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***Research Article***

# LINEAR PROGRAMMING CONSIDERING THE FOOD ADDITIVES AND NUTRIENTS

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## ABSTRACT
Linear programming (LP) is a mathematical tool used to optimize decision-making processes within defined constraints. Initially developed during the 1940s to address wartime logistical challenges, LP has since become integral to operational research, enabling solutions for a variety of complex problems. With its ability to handle numerous variables and constraints, LP serves as a foundation for optimization in fields like nutrition, logistics, and production planning. This study highlights the application of LP in diet optimization, focusing on minimizing food additives while maximizing nutrient content for various age groups. By leveraging TORA software, the research demonstrates how LP can effectively optimize dietary plans while adhering to specific constraints.

***Keywords:*** *Linear Programming, Optimization, Decision-Making, Operational Research, Diet Optimization, Nutrient Maximization, Food Additives Minimization, TORA Software, Constraints, Nutrition Planning, Production Planning, Logistics*

## INTRODUCTION
Linear programming (LP) is a mathematical method designed to determine the optimal scenario and has become an integral part of operational research. Developed as a discipline in the 1940s, its initial motivation was to solve complex planning problems during wartime operations (Dantzig, 1947). Before the advent of linear programming, it was challenging to address intricate plans systematically, which this method successfully overcame. Linear programming can be effectively applied to match diets to nutritional and other constraints while minimizing changes (Stigler, 1945). It provides a mathematical framework for generating optimal solutions that satisfy several constraints simultaneously, as demonstrated in diet optimization studies by Smith (1963) and Anderson & Earle (1983).
Linear programming boasts efficient computational algorithms capable of handling thousands of constraints and variables. This computational efficiency forms the backbone of solution algorithms for other operational research models, including integer, stochastic, and non-linear programming (George & King, 1971). A typical linear programming problem consists of three essential components: an objective function to be maximized or minimized, a set of linear constraints reflecting the problem's technical specifications, and non-negativity constraints since negative production values have no physical counterpart (Balintfy, 1964).
This research applies linear programming to optimize diets by taking food additives and nutrient content as constraints and variables, aiming to minimize harmful additives while maximizing

nutrients across different age groups. Using TORA software, the study formulates solutions for balancing nutritional requirements with health concerns, aligning with methodologies suggested by Darmon *et al.,* (2002) and Reham *et al.,* (2014).

## MATERIALS AND METHODS

### 2.1. Materials

This study focused on seven commonly consumed processed food products, selected for their frequent use among individuals aged 10 to 50 years across all income groups. The food products include:

1. Processed comminuted meat products
2. Dried pasta and noodles
3. Flavored milk
4. Chewing gum
5. Breakfast cereals
6. Ready-to-eat savories
7. Vegetable oils and fats

The research also considered five food additives known for their adverse health effects:

1. Guar gum
2. Sodium nitrate
3. Aspartame
4. Butylated hydroxyanisole (BHA)
5. Butylated hydroxytoluene (BHT)

Nutritional data (sugar, protein, carbohydrates, and fat) for each product were obtained, and acceptable daily intake (ADI) values for food additives were derived from authoritative guidelines such as WHO, FAO, and FDA.

### 2.2. Methodology

Linear programming (LP) was employed to address various optimization problems, including minimizing food additives, maximizing nutrient content, and balancing consumer costs and producer profits. The study used the following approach:

#### 2.2.1. Data Collection

Nutritional composition (sugar, protein, carbohydrate, and fat) and food additives content (in

**Maximum amount of Food additives in products**

| | Guar gum $(x_1)$(g/kg) | Sodium nitrate $(x_1)$(g/kg) | Aspartame $(x_1)$(g/kg) | BHT $(x_1)$ (g/kg) | BHA $(x_1)$ (g/kg) |
|---|---|---|---|---|---|
| Processed communited meat, poultry $(p_1)$ | 5 | 0.08 | 0 | 0.1 | 0.2 |
| Dried pasta, noodles$(p_2)$ | 0.6 | 4.5 | 0 | 0 | 0 |
| Flavouredmilk $(p_3)$ | 0.6 | 0.2 | 0.6 | 0 | 0 |
| Chewingum $(p_4)$ | 1 | 0 | 10 | 0.4 | 0.4 |
| Breakfast cereals $(p_5)$ | 1 | 0 | 1000 | 0 | 200 |
| Ready to eat savories $(p_6)$ | 20 | 0 | 0.5 | 0.2 | 0 |
| Vegetable oil and fats$(p_7)$ | 2 | 0.2 | 0 | 0 | 0.2 |

grams per kilogram) for each product were compiled.
Acceptable daily intake (ADI) levels for additives and nutrients were set as constraints.

Acceptable Daily Intake (ADI) of monosodium glutamate (MSG) is 30 mg per kilogram of body weight. The European Union (EU) has established a maximum permitted level of 10 grams per kilogram of food for monosodium glutamate (MSG).

**Nutrients present in these products**

| | Sugar (gram per 100g) | Protein (gram per 100g) | Carbohydrate(gram per 100g) | Fat(gram per 100g) |
|---|---|---|---|---|
| Processed communited meat, poultry ($p_1$) | 1-1.5 | 20 | 1.2 | 30 |
| Dried pasta, noodles ($p_2$) | 3 | 13 | 71 | 1.5 |
| Flavouredmilk ($p_3$) | 7.7 | 2 - 3.5 | 12 - 26 | 3.1 |
| Chewingum ($p_4$) | 66.1 | 0 | 2.9 | 0 |
| Breakfast cereals ($p_5$) | 1 | 13 | 68 | 7 |
| Ready to eat savories ($p_6$) | 49.3 | 14 | 39.83 - 48.35 | 14.56 |
| Vegetable oil and fats ($p_7$) | 0 | 0 | 0 | 95 |

**Food additives maximum intake for human**

| | |
|---|---|
| Guar gum | 128-429 mg/kg/day |
| Sodium nitrate | 3.7 mg/kg / day |
| Monosodium glutamate | 120 mg/kg / day |
| Aspartame | 40 mg/kg /day |
| BHT | 0 - 0.125 mg/kg /day |
| BHA | 0-0.05 mg/kg / day |

**Nutrients maximum intake for human**

| | |
|---|---|
| Sugar | 25g g/kg / day |
| Protein | 0.83 g/kg / day |
| Carbohydrate | 130 g/kg / day |
| Fat | Not more than 10g (10%) |

**2.2.2. Formulation of Linear Programming Problems**

Objective functions were defined for each problem:

a. Minimizing food additives while maximizing nutrients.
b. Minimizing consumer purchasing costs.
c. Maximizing producer profit.
d. Constraints were established for food additives, nutrients, and product-specific limits.

**2.2.3. Optimization Tools**

The TORA software was used to solve the formulated LP problems using the simplex method.
TORA (Temporary Open-source Repository for Algorithms) is a software tool used for solving various operations research problems, including linear programming. Linear programming is a method to achieve the best outcome in a mathematical model whose requirements are represented by linear relationships.

Results were evaluated for each problem based on the optimal values of the objective function and decision variables.

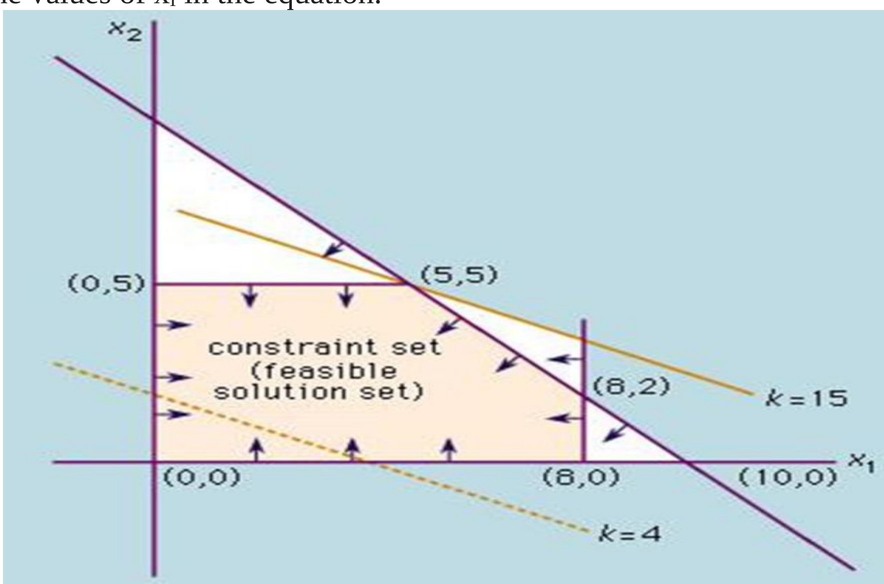
**3. PROBLEM FORMATION**

**Calculation methods**

This project focus on optimization through the application of linear programming. This section explains the background of this method. The result of a LP problem shrinks to discover the optimum worth (maximum or minimum, liable to the problem) of the linear equation (named the "objective function"):

$$Z = c_1p_1 + c_2p_2 + \cdots + c_np_n$$

The function is conditional on different constraints, stated as inequalities (see below Figure). According to mathematicians "the basic assumption in this method is that the various relationships between demand and availability are linear." To obtain the solution, "it is necessary to find the solution of the system of linear inequalities (that is, the set of *n*-values of the variables $x_i$ that simultaneously satisfies all the inequalities). The objective function is then evaluated by substituting the values of $x_i$ in the equation.




Concept of linear programming: The constraints ($x_i$; purple lines) result in a feasible solution set (yellow area). The objective function (k; yellow line) results in the highest possible solution at the edge of the solution area.

Solving such complex problem subjected to several constraints either to optimize the daily energy allowance, macro or micro nutrient intakes, or constraints on economic issues (price, income) and food additives are added to food (such as flavour enhancer, preservatives, thickening agent, sweetener,etc..). we assume that constraints, such as food additives and nutrient content are linearly related to food weight, but this could be a simplification of the reality. Macro nutrients (e.g., advised daily intake vs.harmness) or costs (e.g.,profit of producer and consumer purchasing price) could be non-linear. There are several open problems in the theory of linear programming, for instance the strongly polynomial-time performance in the number of constraints and the number of variables. Besides linear optimization functions, several authors suggest using quadratic functions for optimization on popularity or acceptability.

**Problem 1**

Optimizing the best product at lowest price with minimizing the food additives and maximizing the nutrient content.

In this problem my objective function is

Minimize Z = 123.39($p_1$) + 255($p_2$) + 360($p_3$)+ 400($p_4$) + 185($p_5$)+ 90($p_6$)+ 127($p_7$)

Subjective to the constraints are,

macro nutrients present in each of the above food products, we take only four nutrients such as sugar, protein, carbohydrate and fat.

Tabulation

| | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ | Requirement |
|---|---|---|---|---|---|---|---|---|
| Sugar | 1.5 | 3 | 7.7 | 66.1 | 1 | 49.3 | 0 | 25 |
| Protein | 20 | 13 | 3.5 | 0 | 13 | 14 | 0 | 0.83 |
| Carbohydrate | 1.2 | 71 | 26 | 2.9 | 68 | 48.35 | 0 | 130 |
| Fat | 30 | 1.5 | 3.1 | 0 | 7 | 14.56 | 95 | 10 |

**Sugar**

$p_1(1.5)+p_2(7.7)+p_3(7.7)+p_4(66.1)+p_5(1)+p_6(49.3)+p_7(0) \leq 25$

**Protein**

$p_1(20)+p_2(13)+p_3(3.5)+p_4(0)+p_5(13)+p_6(14)+p_7(0) \geq 0.83$

**Carbohydrate**

$p_1(1.2)+p_2(71)+p_3(26)+p_4(2.9)+p_5(68)+p_6(48.35)+p_7(0) \geq 130$

**Fat**

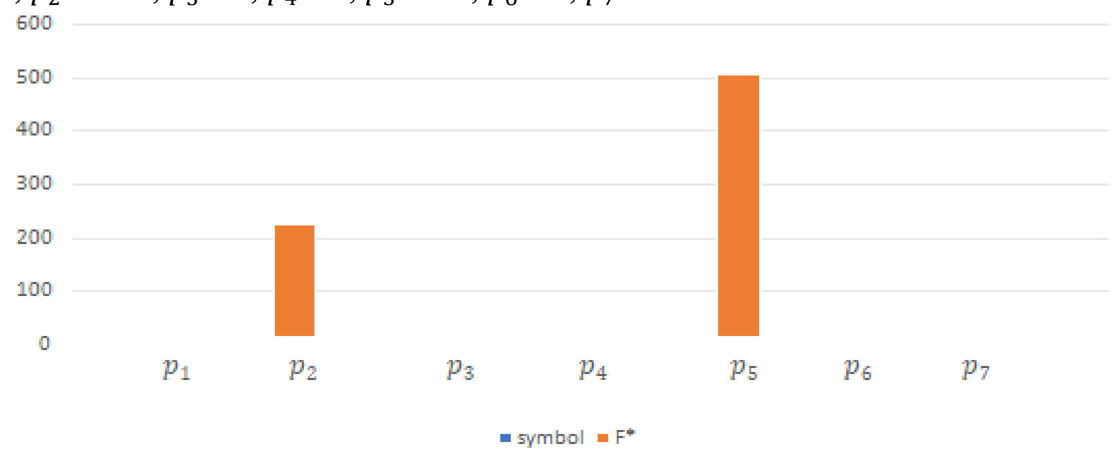
$p_1(30)+p_2(1.5)+p_3(3.1)+p_4(0)+p_5(7)+p_6(14.56)+p_7(95) \leq 10$

Above this problem's solution, the objective function is minimizing the consumer buying price according to the result by TORA software

**Answer:**

The value of the objective function: Z* = 389.68;

$p_1$ = 0; $p_2$ = 0.58; $p_3$ = 0; $p_4$ = 0; $p_5$ = 1.3; $p_6$ = 0; $p_7$= 0



This graph shows among these food products the optimal food products are dried pasta and breakfast cereals.this shows these two products are satisfied the constraint conditions, that is increased amount of carbohydrate and protein , decreased amount of sugar and fat.

**Problem 2**

Consider the producers maximizing the profit with minimizing the use of food additives in food products. objective function is

**Z max =** $\mathbf{15(p_1)+43(p_2)+103(p_3)+160(p_4)+74(p_5)+23(p_6)+32(p_7)}$

We take food additives in the unit of gram per kilo gram of human's body weight. According to this weight consider 0years to 20 years average weight.

**Profit calculation**

Profit $= consumer\ purchasing\ price\ *\ profit\ percentage$

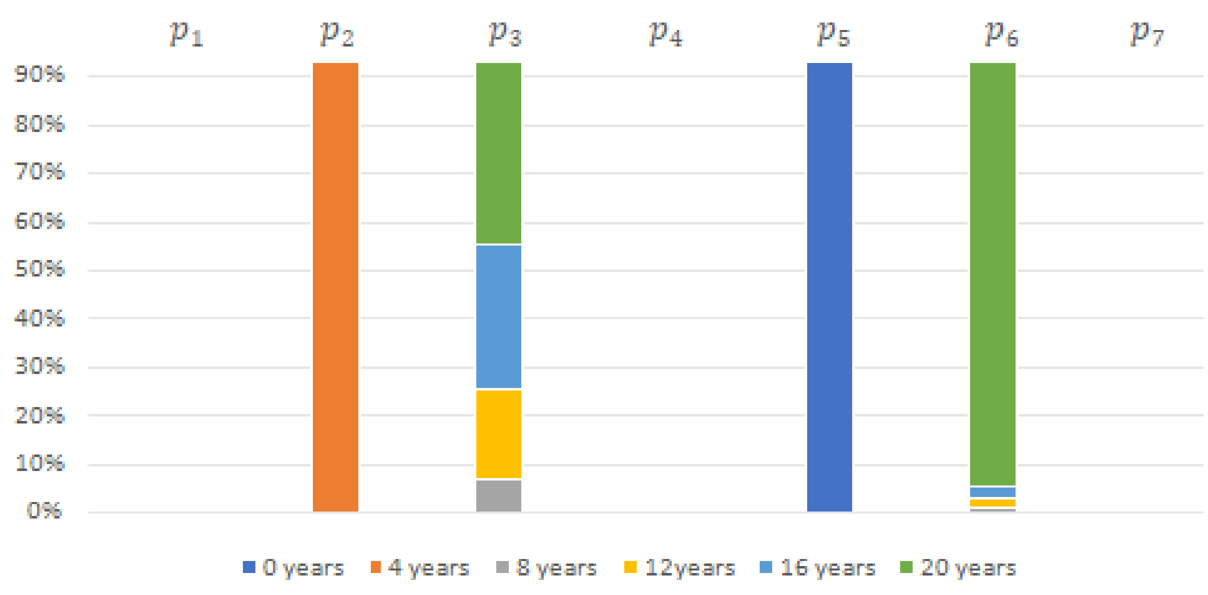
| Products | Profit percentage | Profit |
|---|---|---|
| $p_1$ | 12 | 15.36 |
| $p_2$ | 17 | 43.35 |
| $p_3$ | 28.7 | 103.32 |
| $p_4$ | 40 | 160 |
| $p_5$ | 40 | 74 |
| $p_6$ | 25 | 22.5 |
| $p_7$ | 25 | 31.75 |

| | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ | 0 years | 4 years | 8 years | 12 years | 16 years | 20 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_1$ | 5 | 0.6 | 0.6 | 1 | 1 | 20 | 2 | 0.301 | 4.6 | 7.8 | 12.5 | 16.1 | 17.5 |
| $X_2$ | 0.08 | 4.5 | 0.2 | 0 | 0 | 0 | 0.2 | 0.0037 | 0.06 | 0.09 | 0.15 | 0.198 | 0.215 |
| $X_3$ | 0 | 0 | 0.6 | 10 | 1 | 0.5 | 0 | 0.04 | 0.616 | 1.03 | 1.66 | 2.14 | 2.32 |
| $X_4$ | 0.1 | 0 | 0 | 0.4 | 0 | 0.2 | 0 | 0.000125 | 0.0019 | 0.00323125 | 0.0051875 | 0.00669 | 0.00725 |
| $X_5$ | 0.2 | 0 | 0 | 0.4 | 0.2 | 0 | 0.2 | 0.000005 | 0.0000771 | 0.0012925 | 0.0002075 | 0.0002676 | 0.0002903 |

**This table shows amount of used food additives in food products and these maximum limits according to their age and average weight.**

| | $Z^*$ | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ |
|---|---|---|---|---|---|---|---|---|
| 0 years | 1.92 | 0 | 0 | 0.02 | 0 | 0.04 | 0 | 0 |
| 4 years | 7.32 | 0 | 0.01 | 0.07 | 0 | 0 | 0 | 0 |
| 8 years | 46.77 | 0 | 0 | 0.45 | 0 | 0 | 0.02 | 0 |
| 12years | 77.92 | 0 | 0 | 0.75 | 0 | 0 | 0.03 | 0 |
| 16 years | 98.72 | 0 | 0 | 0.95 | 0 | 0 | 0.03 | 0 |
| 20 years | 130.22 | 0 | 0 | 1.07 | 0 | 0 | 0.84 | 0 |

This below graph shows producers profit focusing on age group of the consumer at the same time minimizing the use of food additives in their products according to this graph the producer consider the flavour milk($p_3$) and ready to eat savories ($p_6$) so we understand these products contains lower amount of food additives among these two products flavour milk($p_3$) is the most preferable product because it satisfied the all age group maximum consumable amount of food additives.




**Problem 3**

Consider nutrient(carbohydrate) maximization with minimization of use of food additives in food products.

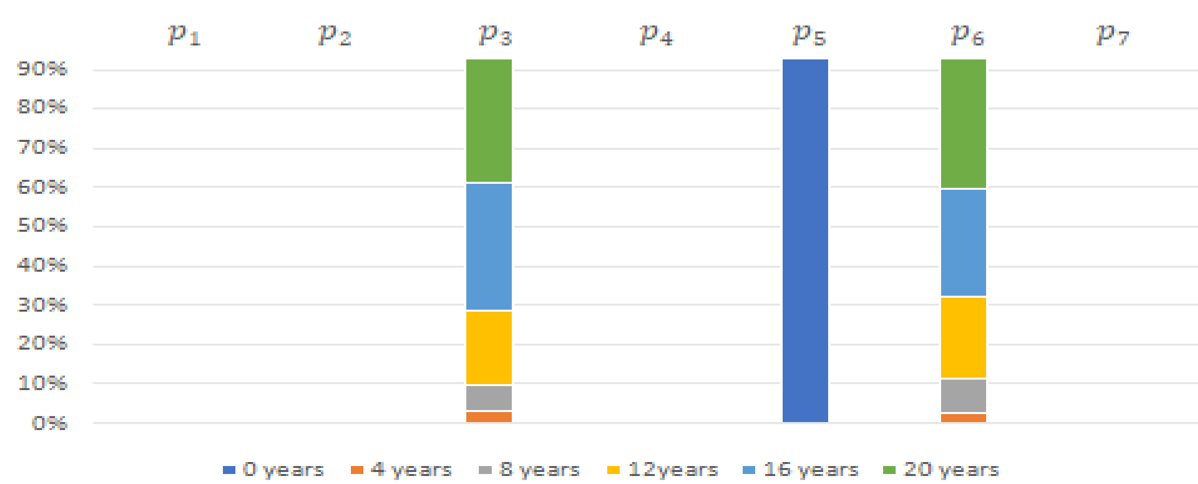
The common Objective function is

Z maximization= $1.2(p_1)+71(p_2)+26(p_3)+2.9(p_4)+68(p_5)+48.35(p_6)+0(p_7)$

| | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ | 0 years | 4 years | 8 years | 12 years | 16 years | 20 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 5 | 0.6 | 0.6 | 1 | 1 | 20 | 2 | 0.301 | 4.6 | 7.8 | 12.5 | 16.1 | 17.5 |
| $x_2$ | 0.08 | 4.5 | 0.2 | 0 | 0 | 0 | 0.2 | 0.0037 | 0.06 | 0.09 | 0.15 | 0.198 | 0.215 |
| $x_3$ | 0 | 0 | 0.6 | 10 | 1 | 0.5 | 0 | 0.04 | 0.616 | 1.03 | 1.66 | 2.14 | 2.32 |
| $x_4$ | 0.1 | 0 | 0 | 0.4 | 0 | 0.2 | 0 | 0.000125 | 0.0019 | 0.00323125 | 0.0051875 | 0.00669 | 0.00725 |
| $x_5$ | 0.2 | 0 | 0 | 0.4 | 0.2 | 0 | 0.2 | 0.000005 | 0.0000771 | 0.0012925 | 0.0002075 | 0.0002676 | 0.0002903 |

**This table shows amount of used food additives in food products and these maximum limits according to their age and average weight.**

| | Z* | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ |
|---|---|---|---|---|---|---|---|---|
| 0 years | 2.79 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 |
| 4 years | 8.29 | 0 | 0 | 0.3 | 0 | 0 | 0.01 | 0 |
| 8 years | 12.52 | 0 | 0 | 0.45 | 0 | 0 | 0.02 | 0 |
| 12years | 20.82 | 0 | 0 | 0.75 | 0 | 0 | 0.03 | 0 |
| 16 years | 27.45 | 0 | 0 | 0.99 | 0 | 0 | 0.03 | 0 |
| 20 years | 29.8 | 0 | 0 | 1.08 | 0 | 0 | 0.04 | 0 |



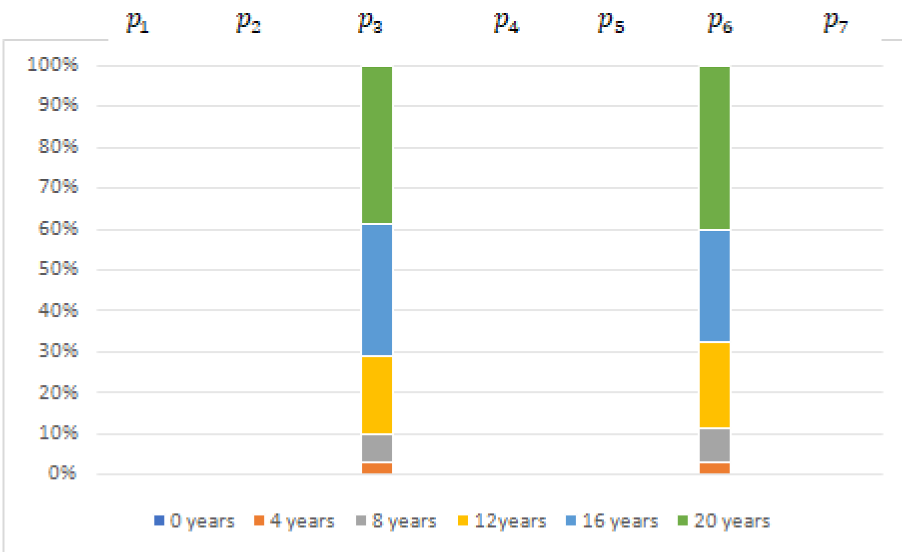
This graph shows which products contains higher amount of carbohydrate at the same time minimal use of the food additives used in foods. Flavoured milk($p_3$) and ready to eat savories($p_6$) these products are satisfied this condition, so who people consider carbohydrate most in foods choose only these two products.

**Problem 4**
Consider nutrient(protein) maximization with minimization of use of food additives in food products.
The common Objective function is
Z maximization= $20(p_1)$+$13(p_2)$+$3.5(p_3)$+$0(p_4)$+$13(p_5)$+$14(p_6)$+$0(p_7)$

| | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ | 0 years | 4 years | 8 years | 12 years | 16 years | 20 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 5 | 0.6 | 0.6 | 1 | 1 | 20 | 2 | 0.301 | 4.6 | 7.8 | 12.5 | 16.1 | 17.5 |
| $x_2$ | 0.08 | 4.5 | 0.2 | 0 | 0 | 0 | 0.2 | 0.0037 | 0.06 | 0.09 | 0.15 | 0.198 | 0.215 |
| $x_3$ | 0 | 0 | 0.6 | 10 | 1 | 0.5 | 0 | 0.04 | 0.616 | 1.03 | 1.66 | 2.14 | 2.32 |
| $x_4$ | 0.1 | 0 | 0 | 0.4 | 0 | 0.2 | 0 | 0.000125 | 0.0019 | 0.00323125 | 0.0051875 | 0.00669 | 0.00725 |
| $x_5$ | 0.2 | 0 | 0 | 0.4 | 0.2 | 0 | 0.2 | 0.000005 | 0.0000771 | 0.0012925 | 0.0002075 | 0.0002676 | 0.0002903 |

| | Z* | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $p_7$ |
|---|---|---|---|---|---|---|---|---|
| 0 years | 0.07 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0 |
| 4 years | 1.19 | 0 | 0 | 0.3 | 0 | 0 | 0.01 | 0 |
| 8 years | 1.81 | 0 | 0 | 0.45 | 0 | 0 | 0.02 | 0 |
| 12years | 3 | 0 | 0 | 0.75 | 0 | 0 | 0.03 | 0 |
| 16 years | 3.95 | 0 | 0 | 0.99 | 0 | 0 | 0.03 | 0 |
| 20 years | 4.29 | 0 | 0 | 1.07 | 0 | 0 | 0.04 | 0 |

This below graph shows, those products containing higher amount of protein at the same time minimal use of the food additives used in foods. flavoured milk ($p_3$) and ready to eat savories ($p_6$) these products have satisfied this condition, so these people consider protein most in foods choose only these two products.




## RESULTS AND DISCUSSION

| OBJECTIVE FUNCTION | CONSTRAINTS | Z* VALUE |
|---|---|---|
| Minimizing consumer purchasing price | Nutrients | 389.68 |
| Maximizing producers profit | Foodadditives | 60.47833333 |
| Maximizing nutrient (carbohydrate) | Foodadditives | 16.945 |
| Maximizing nutrient (protein) | Foodadditives | 2.385 |
| Maximizing nutrient | Sugar and fat | 473.55 |

These are problems result, we compare these result and solution, we consider nutrient is the most important in our diet the product consumption value is 389.68 at the same time third and fourth problem's result is 16.945 and 2.385 we compare this three problems difference between the first and third problems Z* value is 372.735 and difference between the first and fourth problem's F* value is 387.295.

Other perspective is the consumer and producer point of view, according to these the Z* value difference between the first and second problem is -329.201667. now we understand the production possibility value is very low according to food additivesside but the consumption value is comparatively high according to nutrients side.

The extreme result is we understand, our diet or food choice to eat not only consider the nutrient content in the food label, we must consider the other food ingredients such as food additives, this was mathematically proven by this problem.

## CONCLUSION

This study demonstrated the application of linear programming (LP) as a robust mathematical tool for optimizing dietary patterns by addressing multiple constraints, such as minimizing harmful food additives and maximizing nutrient content. By focusing on commonly consumed processed food products, the research highlighted the dual priorities of ensuring nutritional adequacy and reducing exposure to additives known for their adverse health effects. High consumption of food additives is lead to many health issues so the food additives are the main constraints in this problem.

Using TORA software, the study successfully formulated and solved various optimization problems, including consumer-focused scenarios (minimizing costs and optimizing nutrients) and producer-oriented scenarios (maximizing profits while adhering to constraints). The results clearly emphasized the importance of balancing consumer affordability, producer profitability, and public health concerns in food formulation.

And compare the objective values (Z*)389.68(subject to the nutrient constraints), 60.47833333, 16.945, 2.385 of the results, the objective is proven that the food choice to eat is not only consider the nutrient content, we must consider the food additives also.

In context, the findings of this research underscore that dietary choices should not only consider nutrient content but also the presence of food additives, as these can have long-term health implications. The proposed methodology provides a framework for future studies to incorporate more complex variables, such as dietary preferences, cultural factors, and sustainability. Ultimately, the integration of LP in food science has the potential to promote healthier dietary practices while supporting both consumers and the food industry.

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**Link:** National Academies Press - Dietary Reference Intakes
**Link:** Food and Nutrition Board Publications
**Link:** USDA National Nutrient Database
**Link:** WHO Nutrition Guidelines
**Link:** EFSA - Dietary Reference Values
**WHO Reports [No date].** WHO provides guidelines and assessments on food additives. Their Joint FAO/WHO Expert Committee on Food Additives (JECFA) offers detailed reports.
**FAO (No Date).** FAO works closely with WHO on food safety standards and provides valuable information on food additives.
**FDA (No Date).** The FDA provides detailed regulations on food additives in the United States, including the Generally Recognized as Safe (GRAS) list.
**Codex alimentarius:** This collection of internationally recognized standards, guidelines, and codes of practice includes standards for food additives.
https://www.who.int/data/gho/data/themes/theme-details/GHO/body-mass-index
**Centers for Disease Control and Prevention (2020).** *Anthropometric Reference Data for Children and Adults*: United States, 2015-2018. National Center for Health Statistics.