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Designing optimal breakfast for the United States using linear programming and the NHANES 2011-2014 database. A Study from the International Breakfast Research Initiative (IBRI)

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Abstract: The quality of dietary patterns can be optimized using a mathematical technique known as linear programming (LP). LP methods have rarely been applied to individual meals. The present LP models optimized the breakfast meal for those participants in the nationally representative National Health and Nutrition Examination Survey 2011-2014 who ate breakfast (n=11,565). The Nutrient Rich Food Index (NRF9.3) was a measure of diet quality. Breakfasts in the bottom tertile of NRF9.3 scores (T1) were LP-modeled to meet nutrient requirements without deviating too much from current eating habits. Separate LP models were run for children and for adults. The LP-modeled breakfasts resembled the existing ones in the top tertile of NRF9.3 scores (T3), but were more nutrient-rich. Favoring fruit, cereals, and dairy, the LP-modeled breakfasts had less meat, added sugars and fats but more whole fruit and 100% juices, more whole grains, and more milk and yogurt. LP modeling methods can build on existing dietary patterns to construct food-based dietary guidelines and identify individual meals and/or snacks that need improvement.

Keywords: Breakfast, linear programming, NHANES, NRF9.3, nutrient density, food groups, nutrients, optimization.)

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1. Introduction

Breakfast consumers in the US and globally exhibit a variety of eating patterns.[1,2] Analyses of the National Health and Nutrition Surveys (NHANES) in the US suggest that those patterns typically include grain products, consumed either alone, or with fruit juice, milk, whole fruit, sweets, meat and eggs, and coffee or tea.[3,4] Given that breakfast continues to be thought of as the most important meal of the day,[5,6] identifying optimal food patterns at breakfast continues to be a topic of research interest.[1,2]

The International Breakfast Research Initiative recently examined the food and nutrient composition of breakfasts eaten in Canada,[7] Denmark,[8] France,[9] Spain,[10] United Kingdom,[11] and the United States.[12] Nationally representative dietary intake databases were used. Breakfasts associated with highest-quality diets were characterized as to their food and nutrient content. The summary paper made recommendations for a "global" healthy breakfast, based on multi-country findings.[13,14] Those were empirical dietary recommendations based on observed dietary intakes for each population.

The quality of daily diets can also be optimized using a mathematical technique known as linear programming (LP).[15-17] LP methods strive to find the optimal combination of daily foods for a given population subject to a variety of constraints.[18] For example, the US Department of Agriculture Thrifty Food Plan (TFP), a variant of an LP model, was developed to identify the lowest-cost nutritionally adequate diet, while respecting existing eating habits.[19,20] Given adequate dietary data, nutritionally optimal diets can also be constructed for populations, population subgroups, or even for individual respondents.[16] Typically, the optimized diets need to meet energy and nutrient requirements at low cost, while minimizing deviation from existing diets.[17]

Thus far, LP models have been applied to dietary patterns at the population or at the individual level.[15,21] There are few examples where LP methods were applied to individual meals. In a novel application, we used LP to optimize breakfast meals associated with low-quality diets in the 2011-2014 NHANES database. The question was whether the LP-modeled breakfasts would resemble existing ones in the top tertile (T3) of diet quality, or would they follow an altogether different path? In general, dietary guidance that is based on existing eating habits is more feasible and easier to implement than is dietary guidance that breaks entirely with habit, tradition, and culture.[22,23]

2. Materials and Methods

2.1 Study population & dietary data

Analyses were based on the first day of dietary intakes in the 2011-2012 and 2013-2014 cycles of the nationally representative National Health and Nutrition Examination Survey (NHANES).[24,25] The first 24-hour recall in the NHANES was completed in-person at the Mobile Examination Center with a trained interview. The 24-hour recall queries all foods/beverages consumed by participants from midnight-to-midnight on the previous day.[26,27] Dietary supplements were excluded. Breakfast was defined as the self-reported "breakfast/desayuno" and brunch. An energy threshold of 50 kcal was imposed. Breakfast skippers were defined as having no breakfast or an eating episode of <50 kcal.

Data were available for 14,488 children, adolescents and adults aged ≥6y. The sample included 4,057 children (ages 6-17y) and 10,431 adults (ages >18y). Of those, 11,565 persons were previously identified as breakfast consumers. The present analytical sample was therefore based on 3,296 children and 8,269 adults.

The population sample was stratified by 2 age groups (6-17y, >18y) and six race/ethnicity groups (non-Hispanic white, non-Hispanic black, Mexican-American, other Hispanic, Asian, and other/mixed race). Education was defined as: <High School (<12y), High School (12y); Some college (12-16y) and >College (>16y). Income to poverty ratio (IPR) cut-points were set at : <1.3; 1.3-1.849; 1.85-2.99; >3.

2.2 Food categories and food groups

Food categories and food groups were derived from the WWEIA What We Eat in America food items after exclusion of 'alcoholic beverages', 'baby beverages', 'no category', 'other', 'baby food', 'baby beverages', 'infant formula', 'condiments and sauces' and 'water' (the number of food category used in the analysis is 31).[28]

2.3 Measures of dietary quality

Energy and nutrient intakes for NHANES participants were calculated using the Food and Nutrient Database for Dietary Studies FNDDS 2011-2014, customized with the addition of vitamin D and added sugar data.[29] This information was supplemented with data from the Food Patterns Equivalents Database (FPED) from the United States Department of Agriculture (USDA).[30]

The Nutrient Rich Foods (NRF9.3) index, was the principal measure of diet quality.[1,12] The NRF9.3d is based on 9 qualifying and 3 disqualifying nutrients. Reference daily values (DVs) were based on the US Food and Drug Administration (FDA) and other standards.[12,31] The qualifying nutrients and standard reference amounts were as follows: protein (50g), fiber (28g), vitamin A (900 RAE), vitamin C (90 mg), vitamin D (20 mcg), calcium (1300 mg), iron (18 mg), potassium (4,700 mg) and magnesium (420 mg). The 3 disqualifying nutrients and maximum recommended values (MRVs) were: added sugar (50g), saturated fat (20g) and sodium (2,300 mg). The NRF9.3 was calculated as follows

NRF 9.3= (NR-LIM) × 100

with

$$NR = \sum_{i=1}^{9} \frac{{Intake_i}/{Energy} \times 2000}{DV_i} \quad (1)$$

and

$$LIM = \sum_{i=1}^{3} \frac{{Intake_i}/{Energy} \times 2000}{MRV_i} - 1 \quad (2)$$

where $intake_i$ is the daily intake of each nutrient i, and DVi is the reference daily value for that nutrient, In NR calculation, each daily nutrient intake i adjusted for 2000 kcal and expressed in percentage of DV. Following past protocol, percent DVs for nutrients were truncated at 100, so that an excessively high intake of one nutrient could not compensate for the dietary inadequacy of another. In LIM, only the share in excess of the recommended amount was considered

In the present adaptation, vitamin D, a nutrient of public health concern,[32,33] replaced vitamin E. Fiber, vitamin D, calcium, magnesium, and potassium were all identified in the 2010 Dietary Guidelines for Americans as nutrients of concern.[32] The NRF score was adjusted for energy intakes, analogous with the recent versions of the USDA Healthy Eating Index.[34] Age-specific tertiles of NRF9.3 served to stratify children and adults by overall diet quality (T1 T2, T3).

2.4 Linear programming applied to T1 breakfast

Separate LP analyses were run for children and adults. The LP model was used to derive optimized breakfasts for children and adults in the bottom tertile (T1) of diet quality, as indexed by NRF9.3 scores. Table 3 shows that the LP-modeled breakfasts met nutrient recommendations established by the International Breakfast Research Initiative (IBRI) group. The %DVs were taken from "Food Labeling: Revision of the Nutrition and Supplement Facts Labels".[35] For nutrients expressed in percentage of energy, the recommendations derived by the IBRI were used.

To ensure that the LP-optimized breakfasts remained as close as possible to the observed breakfast food patterns, two mathematical functions were applied. The more often used relative function favors the selection by the LP model of foods that are already eaten in reasonable quantities. In other words, the relative function avoids incorporating in the LP model those foods that are eaten rarely or not at all.

"Absolute function": $\min D = \sum_{i=1}^{31} abs(optimized\ quantity^i - Observed\ quantity^i)$ (3)

$$\text{"Relative function": } \min D = \sum_{i=1}^{31} \frac{abs(optimized\ quantity^{i} - Observed\ quantity^{i})}{Observed\ quantity^{i}} \quad (4)$$

Where i is each individual food item.

Compared to the absolute function, the relative function is more likely to modify those foods that are already consumed in large quantities (or to excess). For example, an individual can obtain 480 mg of calcium from 1 serving of milk (250 g) and one serving of cheese (30g). In order to obtain 510 mg calcium (breakfast target), the relative function will increase the amount of milk to 275g (+10%) and not change the amount of cheese (0.1 is a smaller value than increase cheese by 17%). The absolute one will increase by 5g the quantity of cheese (5g is a smaller value than 25g of milk). Optimized breakfasts were derived by using those 2 functions.

2.5 Analytical approach

All analyses were conducted using SAS software, Version 9.4 and are representative of the US population (SAS Institute Inc. Cary, NC, USA). Differences in NRF scores between socio-demographics groups were tested using linear regression.

2.6 Data availability and ethical approval

The necessary IRB approval for NHANES had been obtained by the National Center for Health Statistics (NCHS).[25] For adult participants, written informed consent was obtained directly from the participating adult. For child participants, parental/guardian written informed consent was obtained and children/adolescents ≥ 12y provided additional written consent. All data used here are publicly available on the NCHS and USDA websites.[24,36] Publicly available data, such as those used here per University of Washington policies, do not involve “human subjects” and their use requires neither IRB review nor an exempt determination. According to University of Washington policies, these data may be used without any involvement of the Human Subjects Division or the University of Washington Institutional Review Board.

3. Results

Table 1 shows mean NRF9.3 scores for total diets of breakfast consumers by gender, age group, and socio-demographics. Gender effects depended on age; whereas no gender differences were observed for children (<18 years old), adult women had more nutrient-dense diets than did men. The most nutrient-dense diets were consumed by Asians. Non-Hispanic Blacks had lowest quality diets at every age. Diet quality of adults greatly improved with education and with household incomes. An income gradient for children was not observed. For adults, differences in NRF scores by education and incomes were greater than those observed by race/ethnicity.

Also shown are NRF scores for breakfast consumers in the bottom tertile (T1).

Table 1. Mean (standard error) dietary nutrient density NRF 9.3 scores for breakfast consumers by age and socio-demographics. NHANES 2011-2014, United States.

	All breakfast consumers			**T1 breakfast consumers**		
	All (11,565)	**Children (3,296)**	**Adults (8,269)**	**T1 N=4,020**	**Children (1,144)**	**Adults (2,876)**
Total		433.34 (4.90)	444.00 (4.72)		257.80 (5.34)	254.75 (2.01)
Gender						
Male	5,663	437.14(5.18)	426.02(4.99)	2,084	264.14 (8.09)	253.12 (3.23)
Female	5,902	429.33(7.06)	460.47(5.6)	1,936	251.40 (7.27)	256.69 (3.33)
		0.3057	<0.0001		0.2642	0.4977
Race/ethnicity						
Non-Hispanic White	4,346	419.04(9.94)	448.84(6.32)	1,586	248.92 (7.84)	254.36 (2.71)
Non-Hispanic Black	2,664	413.2(6.45)	390.32(5.94)	1,161	268.86 (7.29)	248.87 (5.01)
Mexican American	1,647	475.2(7.66)	444.35(7.13)	472	273.36 (5.90)	258.15 (4.58)
Asian	1,303	487.78(15.42)	494.84(6.09)	286	266.35 (12.93)	280.37 (7.15)
Other Hispanic	1,164	449.84(14.98)	450.69(6.59)	357	263.15 (9.90)	268.69 (8.41)
Other	441	431.37(17.84)	418.97(20.58)	158	283.22 (13.18)	223.80 (21.72)
		<0.0001	<0.0001		0.0395	0.0051
Family IPR[1]						
<1.3	3,912	433.43(7.32)	403.39(6.32)	1,558	259.31 (8.86)	225.59 (5.37)
1.3-1.849	1,310	440.97(14.37)	426.8(8.91)	478	255.79 (12.93)	253.34 (7.99)
1.85-2.99	1,683	410.48(12.55)	430.64(8.13)	607	261.32 (10.89)	253.09 (6.34)
≥3.0	3,835	439.37(10.33)	471.28(5.74)	1,124	255.90 (6.52)	277.76 (3.79)
		0.1950	<0.0001		0.9600	<0.0001
Education[2]						
<HS	1,625		414.25(5.45)	596		231.35 (5.80)
High school	1,707		404.21(7.99)	757		241.63 (4.35)
Some college	2,362		436.24(6.83)	864		256.19 (3.88)
≥College graduate	2,181		495.28(6.93)	476		291.48 (4.73)
			<0.0001			<0.0001

[1]IPR stands for Income to poverty ratio [2]Missing values were removed from the analysis

3.1 Comparing existing and LP modeled breakfasts

Figure 1 shows differences in the composition of breakfasts in the bottom (T1), middle (T2) and the top (T3) tertile of NRF9.3 scores. The data are shown separately for breakfast-consuming children and adults. There were a number of progressive changes in breakfast composition on going from T1 to T3 of diet quality. First, the consumption of milk and yogurt increased, cheese dropped slightly. Meat and eggs were sharply reduced. The consumption of soy, nuts and seeds was substantially higher for adults. Refined grains showed a very sharp drop, whereas the amounts of whole grains doubled and tripled. The breakfast consumption of citrus fruit, fruit juice, and other fruits was sharply increased.

Figure 1. The composition of breakfasts associated with bottom (T1), middle (T2), and top (T3) tertiles of dietary nutrient density NRF9.3 scores. Data are presented separately for breakfast consuming children (left) and for adults (right). NHANES 2011-2014 United States. Y axis shows MyPyramid units (cup eq and or oz.eq)

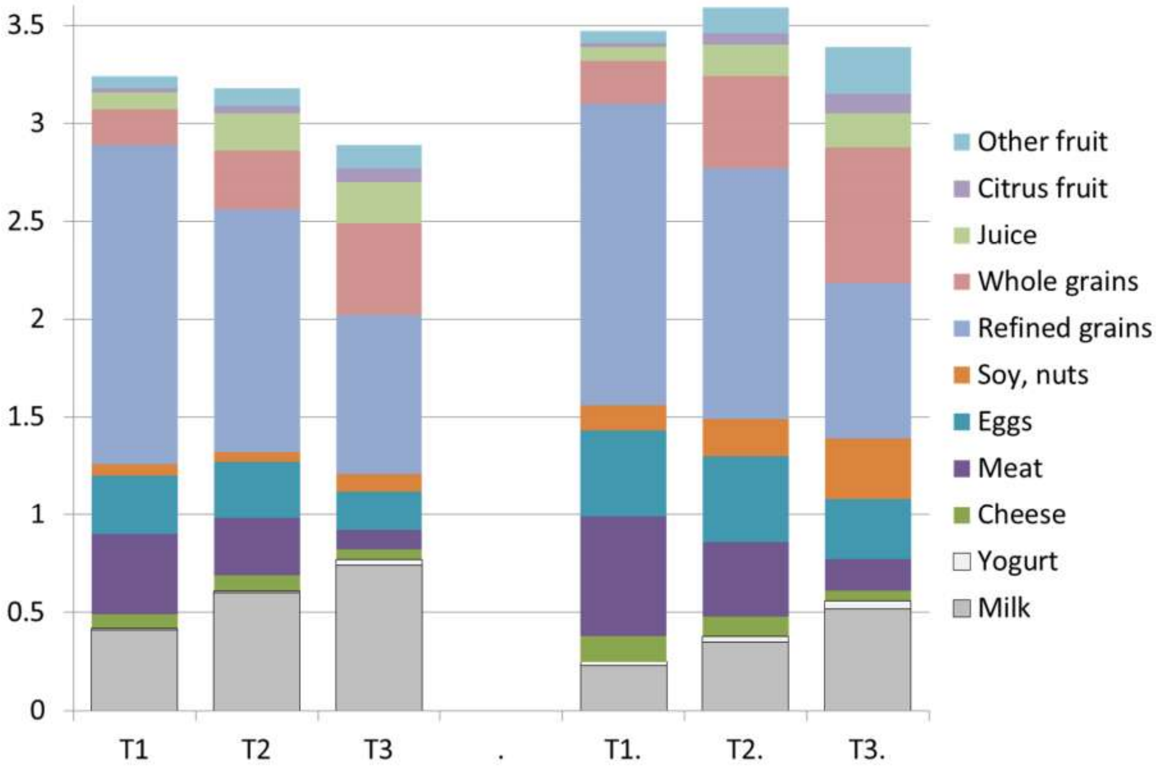

Figure 2 shows differences in the composition of existing T1 breakfasts and LP-modeled breakfasts, separately for children and for adults. Two models were used LP-R and LP-A. First, the modeled amounts of fluid milk were much higher than those observed, especially for the LP-A model. Yogurt was increased slightly, but cheese dropped. Meat and eggs were very sharply reduced by both models.

The modeled breakfast amounts of soy, nuts and seeds was largely unchanged from T1 in model LP-R but was greatly increased in model LP-A. Refined grains showed a very sharp drop in both models, whereas the amounts of whole grains were much higher. The modeled amounts of citrus fruit and other fruits sharply increased in both models. The amounts of fruit juice were unchanged in both models.

Figure 2. A comparison of breakfasts associated with bottom (T1) tertile of dietary nutrient density NRF9.3 scores and breakfast patterns created by LP models.. Data are presented separately for children (left) and for adults (right). NHANES 2011-2014 United States. Y axis shows MyPyramid units (cup eq and or oz.eq)

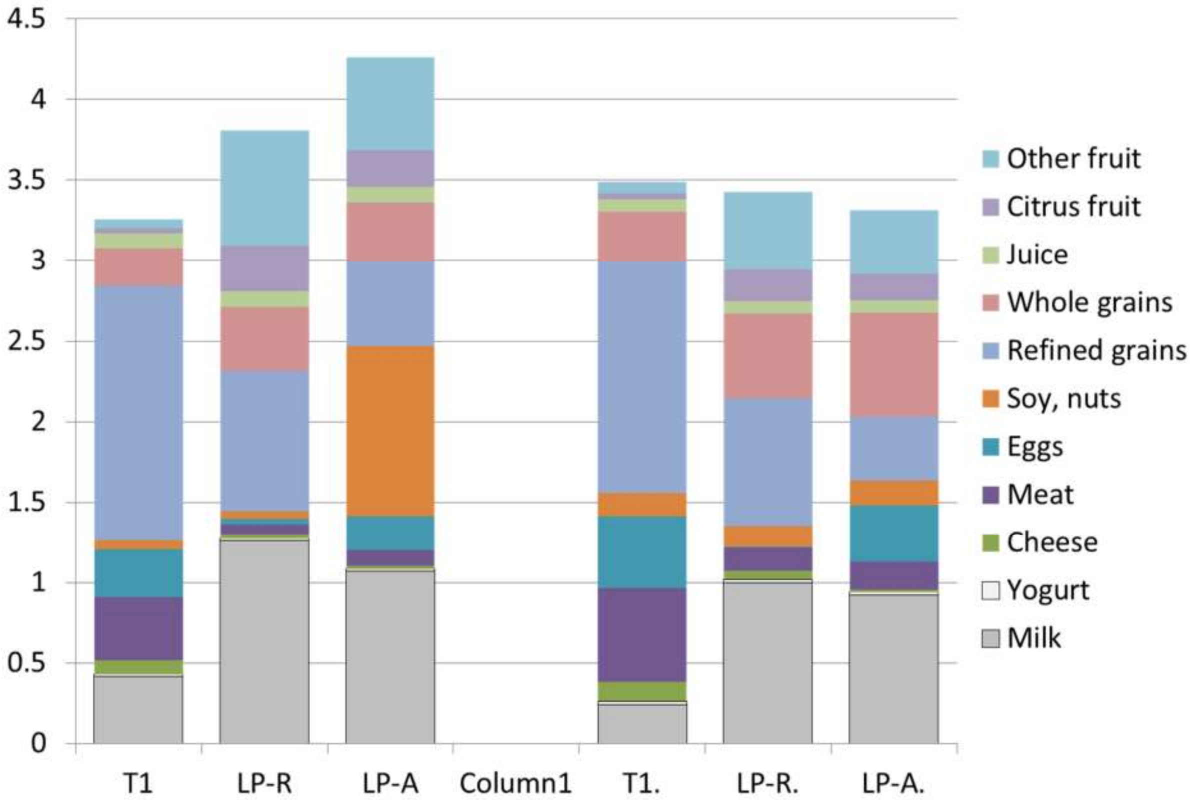

Table 2 shows which specific breakfast foods were increased or reduced by the LP optimization model – or eliminated altogether. For children, the amounts of milk, whole fruit, and RTEC cereals were sharply increased. Sweet bakery goods, mixed dishes, processed breakfast meats and eggs dropped to zero. Quick breads were reduced. No other major changes were observed. For adults, the amounts of milk, whole fruit, and RTEC cereals were sharply increased. Sweet bakery goods, processed breakfast meats, mixed dishes, quick breads and eggs dropped to zero. No other major changes were observed.

Table 2. Comparisons in food composition of T1 breakfasts and the two LP models. Consumption measured in g/day Data are presented separately for children and adults. NHANES 2011-14 United States.

What We Eat in America	Category	Children	Optimized		Adults	Optimized	
		T1	Relative	Absolute	T1	Relative	Absolute
Beverages	Coffee & Tea	24.3	24.3	24.3	231.4	231.4	231.4
	Diet Beverages	2.6	2.6	2.6	12.4	12.4	12.4
	Sweetened Beverages	55.9	55.9	55.9	75.5	75.5	75.5
Fats & Oils	Fats & Oils	1.7	1.7	0	9.1	9.1	9.1
Fruit	Fruit	8.9	145.7	116.2	9.3	92.1	77.1

	100% Juice	19.5	19.5	19.5	15.8	15.8	15.8
Grains	Breads	7.3	7.3	7.3	16.2	16.2	0
	Cooked grains	6.9	6.9	6.9	8.4	8.4	8.4
	Grains	0.9	0.9	0.9	1.3	1.3	1.3
	Quick Breads	20.0	13.7	0	11.6	0	0
	High Sugar RTE Cereal	6.4	24.2	6.4	3.3	22.9	3.3
	Low Sugar RTE Cereal	0.8	0.8	11.2	1.7	1.7	27.9
Milk & Dairy	Cheese	0.8	0.8	0	2.2	2.2	0
	Flavored Milk	9.7	9.7	9.7	4.5	4.5	4.5
	Milk	75.1	288.0	243.6	32.8	227.6	203.6
	Milk Dessert Drinks	0.8	0.8	0.8	0.6	0.6	0.6
	Yogurt	2.7	2.7	2.7	4.5	4.5	4.5
Mixed Dishes	Mixed Dishes	26.8	0	3.6	33.7	0	0
Protein Foods	Eggs	12.9	0	12.9	21.7	0	21.7
	Nuts, Beans & Soy	0.5	0.5	25.0	1.8	1.8	1.8
	Processed Meat	6.4	0	0	9.1	0	0
	Seafood/Meat	2.2	2.2	2.2	4.9	4.9	4.9
Snacks & Sweets	Candy	0.6	0.6	0.6	0.3	0.3	0.3
	Crackers	0.5	0.5	0	0.4	0.4	0
	Other Desserts	0.3	0.3	0.3	1.0	1.0	1.0
	Savory Snacks	0.9	0.9	0.9	0.7	0.7	0.7
	Snack/Meal Bars	0.4	0.4	0.4	1.0	1.0	1.0
	Sweet Bakery	20.6	2.9	0.6	12.8	2.5	2.9
Sugars	Sugars	7.5	7.5	7.5	8.6	8.6	8.6
Vegetables	Vegetables, Non-potato	0.4	0.4	0.4	2.2	2.2	2.2
	White Potatoes	1.7	1.7	1.7	8.7	8.7	8.7

Table 3 shows nutrient composition of existing and LP-optimized breakfasts. For adults, the most difficult nutrient recommendation to fulfill were those for fiber, vitamin D, and sodium. As shown in Table 3, for those nutrients the LP-modeled content was strictly equal to the recommendation. For children, the limiting breakfast nutrients were fiber, potassium, magnesium and sodium. Both models were limited by energy.

Table 3. Mean intake of nutrients at breakfast at T1 of NRF 9.3 score and for optimized diets (absolute and relative model)

	Children			Adults			
	T1	LP-R	LP-A	T1	LP-R	LP-A	Guidelines
Energy (kcal)	440.9	500.0	500.0	480.7	500.0	489.1	[300,500]
Added sugar (g)	4.7	5.1	3.6	4.9	5.4	4.7	
Carbohydrates (g)	60.7	88.0	73.6	61.3	84.5	77.3	
PUFA (g)	3.3	1.9	3.7	4.2	2.4	2.9	
MUFA (g)	5.8	3.4	6.3	7.1	4.0	4.9	
Saturated Fat (g)	6.1	5.1	5.6	6.5	5.2	5.4	
Proteins (%)	12.4	12.8	15.0	13.9	13.1	14.2	
Carbohydrates (%E)	55.1	70.4	58.9	51.0	67.6	63.2	[55,75]
Added sugars (%E)	4.3	4.1	2.9	4.1	4.3	3.8	<10
Total_Fat (%E)	33.7	20.4	30.0	36.3	22.8	26.5	[20,30]
SFA (%E)	12.4	9.2	10.0	12.3	9.3	10.0	<10
Proteins (g)	13.7	16.0	18.7	16.7	16.4	17.4	>10
Dietary Fiber (g)	2.6	5.6	6.1	3.1	5.6	5.8	>5.6
Sodium (mg)	630.9	460.0	460.0	742.7	460.0	460.0	<460
Vitamin a (g)	195.3	373.9	284.9	186.1	316.9	360.3	>90
Thiamin (mg)	0.4	0.7	0.5	0.4	0.6	0.6	[>0.3,>0.2]
Riboflavin (mg)	0.6	1.1	0.9	0.7	1.1	1.2	[>0.5, >0.4]
Niacin (mg)	5.0	7.5	6.5	5.8	7.6	7.9	>4
Vitamin B6 (mg)	0.5	1.0	0.8	0.5	1.0	1.1	>0.3
Vitamin B12 (g)	1.5	3.2	2.4	1.4	3.0	3.3	[>0.6, >0.5]
Vitamin C (mg)	15.4	43.9	35.7	16.9	32.9	32.7	>18
Vitamin D (μg)	1.9	4.8	4.0	1.6	4.0	4.0	>4
Folate (g)	103.5	191.4	184.7	100.7	187.6	230.9	>80
Calcium (mg)	250.9	489.5	421.2	223.7	423.8	390.3	[>390,>325]
Iron (mg)	4.2	6.2	6.3	4.0	5.7	9.6	>3.6
Potassium (mg)	434.4	940.0	940.0	578.9	966.2	940.0	>940
Magnesium (mg)	45.7	84.0	98.6	61.9	96.1	95.7	>84
Zinc (mg)	2.2	4.2	3.8	2.4	3.8	4.7	>2.2

Purple values show nutrients in observed T1 breakfast that do not meet guidelines;

4. Discussion

The present goal was to take breakfasts associated with T1 diets and optimize them using LP. The question was whether the optimized breakfasts would resemble the observed breakfasts in T3 of diet quality already selected and consumed by US NHANES respondents. Dietary interventions are easier when they build on existing dietary patterns and eating habits.

The Nutrient Rich Foods Index, adapted for use with total diets (NRF9.3d) was the measure of diet quality. As expected, breakfasts associated with T3 of NRF9.3 were associated with higher intakes of some key nutrients, including those that were in the model and those that were not. T3 breakfasts had more food groups of interest, notably fruit, dairy and whole grains.

However, there was room for additional improvement in breakfast quality. For children, the typical observed breakfast foods were milk, baked goods and sweets, with whole grain RTEC and whole fruit further down on the list. Adult breakfast foods included coffee/tea, sweets, fats and white bread. Some of these observed changes were accurately tracked by the LP optimization model; others were not. First, the modeled patterns contained much greater amounts of citrus and other fruits (a several fold increase) and same amounts of 100% juice. Breakfast whole grains almost doubled whereas refined grains dropped by half. Meat, poultry and fish were substantially reduced, as were eggs. Soy, nuts and legumes showed substantial increases. Milk tripled, yogurt was held constant and the amount of cheese was reduced. In the main the observed and the modeled patterns stressed fruit, milk and whole grains.

Optimized patterns were characterized by higher intakes of citrus fruit, whole fruit and juice, soy, nuts, and legumes. Among children, those breakfast patterns were characterized by higher intakes of whole grain cereals, more milk and yogurt and lower intakes of animal protein, less meat, eggs, and saturated fats.

LP-A models in children increased the amounts of nuts and seeds strongly because of their high content in potassium, magnesium and fiber which are nutrients that are far from being reached in observed T1 breakfast. LP-R result display another way to reach nutrient recommendation by prioritizing foods already consumed. By providing results using different mathematical functions, our study defends the possibility to propose different orientations that can be make in order to improve the nutritional quality of breakfast.

The limitations of this study are worth noting. First, data analyses were based on the first day of the 2-day NHANES survey. By contrast, national dietary surveys in France are based on 7-day diaries, whereas the UK data are based on 4 days. Further, breakfast was defined by self-report as opposed to by time of day. Third, the food groups of interest were based on MyPlate food categories. Fourth, no statistical analysis comparing observed and optimized diet was possible because LP was applied to average observed diet. Developing the approach by applying LP to each individual would allow to analysis food quantities modification individual by individual and run statistical analysis making results more robust.

5. Conclusions

The present analyses showed that the American breakfast can do with improvement. LP modeling can build on existing eating patterns to identify areas for potential intervention.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Figure S1: title, Table S1: title, Video S1: title.

Author Contributions: FV and MM conceptualized and designed the study. CR developed the databases. FV carried out the LP and statistical analyses and produced summary tables. All authors reviewed and revised the manuscript, and approved the final manuscript as submitted. AD drafted the initial manuscript, and approved the final manuscript as submitted.

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References

1. Gibney M, Barr S, Bellisle F, et al. Breakfast in Human Nutrition: The International Breakfast Research Initiative. *Nutrients* **2018,** *10*. doi: 10.3390/nu10050559
2. Gibney M, Barr S, Bellisle F, et al. Towards an Evidence-Based Recommendation for a Balanced Breakfast-A Proposal from the International Breakfast Research Initiative. *Nutrients* **2018**, *10*. Doi: 10.3390/nu10101540
3. Albertson AM, Wold AC, Joshi N. Ready-to-Eat Cereal Consumption Patterns: The Relationship to Nutrient Intake, Whole Grain Intake, and Body Mass Index in an Older American Population. *J Aging Res.* **2012**, *2012*. Doi: 10.1155/2012/631310
4. O'Neil CE, Nicklas TA, Fulgoni VL. Nutrient Intake, Diet Quality, and Weight/Adiposity Parameters in Breakfast Patterns Compared with No Breakfast in Adults: National Health and Nutrition Examination Survey 2001-2008. *JAND* **2014**, *114,* S27-S43. Doi: 10.1016/j.jand.2014.08.021
5. Betts JA, Chowdhury EA, Gonzalez JT, Richardson JD, Tsintzas K, Thompson D. Is breakfast the most important meal of the day? Proc Nut Soc **2016**, *75,* 464-474. Doi: 10.1017/S0029665116000318
6. Merten M, Williams A, Shriver L. Breakfast Consumption in Adolescence and Young Adulthood: Parental Presence, Community Context, and Obesity. *J Am Diet Assoc* **2009**, *109*, 1384. Doi: 10.1016/j.jada.2009.05.008
7. Susan IB, Hassan V, Jessica S. Breakfast in Canada: Prevalence of Consumption, Contribution to Nutrient and Food Group Intakes, and Variability across Tertiles of Daily Diet Quality. A Study from the International Breakfast Research Initiative. *Nutrients* **2018,** *10,* 985. Doi: 10.3390/nu10080985
8. Fagt S, Matthiessen J, Thyregod C, Kørup K, Biltoft-Jensen A. Breakfast in Denmark. Prevalence of Consumption, Intake of Foods, Nutrients and Dietary Quality. A Study from the International Breakfast Research Initiative. *Nutrients* **2018**, *10*. Doi: 10.3390/nu10081085
9. Bellisle F, Hébel P, Salmon-Legagneur A, Vieux F. Breakfast Consumption in French Children, Adolescents, and Adults: A Nationally Representative Cross-Sectional Survey Examined in the Context of the International Breakfast Research Initiative. *Nutrients* **2018,** *10,* 1056. Doi: 10.3390/nu10081056
10. Ruiz E, Ávila JM, Valero T, Rodriguez P, Varela-Moreiras G. Breakfast Consumption in Spain: Patterns, Nutrient Intake and Quality. Findings from the ANIBES Study, a Study from the International Breakfast Research Initiative. *Nutrients* **2018,** *10*. Doi: 10.3390/nu10091324
11. Gaal S, Kerr MA, Ward M, McNulty H, Livingstone MBE. Breakfast Consumption in the UK: Patterns, Nutrient Intake and Diet Quality. A Study from the International Breakfast Research Initiative Group. *Nutrients* **2018,** *10,* 999. Doi: 10.3390/nu10080999
12. Drewnowski A, Rehm CD, Vieux F. Breakfast in the United States: Food and Nutrient Intakes in Relation to Diet Quality in National Health and Examination Survey 2011-2014. A Study from the International Breakfast Research Initiative. *Nutrients* **2018,** *10*. Doi: 10.3390/nu10091200
13. Gibney MJ, Uzhova I. Breakfast: Shaping Guidelines for Food and Nutrient Patterns. *In Nurturing a Healthy Generation of Children: Research Gaps and Opportunities*; Nestle Nutr Inst Workshop Ser, 2019**;** Vol 91, pp.133-142. Doi: 10.1159/000493705
14. Gibney M, Barr S, Bellisle F, et al. Towards an Evidence-Based Recommendation for a Balanced Breakfast—A Proposal from the International Breakfast Research Initiative. *Nutrients* **2018,** *10*. Doi: 10.3390/nu10101540
15. Maillot M, Vieux F, Amiot M, Darmon N. Individual diet modeling translates nutrient recommendations into realistic and individual-specific food choices. *Am J Clin Nutr* **2010,** *91,* 421. Doi: 10.3945/ajcn.2009.28426
16. Gazan R, Brouzes C, Vieux F, Maillot M, Lluch A, Darmon N. Mathematical Optimization to Explore Tomorrow's Sustainable Diets: A Narrative Review. *Adv Nutr* **2018,** *9,* 602-616. Doi: 10.1093/advances/nmy049
17. Darmon N, Vieux F, Maillot M, Volatier J-L, Martin A. Nutrient profiles discriminate between foods according to their contribution to nutritionally adequate diets: a validation study using linear programming and the SAIN,LIM system. *Am J Clin Nutr* **2009**, *89,* 1227. Doi: 10.3945/ajcn.2008.26465
18. Maillot M, Ferguson E, Drewnowski A, Darmon N. Nutrient Profiling Can Help Identify Foods of Good Nutritional Quality for Their Price: a Validation Study with Linear Programming. *J Nutr* **2008**, *138,* 1107-1113. Doi: 10.1093/jn/138.6.1107
19. Wilde PE, Llobrera J. Using the Thrifty Food Plan to Assess the Cost of a Nutritious Diet. *J Consum Aff* **2009**, *43,* 274-304. Doi: 10.1111/j.1745-6606.2009.01140.x

20. Carlson, A., M. Lino, W. Juan, K. Hanson, and P. P. Basiotis. Thrifty food plan, 2006. Alexandria, VA: US Department of Agriculture. 2007.
21. Ferguson EL, Darmon N, Briend A, Premachandra IM. Food-based dietary guidelines can be developed and tested using linear programming analysis. *J Nutr* **2004,** *134,* 951.
22. Perignon M, Masset G, Ferrari G, et al. How low can dietary greenhouse gas emissions be reduced without impairing nutritional adequacy, affordability and acceptability of the diet? A modelling study to guide sustainable food choices. *Public Health Nutr* **2016,** *19,* 2662-2674. Doi: 10.1017/S1368980016000653
23. Masset G, Vieux F, Verger E, Soler L-G, Touazi D, Darmon N. Reducing energy intake and energy density for a sustainable diet: a study based on self-selected diets in French adults. *Am J Clin Nutr* **2014,** *99,* 1460. Doi: 10.3945/ajcn.113.077958
24. CDC. About the National Health and Nutrition Examination Survey (NHANES). 2013. Available at: https://www.cdc.gov/nchs/nhanes/about_nhanes.htm
25. CDC. NCHS Research Ethics Review Board (ERB) Approval 2012. 2012. Available at https://www.cdc.gov/nchs/nhanes/irba98.htm
26. CDC. National Health and Nutrition Examination Survey Questionnaire: Dietary Interview Component
27. CDC. National Health and Nutrition Examination Survey Questionnaire: Phone Follow-Up Dietary Interviewer Procedures. 2005. Available at https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx
28. U.S. Department of Agriculture Agricultural Research Service. Nutrient Intakes from Food and Beverages: Mean Amounts Consumed per Individual, by Gender and Age, What We Eat in America, NHANES 2001–2012. Available online: http://www.ars.usda.gov/Services/docs.htm?docid=18349
29. Service AR. Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference. United States Department of Agriculture. 2018. Accessed at https://ndb.nal.usda.gov/ndb/
30. Food Surveys Research Group. Food Patterns Equivalents Database (FPED). 2017. Accessed at https://data.nal.usda.gov/dataset/food-patterns-equivalents-database-fped
31. Drewnowski A. The Nutrient Rich Foods Index helps to identify healthy, affordable foods. *Am J Clin Nutr* **2010**, *91,* 1095S. Doi: 10.3945/ajcn.2010.28450D
32. U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2015 – 2020 Dietary Guidelines for Americans. 8th Edition. December 2015. Available at https://health.gov/dietaryguidelines/2015/guidelines/.
33. Hill KM, Jonnalagadda SS, Albertson AM, Joshi NA, Weaver CM. Top food sources contributing to vitamin D intake and the association of ready-to-eat cereal and breakfast consumption habits to vitamin D intake in Canadians and United States Americans. *J Food Sci* **2012,** *77,* H170-H175. Doi: 10.1111/j.1750-3841.2012.02787.x
34. Krebs-Smith SM, Pannucci TE, Subar AF, et al. Update of the healthy eating index: HEI-2015. *JAND* **2018,** *118,* 1591-1602. Doi: 10.1016/j.jand.2018.05.021
35. Food and Drug Administration. Food Labeling: Revision of the Nutrition and Supplement Facts Labels and Serving Sizes of Foods That Can Reasonably Be Consumed at One Eating Occasion; Dual-Column Labeling; Updating, Modifying, and Establishing Certain Reference Amounts Customarily Consumed; Serving Size for Breath Mints; and Technical Amendments; Extension of Compliance Dates. May 2018. Available at https://www.federalregister.gov/documents/2018/05/04/2018-09476/food-labeling-revision-of-the-nutrition-and-supplement-facts-labels-and-serving-sizes-of-foods-that
36. CDC. National Health and Nutrition Examination Survey Data. Available at https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx