRF can be based on nutrients to encourage. Nutrients that are encouraged are beneficial to health and mostly contain vitamins and minerals. The second option is to base your NRF on nutrients that must be limited, these nutrients are mostly fat, sugars and sodium. The third option is to combine both, so to encourage and to limit nutrients. In previous research, there have been multiple NRF's tested against existing measures of diet quality. The NRF*n*.3 was based on 3 nutrients to limit and *n* nutrients to encourage (n= 6-15) The limited nutrients were saturated fat, added sugar and sodium (Drewnowski & Fulgoni, 2008). All the different NRF's were calculated as a percentage of reference daily values by taking the sum of the encouraged nutrients minus the sum of the limited nutrients (Fulgoni, Drewnowski, & Keast, 2009). Fulgoni et al. (2009) concluded that the NRF9.3 was the most appropriate to index to use. The NRF9.3 contains 9 nutrients to encourage and three nutrients to limit. The encouraged nutrients are protein, fiber, vitamins A and C, calcium, iron, vitamin E, potassium and magnesium. Limited nutrients are added sugar, saturated fat and sodium.

In previous research, NRF9.3 scores of 5058 foods are calculated and foods are ranked into food groups by their fist digit of the coding scheme. Foods that scored very high were vegetables and fruits. Furthermore, grains and dairy also scored good. Foods that were in the group others and foods that were in the group meat had on average a lower NRF score. (Fulgoni et al., 2009)

In this chapter, we've learned that nutrient profiling is a method to analyze the nutrient content of single foods. There are multiple versions of nutrient profiling and the system that is used in this research is the nutrient rich foods index, which encourages 9 nutrients and limits 3. Foods that have high NRF scores are in general fruits and vegetables.

3. LP-diet modelling and the specific diet model

In this chapter, research question 2 will be discussed. Research question 2 is about what linear diet modelling exactly is. Furthermore, the specific LP-diet model that is used in this research will be analyzed.

3.1 What is linear programming diet modelling?

Diet modelling exists for a long-time, and is first used in 1940s. George Stigler tried to determine the minimum cost of a diet that provides enough adequate nutrients. Stigler dealt with a typical resource optimisation problem, subjected to several constraints. This problem is also known as linear programming.

The basics of linear programming are that a linear function – also called the objective function – is maximized or minimized, when subjected to various constraints. Linear programming can helps businesses with quantitative decisions (Gregersen, 2017) and are solved with appropriate software and computer programs (Butriss et al., 2014).

Linear programming diet modelling is used by many governments to test whether public health goals and recommendations are feasible. Furthermore, it is used to test the relevance of nutritional recommendations and to test whether dietary guidelines are useful for nutrient intake (Butriss et al., 2014).

To model a good and palatable human diet, there have to be much constraints in the diet. These constraints are formulated in terms of different food groups. For example, a human diet should consist of a minimum amount vegetables and fruits or fish should be eaten twice a week. (Butriss et al., 2014)

3.2 How does the specific LP-diet model looks like?

To compare nutrient profiling with linear programming diet modelling, a specific LP-diet model is needed. The LP-diet model that is used in this research is a reduced version of the model of Gerdessen & de Vries (2015). This LP-diet model consist of specific food products *(n=81)* and different nutrients *(n=19)*. All the foods are identified with a nevo-code and the foods are divided into sub groups that are more general. Sub groups are for example meat, bread, cheese, dairy yoghurt and so on.

To make the diet healthy and palatable, there are constraints. First of all, there are constraints that say something about the minimum and maximum intake value of the 19 different nutrients used in the model to make a healthy diet. The daily intake of calcium, for example, should be above 500 and below 800 according to the model. Besides the constraints about intake values, there are constraints that make the model palatable. A normal human diet could for example not exists of only vegetables or bread. A diet needs variety, otherwise it wouldn't be a good diet. There are groups set up for these palatability constraints. These groups contain different foods from the model and a palatable human diet should contain at least one food of every food group. A group that is set up for a palatability constraint is for example the group bread total. This group consists of brown bread, white bread and wholemeal bread. Bread total should for example be larger than 3*35 gram and smaller than 7*35 gram, since it is normal to eat such an amount of slices of bread. The LP-diet model selects one specific food of each food group regarding the constraints.

In this chapter we've learned that linear programming diet modelling is a mathematical way of composing diets. A LP-diet model is subjected to several palatability and nutrient constraints to form a diet. The specific diet model in this research consist of 81 foods and 19 nutrients with nutrient and palatability constraints.

4. NRF9.3 indexes of foods in the LP-diet model

In this chapter, research question 3 will be answered: What are the NRF9.3 indexes of the foods in the LP-diet model?

4.1 How are the NRF9.3 scores calculated?

To calculate a NRF9.3 score, the following formula is used:

$$NRF = \sum_{i=1}^{9} \frac{100 \cdot S_i N_i}{RDV_i} - \sum_{i=1}^{3} \frac{100 \cdot S_i N_i}{RDV_i}$$

N_i = Amount of nutrient i in food j

RDV_i = Recommended daily value

S_i = Serving size

MRV = Maximum recommended value

Daily values are calculated per 100 kilocalories and capped at 100% so that foods that contain large amounts single nutrients don't obtain an index score that is disproportionately high (Drewnowski, 2010).

The maximum recommended value and reference daily value are on average sufficient enough for all people to meet daily requirements (97-98%). The reference values are derived from the Dietary Reference Intake (DRI) which is a system of the national institute of health of the United States (NIH, 2015). Reference intakes shown below are for women that are between 19 and 50 years old.

Tabel 1
recommended daily values and maximum recommended values

Nutrient	**RDV**	**MRV**
Protein (gr)	50	-
Fiber (gr)	25	-
Vitamin A (IU)	5000	-
Vitamin C (mg)	60	-
Vitamin E (mg)	30	-
Calcium (mg)	1000	-
Iron (mg)	18	-
Potassium(mg)	3500	-
Magnesium (mg)	400	-
Saturated fat (g)	-	20
Added sugar (g)	-	50

Sodium (mg)	-	2400

To calculate the NRF9.3 scores, data about the amount of nutrients in the specific foods is needed. This data is derived from the Rijksinstituut voor Volksgezondheid en Milieu (RIVM, 2012). All the NRF9.3 scores are calculated with the help of Excel. Because there isn't data available for the amount of added sugar within a product, the total amount of sugar in a product is used instead.

4.2 What are the specific NRF9.3 scores?

In the table below, the separate NRF scores for the nutrients and the final NRF9.3 score of all the foods that are included in the LP-diet model can be found. The numbers in the cells under the 12 nutrients indicate the percentage of the total recommended intake of the nutrient in a food per 100 kcal. Numbers are calculated with the formula at the previous page. The total NRF9.3 score is calculated by taking the sum of the encouraged nutrients minus the sum of the three nutrients that must be limited.

Foods	Nevo	Prot	Fiber	VitA	VitC	Ca	Iron	VitE	K	Mg	Sugar	SFA	Na	NRF9.3
Coffee prepared,	644	0.33	0	0	0	0.33	0.93	0	1	1	0.17	0	0.03	3.40
Vegetables mixture raw	127	0.10	0.26	0.29	0.92	0.14	0.18	0.07	0.4	0.15	0.23	0.03	0.02	2.22
Vegetables average boiled,	1904	0.12	0.32	0.28	0.81	0.14	0.13	0.06	0.2	0.13	0.13	0.02	0.06	1.99
Fruit fresh citrus average,	172	0.03	0.12	0.02	1.58	0.05	0.01	0.03	0.1	0.05	0.33	0.01	0	1.65
Tomato juice,	413	0.09	0.1	0.19	0.83	0.08	0.1	0.37	0.4	0.16	0.39	0	0.7	1.22
Juice orange pasteurized,	410	0.03	0.03	0.01	1.21	0.03	0.01	0.02	0.1	0.07	0.41	0	0	1.09
Fish lean 0-2 g fat raw,	114	0.44	0	0.01	0.02	0.02	0.04	0.01	0.1	0.07	0	0.01	0.04	0.63
Beef <10% fat prepared,	1665	0.37	0	0.01	0.02	0.01	0.1	0.02	0.1	0.05	0	0.05	0.02	0.59
Beans white/brown boiled,	968	0.13	0.23	0	0	0.03	0.09	0.01	0.1	0.05	0.02	0.01	0	0.58
Yoghurt low fat,	301	0.22	0	0	0	0.39	0	0	0.1	0.08	0.21	0.03	0.05	0.53
Fish medium fat > 2-10 g fat raw,	115	0.35	0	0*	0	0.02	0.03	0.01	0.1	0.04*	0	0.05	0.02	0.51
Potatoes wo skins boiled average,	982	0.05	0.08	0	0.18	0.01	0.03	0	0.1	0.06	0	0.01	0	0.51
Pork <10% fat prepared,	1670	0.36	0	0.01	0	0.01	0.03	0.02	0.1	0.05	0	0.05	0.02	0.50
Buttermilk,	289	0.19	0	0	0.05	0.35	0	0	0.1	0.08	0.23	0.03	0.05	0.49
Eggs chicken boiled average,	84	0.19	0	0.11	0	0.05	0.1	0.11	0	0.03	0	0.11	0.05	0.47
Processed meat products 20-30 g fat,	1171	0.09	0	0.44	0.11	0.01	0.05	0	0	0.01	0	0.16	0.13	0.44
Milk skimmed,	294	0.21	0	0	0	0.35	0	0	0.1	0.08	0.27	0.01	0.05	0.44
Pasta wholemeal boiled,	2157	0.08	0.13	0	0	0.02	0.07	0.01	0	0.09	0.01	0	0	0.40
Yoghurt half fat,	1502	0.17	0	0.02	0.06	0.28	0.01	0	0.1	0.06	0.17	0.1	0.04	0.39
Cheese 30+ average,	1382	0.21	0	0.04	0	0.36	0	0.01	0	0.03	0	0.21	0.11	0.35
Processed meat products <10 g fat,	1211	0.24	0.01	0.09	0.18	0.01	0.04	0.03	0.1	0.03	0.01	0.08	0.28	0.32
Fruit fresh average excluding citrus,	173	0.02	0.1	0	0.36	0.01	0.02	0.02	0.1	0.05	0.35	0	0	0.32
Milk semi-skimmed,	286	0.15	0	0.02	0.04	0.27	0	0	0.1	0.07	0.2	0.11	0.04	0.30
Potatoes fried,	1457	0.03	0.05	0.03	0.11	0.01	0.02	0	0.1	0.04	0	0.07	0	0.29
Bread wholemeal average,	246	0.09	0.11	0	0	0.01	0.05	0	0	0.07	0.02	0.01	0.08	0.26
Yoghurt full fat,	278	0.13	0	0.04	0	0.25	0	0.01	0.1	0.06	0.12	0.17	0.03	0.25
Pork 10-19% fat prepared,	1671	0.22	0	0.01	0.04	0.01	0.03	0.03	0.1	0.03	0	0.1	0.07	0.25
Nuts mixed unsalted,	207	0.07	0.04	0	0	0.01	0.03	0.03	0	0.09	0.01	0.06	0	0.22
Beef >10% fat prepared,	1666	0.18	0	0.02	0.04	0.01	0.06	0.03	0	0.02	0	0.11	0.07	0.22
Nuts mixed salted,	1935	0.07	0.04	0	0	0.01	0.03	0.03	0	0.09	0.01	0.06	0.02	0.21
Rice brown boiled,	1014	0.05	0.06	0	0	0.01	0.01	0	0	0.07	0	0.01	0	0.21
Low fat marg prod 20-25% fat <10 g sat,	2061	0.02	0	0.22	0	0	0	0.15	0	0	0	0.16	0.04	0.20
Fish fat > 10 g fat raw,	116	0.13	0	0.07	0.01	0.01	0.02	0.02	0	0.03	0	0.1	0.03	0.19
Pasta white average boiled,	659	0.07	0.04	0	0	0.01	0.03	0	0	0.03	0.01	0	0	0.18
Bread brown wheat,	236	0.08	0.08	0	0	0.01	0.03	0	0	0.05	0.02	0.01	0.08	0.17
Low fat margarine prod 35% fat <10 g sat,	2060	0.00	0	0.17	0	0	0	0.12	0	0	0	0.13	0	0.17
Peanut butter,	455	0.07	0.05	0	0	0.01	0.01	0.04	0	0.05	0.01	0.06	0.02	0.16
Cooking fat liq 97%fat <17g sat unsalted,	2562	0.00	0	0.06	0	0	0	0.14	0	0	0	0.07	0	0.14
Milk whole,	279	0.11	0	0.04	0	0.2	0	0.01	0.1	0.05	0.15	0.18	0.03	0.12
Crisps potato average,	122	0.02	0.03	0	0.03	0	0.02	0.03	0.1	0.03	0.01	0.05	0.05	0.12
Margarine product 60% fat <17 g sat,	2072	0.00	0	0.1	0	0	0	0.13	0	0	0	0.13	0	0.11
Margarine liq 80% fat < 17g sat unsalted,	2558	0.00	0	0.07	0	0	0	0.09	0	0	0	0.07	0	0.10
Rice white boiled,	658	0.04	0.02	0	0	0.01	0.01	0	0	0.02	0	0	0	0.09
Cheese Gouda 48+ average,	513	0.13	0	0.06	0	0.22	0	0.01	0	0.02	0	0.27	0.09	0.09

Low fat margarine 40% fat <17 g sat,	2059	0.00	0	0.15	0	0	0	0.11	0	0	0	0.16	0.02	0.08
Cheese 48+ less salt average,	881	0.13	0	0.06	0	0.2	0	0.01	0	0.02	0	0.27	0.07	0.08
Bread white water based,	248	0.07	0.04	0	0	0.01	0.02	0	0	0.02	0.02	0.01	0.08	0.08
Yoghurt low fat with fruit,	284	0.10	0.01	0	0.02	0.16	0.01	0	0.1	0.04	0.31	0	0.03	0.07
Processed meat products >30 g fat,	1151	0.08	0.01	0.18	0.04	0.01	0.03	0	0	0.01	0	0.17	0.14	0.07
Margarine liq 80% fat <17 g saturates,	2077	0.00	0	0.07	0	0	0	0.04	0	0	0	0.05	0.02	0.04
Cooking fat sol 97% fat>17g sat unsaturated,	2563	0.00	0	0.06	0	0	0	0.14	0	0	0	0.17	0	0.04
Peanuts coated,	546	0.06	0.04	0	0	0.01	0.01	0.03	0	0.04	0.02	0.07	0.07	0.03
Pork >19% fat prepared,	1672	0.12	0	0	0.04	0	0.01	0.01	0	0.02	0	0.16	0.06	0.03
Japanese rice cracker mix wo peanuts,	2147	0.04	0.01	0	0	0	0.01	0	0	0.01	0.01	0	0.06	0.02
Biscuit brown/wholemeal,	263	0.03	0.05	0	0	0.01	0.05	0.03	0	0.03	0.1	0.08	0.04	0.01
Mayonnaise,	451	0.00	0	0.01	0	0	0	0.09	0	0	0.01	0.07	0.02	0.01
Tea prepared,	645	0.00	0	0	0	0	0	0	0	0	0	0	0	0.00
Water 50-100 mg calcium per litre,	599	0.00	0	0	0	0	0	0	0	0	0	0	0	0.00
Sandwich spread original,	575	0.01	0.01	0.01	0.03	0.02	0.05	0.07	0	0.02	0.12	0.03	0.1	0.00
Processed meat products 10-20 g fat,	1172	0.15	0	0.05	0.01	0.01	0.05	0.01	0	0.01	0	0.13	0.18	0.00
Mayonnaise low fat 40% oil,	729	0.01	0	0	0	0.01	0.01	0.08*	0	0.01	0.03	0.08	0.02*	0.00
Margarine 80% fat > 24 g sat unsalted,	2557	0.00	0	0.08	0	0	0	0.09	0	0	0	0.2	0	-0.03
Spread chocolate hazelnut,	436	0.02	0.02	0	0	0.02	0.04	0.06	0	0.03	0.18	0.08	0	-0.04
Biscuit muesli,	636	0.03	0.03	0	0	0.01	0.03	0*	0	0.03	0.11	0.1	0.01	-0.05
Salad cream 25% oil,	458	0.00	0	0.01	0	0	0	0.09	0	0	0.05	0.05	0.09	-0.06
Oil olive,	601	0.00	0	0	0	0	0	0.02	0	0	0	0.08	0	-0.06
Apple pie Dutch w shortbread w marg,	251	0.02	0.03	0.02	0.01	0.01	0.02	0.02	0	0.01	0.16	0.08	0.02	-0.10
Snack sausage roll puff pastry,	266	0.04	0.02	0.01	0.02	0	0.02	0	0	0.01	0	0.15	0.08	-0.10
Chocolate confetti averaged,	1311	0.02	0.05	0	0	0.01	0.08	0.01	0	0.06	0.28	0.1	0	-0.11
Custard several flavours full fat,	1720	0.04	0	0.02	0.02	0.09	0.01	0	0	0.02	0.21	0.1	0.03	-0.11
Salad dressing./sauce approx 13% oil,	2467	0.00	0.02	0	0	0.01	0.01	0.07	0	0	0.04	0.04	0.15	-0.12
Biscuits averaged,	258	0.03	0.03	0.01	0	0.01	0.02	0.01	0	0.01	0.13	0.1	0.03	-0.12
Beer alcohol free <0,1 vol%,	1519	0.02	0	0	0	0.02	0	0	0	0.04	0.24	0	0	-0.13
Flan with fruit filling,	486	0.03	0.02	0.01	0	0.01	0.01	0.02	0	0.01	0.17	0.05	0.04	-0.15
Chocolate milk,	431	0.03	0.02	0.01	0	0.03	0.03	0.01	0	0.02	0.18	0.19	0.01	-0.20
Gateau with whipped cream,	255	0.03	0.01	0.03	0	0.02	0.01	0.01	0	0.01	0.15	0.18	0.01	-0.21
Cake made with butter,	1969	0.03	0.01	0.03	0	0.01	0.01	0.01	0	0.01	0.13	0.17	0.04	-0.22
Butter unsalted,	310	0.00	0	0.08	0	0	0	0.01	0	0	0	0.37	0	-0.27
Juice apple,	383	0.00	0	0	0	0.02	0.01	0	0.1	0.03	0.44	0	0	-0.32
Jam,	445	0.00	0.01	0	0.02	0	0.01	0.01	0	0	0.42	0	0	-0.35
Soft drink wo caffeine,	400	0.00	0	0	0	0	0	0	0	0	0.49	0	0.01	-0.49

The NRF9.3 scores for tea and water are both 0 since they don't have any kilocalories. Furthermore, the NRF for mayonnaise, for the muesli biscuit and for fish medium fat aren't completely reliable because of missing information about the nutrient content. Nutrient content of comparable foods are used instead. Cells are displayed in white when there wasn't information available. Because coffee contains very little calories, and nutrient content is based on 100 kcal, the NRF of coffee is disproportionately high.

In this chapter we've learned how to calculated the NRF9.3 scores of all the foods in the diet model. Scores are calculated per 100kcal and that's why the NRF9.3 score of coffee is disproportionately high.

Experiments

Now that there is a specific diet model and NRF scores from all the foods in the LP-diet model are known, 6 different versions of the diet model will be runned. Small adjustments are made to the original model to see which foods the model selects. There will be analyzed when the model selects foods with high NRF scores and why this is the case.

Model 1 is to run the diet model without making any adjustments to it. It thus includes 81 foods and 19 nutrients with the corresponding constraints. The original model has an objective function that maximizes the intake of fruit, vegetables and salad.

Model 2 includes 81 foods, 19 nutrients and has the same objective function as model 1, so to maximize the intake of fruit, vegetables and salad. However, the upper bounds of encouraged nutrients are removed to see whether the model selects foods with higher amounts of nutrients and therefore higher NRF scores. Palatability constraints aren't adjusted and are the same as in the original model.

Model 3 includes 81 foods, 19 nutrients but has a different objective function to see whether there is a possibility that the LP diet model selects foods that have a higher NRF score. The objective function that is used is to maximize the intake of fiber. Palatability constraints and nutrient constraints are not adjusted and the same as in the original LP-diet model.

Model 4 includes 81 foods and 12 nutrients. The 12 nutrients of the nutrient rich foods index are used in the model to compare the two methods better. There are nutrients removed from the LP-diet model, but there are also new nutrients included in the model. Reference intake of the new nutrients are inserted in the nutrient constraint and palatability constraints are the same as in the original model.

Model 5 includes 81 foods and the same 12 nutrients as model 4. Upper bounds of encouraged nutrients are excluded to see whether the model now selects foods that have a higher NRF score.

The following foods are included in the 5 different models, the amount of food is indicated in grams. Foods that have the highest NRF score among their group are typed in bold.

Table 2

Food intake in grams in 5 different LP-diet models

Food	**Group**	NRF	1.	1.	2.	**3.**	4.
Bread wholemeal average	Bread	**0.26**	**149.68**	**-**	**245.00**	-	**105.00**
Bread brown		0.16	24.10	105.00	-	59.13	-
Bread white water based		0.07	-	-	-	180.50	-
Margarine 20-25% fat	Spread	**0.20**	**-**	**-**	**-**	**-**	**-**
Margarine 35% fat		0.16	-	-	21.00	-	-
Margarine 80% fat		-0.03	33.82	-	-	-	-
Margarine 60% fat		0.11	0.93	21.00	-	-	-
Butter unsalted		-0.27	-	-	-	24.97	-
Cheese 30+	Cheese	**0.35**		**48.47**	**3.04**	**10.05**	**41.78**
Cheese 48+ less salt		0.08	21.07	-	5.10	-	-
Processed meat products 20-30 gram fat	Meat product	**0.44**	**-**	**-**	**-**	**7.19**	**37.50**
Processed meat product < 10 gram fat		0.31	-	-	-	-	-
Processed meat products 10-20 gram fat		0	17.67	15.00	29.58	20.34	-
Peanut butter	Sweet and savory filling	**0.16**	**17.93**	**-**	**70.00**	**33.44**	**-**
Jam		-0.35	-	-	-	0.79	-
Beans white/brown	Starch components	**0.58**	**42.86**	**-**	**85.71**	**85.71**	**85.71**
Potatoes w/o skin boiled		0.51	-	-	-	-	128.57
Pasta wholemeal		0.39	128.57	115.51	128.57	85.71	85.71
Rice brown		0.21	-	-	85.71	-	-
Rice white		0.09	128.57	128.57	-	128.57	-
Vegetables mixture raw	Vegetables	**2.22**	**250.00**	**250.00**	**-**	**-**	**250.00**
Vegetables average boiled		1.99	191.20	400.00	246.63	329.22	400.00
Fish lean 0-2 gram fat	Protein components	**0.63**	**-**	**-**	**42.34**	**-**	**-**
Eggs chicken boiled average		0.47	29.46	-	31.60	-	-
Pork < 10% fat		0.50	47.66	28.96	-	3.93	300.00
Beef <10% fat		0.59	-	231.95		-	-
Fish medium 2-10 gram		0.51	0.38	-	-	56.23	-
Fish fat > 10 gram fat		0.18	14.27	14.55	11.19	-	-

Cooking fat liquid 97% fat	Fat components	**0.13**	**-**	**-**	**-**	**-**	**-**
Cooking fat solid 97% fat		0.04	-	-	-	-	-
Margarine liquid 80% fat		0.09	33.82	-	5	-	30.00
Olive oil		-0.06	30	30.00	-	30.00	-
Mayonnaise	Dressing	**0.01**	**25**	**-**	**-**	**-**	**13.61**
Salad dressing/sauce		-0.11	-	25.00	-	-	11.39
Yoghurt low fat	Dessert	**0.52**	**-**	**-**	**-**	**-**	**-**
Yoghurt full fat		0.25	150.00	150.00	150.00	150.00	150.00
Fruit fresh citrus average	Fruit	1.65	-	206.33	50.55	150.00	150.00
Fruit fresh excluding citrus		0.32	150	-	99.45	-	-
Nuts mixed unsalted	Snacks	**0.22**	**-**	**-**	**39.95**	**-**	**6.85**
Crisps potato average		0.12	-	99.91	-	26.83	86.29
Japanese rice cracker		0.02	100	-	-	-	-
Coffee prepared	Drinks	**3.39**	**109.18**	**-**	**-**	**-**	**654.65**
Tomato juice		**1.21**	**-**	**300.00**	**-**	**-**	**-**
Buttermilk		**0.29**	**-**	**-**	**-**	**-**	**327.32**
Water		**0**	**600.00**	**600.00**	**600.00**	**600.00**	**654.65**
Beer alcohol free		**-0.12**	**300.00**	**-**	**300.00**	**300.00**	**-**
Tea prepared		**0**	**490.82**	**600.00**	**600.00**	**600.00**	**-**
Average NRF9.3			**0.625**	**1.08**	**0.54**	**0.484**	**0.95**

Table 3
Nutrient intake in 5 different LP-diet models

Nutrient	Upper bound	Lower bound	22 foods	1.	2.	3.	4.	5.
Energy	11100	11100	11100	11100	11100	11100	11100	11100
Protein	0.1	0.2	0.13	0.13	0.22	0.17	0.1	0.25
Trans fat	0.25	0.4	0.4	0.38	0.4	0.4	-	-
SFA	0	0.1	0.08	0.1	0.1	0.08	0.1	0.1
MUFA	0.1	0.2	0.19	0.17	0.19	0.19	-	-
PUFA	0.03	0.1	0.1	0.09	0.08	0.09	-	-
Linol	0.02	0.09	0.09	0.08	0.06	0.09	-	-
EPADHA	450	3000	13.61	450	450	450	-	-
Cholesterol	0	200	90.68	200	200	200	-	-
MDSacch	0	0.075	0.15	0.075	0.075	0.075	0.075	0.075
Fiber	3	100	4.00	3	3.03	4.44	3	3.46
Calcium	500	800	800	800	1262	800	755.84	1523.9

Fe	9	23	15.06	12.80	19.23	15.60	10.95	17.60
K	3100	3500	4000	3100	5744.13	3280.63	3100	6670.89
VitB1	0.9	1.4	0.97	1.14	1.4	1.13	-	-
VitB2	1.1	1.7	1.36	1.1	1.66	1.15	-	-
VitB6	1	1.5	2.14	1.5	3.01	1.5	-	-
VitC	50	75	128.87	75	224.31	75	75	185.84
Folate	200	400	442.24	332.86	453.67	399.742	-	-
Vitamin A	600	900	-	-	-	-	900	2079.67
Vitamin E	6	10	-	-	-	-	10	23.27
Magnesium	270	350	-	-	-	-	350	545.21
Sodium	0	2400	-	-	-	-	2400	2400

5. Feasbility of the LP-diet model when foods with high NRF9.3 scores are included

In this chapter, research question 4 is answered: is the LP-diet model feasible when only foods with a high NRF scores are used? Foods are ranked into groups and the food with the highest NRF score among the group is selected and included in the LP-diet model. Afterwards, the model is runned to see whether the model is feasible or not.

5.1 How are the foods with the highest NRF9.3 selected?

To find out whether the LP-diet model selects the healthiest food according to nutrient profiling system, foods are separated into groups. The groups are based on the function of a food in a normal human diet and already set up in the LP-diet model by Gerdessen & de Vries (2015). A palatable human diet should – according to the diet model – contain at least one, but sometimes more foods of one food group. There is for example the food group bread which exists of multiple kinds of bread like whole meal, brown and white bread. A normal palatable human diet should contain at least one food of the foods in the bread group. Constraints for 14 different groups are used in the model. The following groups are used:

1. Bread
2. Spread
3. Cheese
4. Meat products
5. Sweet and savory filling
6. Starch components
7. Protein components
8. Fat components
9. Vegetables
10. Fruit

11. Dressing
12. Snacks
13. Drinks
14. Dessert

In the model of Gerdessen & De Vries (2015), there is also a group ‘pastries’ and ‘cookies and sweets’. However, there isn’t a palatability constraint for these groups in the reduced diet model. As a result of this, cookies, pastries and sweets aren’t selected by the LP-diet model. This is why these groups aren’t included in the research.

All the groups with the foods, constraints and NRF scores are listed below. The food with the highest NRF score among their group is typed in bold and the food or foods that are selected by the LP-diet model are typed in green.

Table 4

Food groups, foods and NRF9.3 scores

Bread	NRF9.3
Bread is filled with cheese, meat or sweet/savory. At least two types of filling should be used. 3-7 slices of 35 gram of bread.	
Bread brown wheat	0.16
Bread white water based	0.07
Bread wholemeal average	**0.26**
Spread	
3-7 gram spread should be used per slice.	
Low fat margarine, 20-25% fat, < 10 gr. Saturated	**0.2**
Low fat margarine, 40% fat, < 17 gr. Saturated	0.08
Low fat margarine, 35% fat, < 10 gr. Saturated	0.16
Margarine, 80% fat, > 24 gr. Saturated	-0.03
Margarine, 60% fat, < 17 gr. Saturated	0.11
	-0.27
Cheese	
Can be used as filling or at dinner. On bread, one cheese filling is 15-30 gram.	
Cheese Gouda 48+ average	0.09
Cheese 48+ less salt average	0.08
Cheese 30+ average	**0.35**
Meat product	
One meat filling is 10-25 gram	
Processed meat products < 10 gr fat	0.32
Processed meat products 10-20 gr fat	0
Processed meat products 20-30 gr fat	**0.44**
Processed meat products > 30 gr fat	0.06

Sweet and savory filling

one sweet/savory filling is 10-20 gram

Peanut butter	**0.16**
Sandwich spread original	0
Chocolate confetti average	-0.11
Jam	-0.35
Spead chocolate hazelnut	-0.04

Starch components

No more than 300 gram. Legumes should not be eaten more than twice a week. Potatoes, rice and pasta no more than 3 times a week. This means that at least 3 different starch components should be used in the model.

Potatoes without skin, boiled average	**0.51**
Potatoes fried	0.29
Pasta wholemeal boiled	0.39
pasta white average boiled	0.18
Rice brown broiled	**0.21**
Rice white boiled	0.09
Beans white/brown boiled	0.58

Vegetables

No more than 400 gram of cooked vegetables and no more than 250 gram of salad.

Vegetables average boiled	**1.99**
Vegetables mixture raw	**2.22**

Protein components

50-300 gram, nuts can be eaten as snack or as protein component. Eggs can be eaten with bread or as protein components

Eggs chicken boiled average	0.47
Beef < 10% fat prepared	0.59
Beef > 10% fat prepared	0.21
Pork < 10% fat prepared	0.5
Pork > 19% fat prepared	0.02
Pork 10-19% fat prepared	0.25
Fish lean 0-2 gr fat raw	**0.63**
Fish medium 2-10 gr fat raw	0.51
Fish fat > 10 gr fat raw	0.18
Nuts mixed unsalted	0.22

Fat components

50-30 gram

Cooking fat liquid, 97% fat, < 17 gr saturated	**0.13**
Cooking fat solid, 97% fat, > 17 gr saturated	0.04
Margarine liquid, 80% fat, < 17 gr saturated	0.09
Margarine liquid, 80% fat, < 17 gr saturated, salted	0.04
Olive oil	-0.06

Dressing	
10-30 gram per 100 gram salad	
Salad cream 25% oil	-0.06
Salad dressing/sauce, approximately 13% oil	-0.11
Mayonnaise	**0.01**
Mayonnaise low fat 40% oil	0
Dessert	
150-300 gram	
Yoghurt low fat with fruit	0.07
Yoghurt low fat	**0.52**
Yoghurt half fat	0.38
Yoghurt full fat	0.25
Custard several flavors full fat	-0.11
Fruit	
No more than 300 gram	
Fruit fresh average excluding citrus	0.32
Fruit fresh citrus average	**1.65**
Snacks	
25-100 gram	
Crisp potato average	0.12
Japanese rice cracker mix without peanuts	0.02
Snack sausage roll puff pastry	-0.09
Nuts mixed unsalted	**0.22**
Nuts mixed salted	0.21
Peanuts coated	0.03
Drinks	
1500-3000 gram, spread over categories	
Coffee prepared	**3.39**
Tea prepared	**0**
Juice apple	-0.32
Juice orange pasteurized	1.08
Tomato juice	**1.21**
Beer alcohol free	**-0.12**
Soft drink w/o caffeïne	**-0.49**
Water 50-100 mg calcium per litre	**0**
Milk skimmed	**0.44**
Milk whole	0.12
Buttermilk	0.49
Milk semi skimmed	0.29

From these results, it becomes clear that running the LP-diet model doesn't always recommend the same foods as the nutrient profiling system would recommend. In many groups, foods with a lower NRF9.3 score than other foods within their group are selected by the LP-diet model.

5.2 Is the model feasible with foods that have high NRF scores and why?

To find out whether the model is feasible when using the foods with high scores, the LP-diet model will be runned with only those foods. The foods that are typed in bold in the table above are included in the new reduced LP-diet model.

After including all these foods in the model and running it with the same objective function as before, it becomes clear that the model is infeasible. Since the groups are based on the palatability constraints that are included in the LP-diet model, they can't be a problem so nutrient intake must be problematic. When the constraint with reference intake of nutrients is deleted, the model indeed becomes feasible.

First of all, there is checked whether there is a single nutrient that makes the model infeasible. To do this the upper and lower bound for each single nutrient are inserted back in the model, while all the other reference intakes of nutrients are left out of the model. This means that the lower bounds are set on zero and upper bounds are set on a very high value so that they won't influence the result of the model. The following nutrients are included in the LP-diet model:

1. Energy
2. Protein
3. Trans fat
4. saturated fat
5. mono unsaturated fat
6. polyunsaturated fat
7. Linoleum
8. omega 3
9. Cholesterol
10. mono and disaccharides
11. fiber
12. Calcium
13. Iron
14. Potassium
15. vitaminB1
16. vitaminB3
17. vitaminB6
18. vitamin
19. folate

For each nutrient, the model is feasible, so there can be concluded that a combination of nutrients must be problematic instead of one single nutrient.

To find out which combination of nutrients are problematic for the model, nutrients are inserted back in the model one by one to see when the model becomes infeasible. When a reference intake makes the model infeasible, the upper bound will be set on a higher level so that the model is feasible again. Because there is very much interaction in a LP model, there are many combinations of nutrient upper bounds that can be set on a higher level to make the model feasible again. An example for such a combination can be found in table 3.

There can be concluded that a combination of the 21 foods isn't possible, but there is still the possibility that the foods with a high score can fit in a palatable human diet in combination with other foods. This is checked by looking whether the model is still feasible when from one group the food with the highest NRF score among their group is included, and from all the other groups all of the foods are included. For example, in the bread group, the food with the highest NRF score will be included – which is the whole meal bread – and for all the other groups, all foods are included. Because the model can compensate with other foods to get a healthy diet, it is feasible for every food.

Results above pointed out that foods with a lower NRF score are chosen in model 1 because of nutrient content. There are a couple of nutrients that have reach their upper or lower bound, which could be a reason for the LP-diet model to select foods with a lower NRF. To see whether this is indeed the case, nutrient content of food within groups are compared to each other. In table 2, information about nutrient intake in model 1 can be found. There are a couple of nutrients that have reached the upper bound or lower bound. The upper bounds are reached for saturated fat, cholesterol, mono- and disaccharides, calcium, vitaminB6 and vitamin C. For omega3 and potassium, the lower bounds are reached.

5.3 Reasons for selecting other foods

- In the bread group, wholemeal average has the highest NRF score. Bread brown wheat is chosen instead because it contains less vitamin B6 and less potassium.
- In the spread group low fat margarine, 20-25% fat, < 10 gram saturated has the highest NRF score. Margarine > 80% fat is chosen instead because it contains less mono- and disaccharides. However, the margarine contains a greater amount of saturated fat
- In the cheese group, 30+ average cheese has the highest NRF score. Cheese 48+ less salt is chosen instead because it contains less calcium, less vitamin B6 and a little less potassium.
- In the meat group, processed meat products 20-30 gram has the highest NRF score. Processed meat products 10-20 gram is chosen instead because it contains less mono- and disaccharides, less vitamin B6 and less potassium.
- In the starch components group, rice brown has a higher NRF score than white rice that is chosen instead. This is because it contains less vitamin B6, less calcium, less saturated fat and less potassium.

- In the fat components group, cooking fat liquid 97% fat > 17 gram saturated has the highest NRF score. Olive oil is chosen instead because it contains less cholesterol, less sugars, less calcium and less saturated fat.
- In the fruit group, fruit fresh citrus has the highest NRF score. Fruit fresh average excluding citrus is chosen instead because it contains less vitamin C.
- In the dessert group, yoghurt low fat has the highest NRF score. Yoghurt full fat is chosen instead because it contains less sugars, less calcium, less vitamin B6 and less potassium. However, yoghurt full fat contains more saturated fat.
- In the snacks group, the nuts unsalted had the highest NRF. Japanese rice crackers are chosen instead because they contain less saturated fat, less sugars, less potassium and less vitaminB6

5.4 What is the result of removing problematic upper bounds?

The model isn't feasible for foods that have the highest NRF score among their group because there are some nutrients that exceeded their upper or lower bound. Among the problematic nutrients, there were many positive. As upper bound, the model uses the intake that would be adequate for 97.5% of the population. It need therefore not immediately to be a problem if a solution contains more of a nutrient than the defined upper bounds. To check whether the LP-diet model indeed selects foods with a higher NRF score, upper boundaries of encouraged nutrients are removed. The upper bounds of folate, vitamin C, vitamin B6, vitamin B2, potassium, calcium, iron and protein are removed to see whether the LP-diet model selects foods with a higher NRF score. Foods that are selected after removing upper bounds can be find in table 2.

The average NRF of the foods, weighted by their amount in grams is now 1.08, which is much higher than the average NRF 0.63 of the original model where the upper bounds for the encouraged nutrients were still included. It makes sense that the NRF is higher because there is more space in the LP-diet model for foods that have high amounts of encouraged nutrients. Furthermore, for three groups there are better foods chosen according to nutrient profiling: drinks, fruit and cheese. For drinks, the tomato juice is chosen instead of alcohol free beer which has an NRF that is much more higher. Furthermore, the cheese 30+ average is chosen instead of the cheese 48+ and for fruit, the fruit including citrus is chosen instead of the fruit without the citrus. However, bread brown is still chosen instead of bread wholemeal average and rice white is still chosen instead of rice brown. This could be explained by the fact that the objective function is to maximize vegetables, fruit and salad and bread and rice don't contribute to that.

In this chapter, we've learned that the LP-diet model isn't feasible when foods with a high NRF score only are included in the model because of the nutrient constraints. Thus, when the 81 foods are included in the model, the model is forced to select foods with a lower NRF score to stay feasible. When upper boundaries of encouraged nutrients are removed, the model indeed selects foods that have a higher NRF score.

6. Consequences of including another objective function

In this chapter, research question 5 is answered: does the LP-diet model selects foods with a higher NRF score when another objective function is used?

Until now, the same objective function is used. After excluding nutrient boundaries it became clear that the model selects foods with a higher NRF score. However, the boundaries of nutrient intakes are set by experts and can't be removed that easily. To check whether the LP-diet model selects healthier foods with another objective function, the function max{fruit + vegetables + salad} is replaced by the function max{intake(fiber)}.

Foods that were result of running the LP-diet model can be found in table 2. There are 4 groups more compared to the original model where the food with the highest NRF score is selected. However, the average NRF, weighted by the amount of food in the diet has decreased to 0.54. This could be explained by the fact that the previous model tried to include as much fruits, vegetables and salad as possible in the diet. The NRF score of these three groups are very high, with the result that the average NRF of that model also was pretty high. Now, there are fewer vegetables, salads and fruit and as a result the average NRF decreases.

We've learned that the diet model can select foods with a higher NRF score among their group. However, the average NRF score could decline as a result of this.

7. Consequences of including the 12 nutrients of the nutrient profiling system

In this chapter, research question 6 is answered: Are foods with a higher NRF score selected when the 12 nutrients of the NRF are included in the LP-diet model?

7.1 Which foods are selected when the nutrients of the NRF are included?

Until now, the model is runned with the nutrients that were already in the model. It became clear that there wasn't enough omega-3 in the 22 foods with the highest NRF. This makes sense because this nutrient isn't included in the NRF score. The next experiment is to check whether foods with a higher NRF9.3 score are chosen when including the 12 nutrients of the nutrient profiling system and their upper and lower bounds. For sodium, there are two reference intakes. One is 1500 mg and the other is 2400 mg (De Vries, personal communication). When including the reference intake of 1500 mg, the model was infeasible so the second reference intake is used in the model.

The function is normalized, lower bound are set on 0 while upper bounds are set on 1 so that all the nutrients are weighted equally. The following objective function is used:

Maximize (Protein + Calcium + Iron + Vitamin C + Fiber + Potassium + Vitamin A + Vitamin E + Magnesium – Sodium – SFA – MDSacch)

Foods that are selected in the model can be found in table 2.

7.2 What are reasons for the LP-diet model to select the foods

Now, only for 5 groups, the food with the highest NRF9.3 was chosen which was a bit surprising. To see why this is the case, nutrient intake must be analyzed. It becomes clear that 8 of the 12 nutrients have reached their upper bound, which the reason was for the LP-diet model to select foods that have a lower NRF score.

- Bread brown wheat is chosen instead of the bread wholemeal average because it contains less magnesium
- Bread white water based is chosen instead of bread whole meal average because it contains less magnesium. However, the white water based bread contains less fiber.
- Rice white boiled is chosen instead of rice brown boiled because it contains less magnesium, less saturated fat. However, rice white boiled contains less fiber.
- Butter unsalted is chosen instead of low fat margarine, 20-25% fat because it contains less vitamin A, less vitamin E, less sodium. However, butter unsalted contains more saturated fat.
- Olive oil is chosen instead of cooking fat liquid, 97% > 17 gram saturated because it contains less vitamin A and less vitamin E.
- Fish medium fat is chosen instead of fish lean 0-2 gram fat because it contains less protein, less vitamin A, less vitamin C, less iron and less sodium.

- Fruit fresh average is chosen instead of fruit fresh citrus average because it contains less vitamin C, less vitamin A, less vitamin E and less sodium. However, it contains more added sugar and less fiber.
- Pork< 10 % fat is chosen instead of fish lean 0-2 gram fat because it contains less protein, less vitamin C, less iron, less magnesium and less sodium. However, it contains more vitamin C.
- Processed meat products 10-20 gram fat is chosen instead of the processed meat 20-30 gram because it contains less vitamin C, less vitamin A and less saturated fat. However, it contains more sodium.
- Yoghurt full fat is chosen instead of yoghurt low fat because it contains less magnesium, less added sugar and less sodium. However, it contains more saturated fat and more vitamin A.
- Crisps potato average are chosen instead of the nuts mixed unsalted because it contains less magnesium. However, it contains more vitamin C and more sodium.
- Jam is chosen instead of peanut butter because it contains more fiber, less vitamin E, less magnesium and less sodium. However, it contains less fiber and more added sugar.
- Vegetables average boiled are chosen instead of the vegetables mixture raw because it contains more fiber, less vitamin A, less vitamin C, less vitamin E, less magnesium, less added sugar and less saturated fat. However, it contains more sodium. Another reason for choosing the vegetables average instead of the vegetables mixture raw is that, when choosing the vegetables mixture, a salad dressing has to be added. All the salad dressings contain sugar and saturated fat.

7.3 What's the result of moving problematic upper bounds?

Again, the model didn't select the foods with the highest NRF9.3 score because of the boundaries of nutrient intake. To check whether the model indeed selects healthier foods, upper bound of encouraged nutrients are removed. Foods that are selected can be found in table 2.

Now, for 7 of the 14 groups, the foods with the highest NRF score are chosen. The foods that are chosen are healthier, but still, not every food with the highest NRF score is chosen. A reason for this could be that the NRF score is calculated with the help of the amount of kilocalories, while the model select foods by looking at the amount of nutrients in the whole diet. It could be, that the amount of nutrients within a product of 100 grams are low, but that the amount of nutrients per 100 kcal in the same products are much higher.

From this chapter we've learned the LP-diet model didn't select foods with a higher NRF score when the 12 nutrients of the NRF are included. However, when removing upper bounds the model did select foods with a high NRF score.

Group	Best foods	Foods selected with: **Max (Fruit + salad + vegetables)**	Foods selected with: **Max (fruit + salad + vegetables)** *No upper bounds for encouraged nutrients*	Foods selected with: **Max (fiber)**	Foods selected with: **Max ($\sum_{1-9} - \sum_{1-3}$)**	Foods selected with: **Max ($\sum_{1-9} - \sum_{1-3}$)** *No upper bounds for encouraged nutrients*
Bread	Bread wholemeal average	**Bread wholemeal average** Bread brown wheat	Bread brown wheat	**Bread wholemeal average**	Bread brown wheat Bread white water based	**Bread wholemeal average**
Spread	Low fat margarine, 20-25% fat, < 10 gram saturated	Margarine 80% fat, > 24 gram saturated Margarine 60% fat < 17 gram saturated	Margarine 80% fat, > 24 gram saturated Margarine 60% fat < 17 gram saturated	Low fat margarine, 35% fat < 10 gram saturated	Butter unsalted	Margarine product 60% fat
Cheese	Cheese 30+ average	Cheese 48+	**Cheese 30+ average**	**Cheese 30+ average** Cheese gouda 48+ average	**Cheese 30+ average**	**Cheese 30+ average**
Meat product	Processed meat products 20-30 gram fat	Processed meat 10-20 gram fat	Processed meat 10-20 gram fat	Processed meat products 10-20 gram fat	**Processed meat products 20-30 gram fat** Processed meat products 10-20 gram fat	**Processed meat products 20-30 gram fat**
Sweet and savory filling	Peanut butter	**Peanut butter**	-	**Peanut butter**	**Peanut butter**	**Peanut butter**

					Jam	
Starch components	Potatoes w/o skin boiled Beans white/brown boiled Pasta wholemeal boiled	**Pasta wholemeal boiled** **Beans white/brown boiled** Rice white boiled	**Pasta wholemeal boiled** Potatoes fried Rice white boiled	**Pasta wholemeal boiled** **Rice brown boiled** **Beans white/brown boiled**	**Pasta wholemeal boiled** **Beans white/brown boiled** Rice white boiled	**Beans white/brown** **Pasta wholemeal boiled** **Potatoes w/o skin boiled**
Vegetables	Vegetables mixture raw	**Vegetables mixture raw** Vegetables average boiled	**Vegetables mixture raw** Vegetables average boiled	Vegetables average boiled	Vegetables average boiled	**Vegetables mixture raw** Vegetables average boiled
Protein components	Fish lean 0-2 gram fat	Eggs chicken boiled Pork, < 10% fat prepared Fish medium 2-10 gram fat Fish fat > 10 gram fat	Pork < 10% fat prepared	**Fish lean 0-2 gram fat raw** Eggs chicken boiled average Fish fat > 10 gram fat raw	Fish medium fat Pork < 10% fat	Pork < 10% fat prepared
Fat components	Cooking fat liquid, 97% fat < 17 gram saturated	Olive oil	Olive oil	Margarine liquid, 80% fat, < 17 gram saturated	Olive oil	Margarine liquid 80% fat, <17 gram saturated
Dressing	Mayonnaise	**Mayonnaise**	**Mayonnaise** Salad dressing/sauce	-	-	**Mayonnaise** Salad dressing/sauce

Dessert	Yoghurt low fat	Yoghurt full fat	Yoghurt full fat	Yoghurt full fat	Yoghurt full fat	Yoghurt full fat
Fruit	Fruit fresh citrus average	Fruit fresh average excluding citrus	**Fruit fresh citrus average**	**Fruit fresh citrus average** Fruit fresh average excluding citrus	Fruit fresh average	**Fruit fresh citrus average**
Snacks	Nuts mixed unsalted	Japanese rice cracker mix w/o peanuts	Crisps potato average	**Nuts mixed unsalted**	Crisps potato average Japanese rice crackers	Crisps potato average
Drinks	Coffee prepared Tea prepared Tomato juice Beer alcohol free Water 50-100 mg calcium Buttermilk	**Coffee** **Tea** **Beer alcohol free** **Water** Milk skimmed	**Tea prepared** **Tomato juice** **Water**	**Coffee** **Tea** **Beer alcohol free** **Water 50-100 mg calcium**	**Tea prepared** **Beer alcohol free** **Water**	**Coffee** **Water** **Tea** **Buttermilk**
Average NRF9.3		**0.63**	**1.08**	**0.54**	**0.48**	**0.95**

Table 4
Selected foods

Conclusion

Research question one was about what nutrient profiling was en which foods the method would recommend. We have learned that nutrient profiling a quantitative system is that nutrient content of a single foods analyzes. Foods that have on average a very high NRF score are fruits and vegetables.

Research question two answered the question about what LP-diet modelling exactly is and which specific LP-diet model is used in the research. We've learned that LP-diet modelling a resource optimization problem is that is mathematically solved. The specific LP-diet model that is used in this research contains 81 foods and 19 nutrients with corresponding nutrient and palatability constraints.

Research question three answered the question about which NRF9.3 scores all the 81 foods in the LP-diet model have. The NRF scores are calculated with a formula that sums the percentages of daily values of the 9 nutrients to encourage, and subtracts the sum of the percentage of the daily values of the 3 nutrients that must be limited. Scores are capped at 100% and fluctuate from a high score of 3.3 for coffee till a score of -0.49 for soft drinks.

Research question four checked whether the LP-diet model feasible was when foods with the highest NRF9.3 score among their group. After including the 22 foods with the highest NRF9.3 score, the model became infeasible. Reference values of nutrient intake were problematic. There are different reference intake of nutrients that were exceeded, which was a reason for the model with 81 foods to select foods with a lower NRF9.3 score. To see whether this was really the case, upper bounds of encouraged nutrients are removed, after which the model indeed selected foods with a higher NRF9.3 score.

Research question five answered the question whether foods with a higher NRF9.3 score are selected by the LP-diet model when another objective function is used. The objective function of maximizing the amount of fruit, vegetables and salad is replaced by an objective function that maximizes the intake of fiber. The model selected now for more groups the food with the highest NRF9.3 score. However, the average NRF score, weighted by the amount of food in the diet decreased. This could be explained by the fact that the previous objective function was to maximize fruit, vegetables and salad, who all have a very high NRF score.

Research question six answers the question whether the LP-diet model selects foods with a higher NRF score when the 12 nutrients of the nutrient profiling system are included. After including reference intakes of all the 12 nutrients, the model selected for only 5 groups the food with the highest NRF score and average NRF has decreased till 0.48. For many encouraged nutrients, upper bounds are reached which is a reason for the model to select foods with a lower NRF score. To check whether this is really the case, upper bounds for encouraged nutrients are removed. After running the model, average NRF increased till 0.95 and for 9 groups, the food with the highest NRF is selected. Still, not for every group the food with the highest NRF9.3 is chosen. Reason for this could be that the LP-diet model analyzes the nutrient content of foods per 100 mg while the nutrient profiling system analyzes nutrient content per 100 kcal.

The goal of this research was to determine differences in outcomes between nutrient profiling and linear programming diet modelling. Despite the fact that both techniques are aiming to select the most healthy foods for a diet, the LP-diet model and the nutrient profiling system often recommend different foods. An explanation for the differences between both methods is that the LP-diet model composes a whole diet, while only one food is examined in the nutrient profiling system. Thus, the LP-diet model has to take many other factors in consideration.

The reason that the LP-diet modelling and nutrient profiling don't recommend the same foods in many cases is because of nutrient intake. The LP-diet model couldn't select the foods with the highest NRF score because of the following reference intake of nutrients: cholesterol, mono- and disaccharides, calcium, vitaminB6, vitamin C and potassium. Furthermore, there isn't enough EPADHA in the foods with a high score, which also makes sense since this nutrient isn't included in the NRF score. There can be concluded that the foods with the highest NRF together can't meet the nutritional requirements according the LP-diet model.

All together, there can be stated that the LP-diet model is strict in the upper and lower bounds of nutrient intake, with the result that the LP-diet model had to select foods that had a lower NRF. When removing and adapting upper and lower bounds, foods with higher NRF scores are chosen. However, the nutrient profiling system only analyzes 12 nutrients in foods and is a method that is simplified. The LP-diet model includes many more nutrients.

Discussion

Conclusions of this thesis are based on small adjustments of the diet model. When exactly the same research will be carried out again, the same results will be obtained. There can be concluded that the LP-diet model is a reliable instrument. However, not all NRF scores were completely reliable. There was missing information about vitamin A and magnesium for the fish medium fat, which resulted in an unreliable NRF score. Also for mayonnaise, not all the information about the nutrient content was available. It could be that in the groups of these two foods, the food with the highest NRF score is wrongly chosen. Furthermore, the nutrient profiling system includes added sugar as a limited nutrient. Because there wasn't available information about the amount of added sugar in a products, the total amount of sugar is used instead. This could result in a lower NRF score in some foods.

The results of this thesis didn't fully match my expectations. Because both methods are proven to be effective, expectation was that they would recommend the same foods. This wasn't the case due to the limitations of the nutrient intake. Further research need to be done whether exceeding upper bounds for the encouraged nutrients that were exceeded is obstructive for a healthy diet.

It must be highlighted that the two methods that were compared in this research weren't completely equal. While nutrient profiling focused on one food, the LP-diet model analyzed a whole diet. Nutrient profiling could be a way of validating the LP-diet model so it could be a part of the LP-model. It therefore doesn't have to be a problem that the outcomes of the LP-diet model and the nutrient profiling system are different.

There are many adjustments and experiments that can be executed with the LP-diet model. Because of limited time, a selection had to be made. Another experiment that could be done is to include nutrient content per 100kcal in the LP-diet model. This is because the LP-diet model analyzes nutrient content in the whole diet while the nutrient profiling system analyzed the nutrient content per 100 kcal. The two methods are therefore not completely comparable.

Furthermore, there could be questioned whether all the palatability constraints were right. Palatability constraints are set up to make a normal human diet. The palatability constraints forced the model to include at least 3 slices of bread, but there is a possibility that a healthy diet doesn't include any slices of bread.

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