Low-cost Dietary Plan for COVID-19 Immunity Response Using Mixed-Integer Linear Programming

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Abstract

Coronavirus disease 2019 (COVID-19) has wreaked havoc on various sectors worldwide affecting people with compromised immunity. A healthy diet plan should include adequate levels of select micronutrients and macronutrients to enhance immunity. Although dietary habits can be modified, the cost of nutritious food has been a significant challenge to Filipino adults due to its cost. Through Mixed Integer Linear Programming (MILP), a low-cost healthy meal plan is developed following the recommended nutritional intake of a healthy adult. 120 survey respondents aged 19-50 years old from National Capital Region (NCR) initially participated in this study. After exclusion criteria for defined healthy adults, eligible participants proceeded in the second phase. Data collection on socio-demographic, anthropometry, and the participants' food intake was accomplished. Long-term dietary habits were acquired through 24-hour Food Recall Record and Food Frequency Questionnaire (FFQ). A majority of female respondents did not reach the recommended daily intake of Vitamin A(465±519.44mcg), Vitamin D(24±61.12IU/mcg), Vitamin C(72±156.96mg), Vitamin E(18±32.90mg), Zinc(14±8.02mg), Selenium(110±108.77mcg), and daily Protein intake. The same with majority of male respondents in Vitamins A(462±417.40mcg), D(19±31.20IU/mcg), C(50±48.18mg), E(22±38.94mg), and Protein. The remained 391 food items were the variables in the model with 31 constraints and four models were optimized for both males and females which resulted in a 7-day meal plan. The model optimization identified food items in a minimum cost of ₱68.75 and ₱69.08 for Males aged 19-29 and 30-50 years old, respectively. For females, a cost of ₱71.13 (for aged 19-29) and ₱82.57 (for aged 30-50 years old) were obtained.

Keywords

Mixed Integer Linear Programming, Low-cost, diet, COVID-19, Immunity, Food Recall Record, Food Frequency Questionnaire (FFQ

1. Introduction

Epidemic outbreaks are distinct from other cataclysms because of two different characteristics: long-term disturbance and exponential increase. Failure to manage such disasters creates significant disruptions in supply chains and populations, resulting in irreversible losses. Coronavirus disease 2019 (COVID-19) is one of these disasters that has wreaked havoc on supply chains worldwide, especially in the healthcare industry (Govindan, Mina, & Alavi, 2020). COVID-19 is an acute illness, but it can be fatal in extreme cases. It was identified last December 2019 in Wuhan, China, which has infected 26 countries worldwide (Xu et al., 2020). The World Health Organization (WHO) announced COVID-19 as a public health emergency of international significance. In 215 countries, over 3 million injuries were reported, and over 200,000 deaths were confirmed by May 2, 2020. Despite the closing of critical transport borders, reported cases and deaths are emerging, possibly because of population transmission and expanded ability for research (Nzediegwu & Chang, 2020). COVID-19 symptoms can range from asymptomatic to severe cases, including coughing, fever, and shortness of breath (Rothan & Byrareddy, 2020). Acute respiratory failure syndrome, acute coronary problems, multiple organ dysfunction syndrome, septic shock, and death are possible symptoms in more severe cases. The outbreak of this new infectious disease has been moving rapidly (Bansal, 2020; Singhal, 2020; Zhou et al., 2020; Kochi, Tagliari, Forleo, Fassini, & Tondo, 2020). To combat the epidemic, strict nationwide policies have been adopted, including social distancing policies and urging or even requiring people to stay at home. Individuals are often at a loss about appropriate dietary habits and sufficient nutrient status to remain healthy, particularly during this self-containment, which is often viewed as exhausting. A stable, functioning immune system

is essential for infection prevention, and a sufficient and nutritious diet is a vital basis for an optimal immune response (Jahns et al., 2018). However, the vast disparity in the affordability of eating healthy foods plays a significant role in establishing a healthy and balanced diet (Kern et al., 2017). Linear programming is one method of investigating this dynamic problem of minimizing the cost of diet plans to boost immunity response in the face of numerous constraints. Given this context, this research aims to formulate a low-cost dietary plan for Filipino citizens by conducting an optimization study considering various constraints.

1.1 Objectives

This study generally aims to formulate a seven-day low-cost dietary plan consisting of food items for meals per day. The low-cost diet plan aims to boost the immune response of healthy Filipino adults as a supplementation in the fight against COVID-19. In order to achieve the aim of the study the following objectives were defined:

- To obtain the anthropometric and socio-demographic factors of the participants for descriptive analysis;
- To identify the average daily intake of selected micronutrients and macronutrients of the participants;
- To analyze the daily dietary information of the participants through the 24-hour Food Recall Record;
- To determine the Recommended Nutrient Intake (RNI) of the selected micronutrient and macronutrient intake per day;
- To identify the cost of each food item selected from the participants' Food Frequency Questionnaire (FFQ) and;
- To formulate and solve the optimization problem using Mixed Integer Linear Programming (MILP)

2. Literature Review

Over the last two decades, three extremely pathogenic and lethal coronaviruses have appeared: Severe acute respiratory syndrome coronavirus (SARS-CoV), Middle East respiratory syndrome coronavirus (MERS-CoV), and Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). These coronaviruses' economic impact and health risks are enormous and are becoming more severe as the number of global infections and deaths due to SARS-CoV-2 and MERS-CoV increases (Zhu et al., 2020). SARS-CoV-2 is generally spread from person to person by family members, including relatives and friends who have had direct contact with patients or incubation carriers (Chan et al., 2020). The most recent research suggests the propagation of the disease is mainly by droplets. Some secondary transmission routes involve areas contaminated by infectious droplets later entering the mouth, nose, or eyes. SARS-CoV-2 was more robust on plastic and stainless steel than on copper and carton. A viable virus was observed up to 72 hours after surface application, while the virus's incubation period can extend up to 14 days (Di Maria et al., 2020; Lauer et al., 2020). Most transmissions take place within an infected person, and pre-symptomatic transmission does happen. The detection of milder infections in secondary cases may reflect the disease's actual severity (Ren et al., 2020). Several studies link the nutritional status as an essential determinant of the immune response against pathogens due to the relationship between metabolism and functions of immune cells (Alwarawrah et al., 2018). An optimized immunity is influenced by good sources of macronutrients and micronutrients (Maggini et al., 2018). It was discussed in different studies that undernutrition is related to the suppression of the immune response leading to susceptibility to infections and autoimmune disease protection. On the contrary, overnutrition can be linked to chronic inflammation, a higher risk of cardiovascular and metabolic disease, and a disturbance in the immune response. Nutritional status can be compromised by poor diet, a stressful lifestyle, insufficient micronutrient intake, and energy-dense consumption of daily meals. These lifestyle factors, alongside other factors, highly affect immunological competence in healthy adults. To optimize the immune system, adequate nutrition is required (Alwarawrah et al., 2018). Enough micronutrients ensure the immune cells' regular function. In the immune response and synergistic roles, specific micronutrients such as vitamins A, D, C, E, B6, B12, Folate, Zinc, Iron, Copper, and Selenium. Vitamin C, D, and Zinc were said to have the most substantial effects on the immune response (Gombart et al., 2020). A study by de Faria Coelho-Ravagnani et al. (2020) stated that 31 percent of research documents concerning dietary recommendations during the COVID-19 were concluded to provide importance to minerals as well as vitamins. The ones highlighted were specifically zinc, Selenium, vitamins C, A, and D to sustain the immune system functions. The intake of these micronutrients is vital in the immune system function with varying degrees of effect and required intake. In addition, macronutrients are required in relatively more significant amounts to maintain and regulate daily bodily functions to execute everyday activities (Dolson & Fogoros, 2021). According to Jayawardena & Misra (2020),

protein intake is significant for maintaining a balanced diet; it is also essential in preventing COVID-19 and diet-related chronic diseases and may have a beneficial effect on COVID-19 mortality. It is important to note that Indian states with a high prevalence of underweight and anemia have the highest COVID-19 case count. The COVID-19 pandemic is considered a major world health crisis and deemed highly relevant for further studies to manage and improve the current state. As a response to the virus and its detrimental effects, the immunity response of a person is one of the primary defenses of the host to fight with varied methods and numerous factors to be considered for its enhancement. Several factors with varying degrees of effect in the response can affect the immune system, a highly essential one being nutritional factors obtained through dietary planning. Meeting dietary requirements, optimization of specific amounts of selected micronutrients and macronutrients to be consumed is proven to be highly essential in maintaining normal immune functions.

3. Methods

3.1 Research Design

The researchers formulated and optimized a Mixed Integer Linear Programming (MILP) model that provided a meal plan at a minimized cost. The factors used for descriptive analysis are the anthropometric, socio-demographic, food intake from the 24-hour Food Recall Record, and Food Frequency Questionnaire (FFQ). The obtained data such as the nutritional content per food item in terms of the selected micronutrients and macronutrients, the upper and lower limit of the required nutrients for males and females (both aged 19-29 and 30-50 years old), the edible portion of the food items, the amount required per food category, and the daily food allocation of a Filipino individual served as the independent variables from the constraints. On the other hand, the dependent variable is the objective function in the mathematical model, which is the low-cost diet plan. The researchers utilized selected micronutrients and macronutrients that significantly boost a person's immunity response in developing the MILP model. Adequate micronutrients such as Vitamin A, Vitamin D, Vitamin C, Vitamin E, Zinc, Selenium, and Protein were significant in enhancing the immune response.

3.2 Subjects and Study Site

The participants of the study initially were 120 healthy Filipino adults aged 19-50 years old who are residing in the National Capital Region (NCR). The participants have undergone exclusion criteria for identifying healthy adults, which were defined based on the existing studies of Alfenas and Mattes (2005), McDeavitt et al. (2021), Smiljanec et al. (2020), Haddad et al. (2014), and Ahn et al. (2019). The sample size was acquired from the existing studies of Alaini et al. (2019), Baki et al. (2019), and Santika et al. (2009). Moreover, the chosen age range was the group with the highest percentage of COVID-19 cases reported in the Philippines, according to the World Health Organization (2020). The data gathering was done online using materials such as Food Frequency Questionnaire (FFQ) and the 24-hour Food Recall Record in an editable PDF, together with the Participants' Information Sheet and Consent Form. The survey materials used in the study are the 24-hour Food Recall Record and the Food Frequency Questionnaire (FFQ) in an editable PDF wherein participants were asked about their consumed food in a day and the frequency of their intake on the listed food items, respectively. The FFQ was composed of 447 food items based on the Food Exchange List for Meal Planning (4th Edition) published by the Food and Nutrition Research Institute - Department of Science and Technology (FNRI-DOST). It was categorized into eight food groups such as (1) Egg, (2) Fats & Oils, (3) Fish, Shellfish, Meat & Poultry, Dried Beans & Nuts, (4) Fruits, (5) Milk & Milk Products, (6) Rice, Rice Products, Corn, Root Crops, Bread, Noodles (7) Sugar/Sweets, and (8) Vegetables.

3.3 Data Measures

This research utilized a survey questionnaire to identify eligible participants from Filipino adults within the age range of 19-50 years old. The exclusion criteria included: (1) Adults who are non-smokers, (2) Adults who are not pregnant or lactating women, (3) Adults with no comorbidities, (4) Adults with no medical history of cardiovascular disease, hypertension, malignancy, diabetes, kidney, autonomic or metabolic diseases, and renal impairment, (5) Adults with Body Mass Index (BMI) within the normal range of 18.50 to 24.90 kg/m^2, and (6) Adults who regularly eat at least three (3) meals (breakfast, lunch, and dinner) per day. Out of the remaining 103 respondents, four (4) were smokers, while three (3) were pregnant or lactating women. Moreover, 14 participants have comorbidities, and four (4) respondents have a medical history in the initially stated diseases that made them unqualified for a healthy individual. In the remaining 64 respondents, 14 of whom do not eat regularly at least three meals per day, while nine (9) are not willing to participate in the second phase of the study. For the last part of the exclusion criterion, the Body Mass Index (BMI) of the participants were identified, and only 33 were within a normal range of 18.5 to 24.9 kg/m^2. The final

qualified, healthy individuals were emailed to participate in the second phase of the study. Only twenty responded and have given back the completed Food Frequency Questionnaire (FFQ), 24-hour Food Record, and Consent Form. According to the studies of Pettersson et al. (2021), Ho et al. (2021), Davis et al. (2010), and Storniolo et al. (2015), this study utilized the exclusion criteria wherein a specific criterion for healthy people was surveyed from the respondents. The exclusion criteria removed a potential participant from the total pool of participants of interest if the particular respondent did not fit the requirements. The amounts of micronutrients such as Vitamin A, Vitamin D, Vitamin C, Vitamin E, Zinc, Selenium, and Protein had a unit of measurement in milligrams (mg), and micrograms (μg) while the height and weight were in centimeters (cm) and kilograms (kg), respectively, for descriptive analysis.

3.4 Model Description

The low-cost diet model that was formulated in this study was subjected to the upper and lower limits of the select micronutrients and macronutrients constraints, average food expenditure constraint, food categorical constraints, and nonnegativity constraint. The constraint for the select micronutrients and macronutrients ensured that the daily Recommended Nutrient Intake (RNI) was satisfied. On the other hand, the constraint for the average food expenditure ensured that the daily food cost is less than or equal to the expected food allocation expense of a Filipino individual. The food categorical constraints complied with the Daily Nutritional Guide Pyramid set by the Department of Science and Technology - Food and Nutrition Research Institute (DOST-FNRI) for Filipino adults were met. To vary the food items in the daily meal plans, the researchers limited the amount of each food item per food category and the variables that were already acquired from the preceding optimal solution were omitted to the Mixed Integer Linear Programming (MILP) model for the succeeding runs. The objective function was the total cost of food items to be minimized, denoted by z. The decision variable, Xj, represents the food item j to which the cost of the diet plan will be minimized. The amount of nutrient i from the food item j portion was denoted by aij. The cost of food item j is denoted by cj and the acceptable quantity of nutrient i was represented by bi. The Recommended Nutrient Intake (RNI) of the selected micronutrients and macronutrients was adapted from the Philippine Dietary Reference Intake (FNRI-DOST, 2015). The recorded food items from the 24-hour diet recall and the selected food items from the Food Frequency Questionnaire (FFQ) served as the food item j. The micronutrient intake of each food item was based on the Food Composition Table (FCT) of the Food and Nutrition Research Institute, Department of Science and Technology (FNRI-DOST).

3.5 Mathematical Formulation

$$Minimize\ z = \sum_{j=1}^{j} c_j x_j$$

Subject to:

$\sum a_{1j} x_j \leq U_1$	$\forall j \in \{1 \ldots 391\}$	*Vitamin A upper bound Constraint*
$\sum a_{1j} x_j \geq l_1$	$\forall j \in \{1 \ldots 391\}$	*Vitamin A lower bound Constraint*
$\sum a_{2j} x_j \leq U_2$	$\forall j \in \{1 \ldots 391\}$	*Vitamin D upper bound Constraint*
$\sum a_{2j} x_j \geq l_2$	$\forall j \in \{1 \ldots 391\}$	*Vitamin D lower bound Constraint*
$\sum a_{3j} x_j \leq U_3$	$\forall j \in \{1 \ldots 391\}$	*Vitamin C upper bound Constraint*
$\sum a_{3j} x_j \geq l_3$	$\forall j \in \{1 \ldots 391\}$	*Vitamin C lower bound Constraint*
$\sum a_{4j} x_j \leq U_4$	$\forall j \in \{1 \ldots 391\}$	*Vitamin E upper bound Constraint*
$\sum a_{4j} x_j \geq l_4$	$\forall j \in \{1 \ldots 391\}$	*Vitamin E lower bound Constraint*
$\sum a_{5j} x_j \leq U_5$	$\forall j \in \{1 \ldots 391\}$	*Zinc upper bound Constraint*
$\sum a_{5j} x_j \geq l_5$	$\forall j \in \{1 \ldots 391\}$	*Zinc lower bound Constraint*
$\sum a_{6j} x_j \leq U_6$	$\forall j \in \{1 \ldots 391\}$	*Selenium upper bound Constraint*
$\sum a_{6j} x_j \geq l_6$	$\forall j \in \{1 \ldots 391\}$	*Selenium lower bound Constraint*

$$\sum a_{7j}x_j \le U_7 \quad \forall j \in \{1\ldots391\} \quad Protein\ upper\ bound\ Constraint$$

$$\sum a_{7j}x_j \ge l_7 \quad \forall j \in \{1\ldots391\} \quad Protein\ lower\ bound\ Constraint$$

$$\sum x_j \ge l_e \quad \forall j \in \{1\ldots6\} \quad Egg\ lower\ bound\ Constraint$$

$$\sum x_j \le U_o \quad \forall j \in \{7\ldots24\} \quad Fats\ and\ Oils\ upper\ bound\ Constraint$$

$$\sum x_j \ge l_o \quad \forall j \in \{7\ldots24\} \quad Fats\ and\ Oils\ lower\ bound\ Constraint$$

$$\sum x_j \le U_N \quad \forall j \in \{25\ldots136\} \quad Fish, Shellfish, Meat\ \&\ Poultry, Dried\ Beans\ \&\ Nuts\ upper\ bound\ Constraint$$

$$\sum x_j \ge l_N \quad \forall j \in \{25\ldots136\} \quad Fish, Shellfish, Meat\ \&\ Poultry, Dried\ Beans\ \&\ Nuts\ lower\ bound\ Constraint$$

$$\sum x_j \le U_F \quad \forall j \in \{137\ldots201\} \quad Fruits\ upper\ bound\ Constraint$$

$$\sum x_j \ge l_F \quad \forall j \in \{137\ldots201\} \quad Fruits\ lower\ bound\ Constraint$$

$$\sum x_j \ge l_M \quad \forall j \in \{202\ldots217\} \quad Milk\ and\ Milk\ Products\ lower\ bound\ Constraint$$

$$\sum x_j \le U_R \quad \forall j \in \{218\ldots297\} \quad Rice, Rice\ Products, Corn, Root\ crops, Bread, Noodles\ Products\ upper\ bound\ Constraint$$

$$\sum x_j \ge l_R \quad \forall j \in \{218\ldots297\} \quad Rice, Rice\ Products, Corn, Root\ crops, Bread, Noodles\ Products\ lower\ bound\ Constraint$$

$$\sum x_j \le U_S \quad \forall j \in \{298\ldots322\} \quad Sugar/Sweets\ upper\ bound\ Constraint$$

$$\sum x_j \ge l_S \quad \forall j \in \{298\ldots322\} \quad Sugar/Sweets\ lower\ bound\ Constraint$$

$$\sum x_j \ge l_S \quad \forall j \in \{323\ldots391\} \quad Vegetables\ Category\ lower\ bound\ Constraint$$

$$\sum x_j \ge 0 \quad \forall j \in \{1\ldots391\} \quad Non-negativity\ constraint$$

Figure 1: Mathematical Formulation of Mixed Integer Linear Programming Model

Table 3.1: Upper and Lower Limit of Select Micronutrients and Macronutrients
Source: FNRI-DOST

MICRONUTRIENT AND PROTEIN CONSTRAINT				
	Male		Female	
	Lower Limit	Upper limit	Lower Limit	Upper limit
Vitamin A (RE) (mcg)	700	3000	600	3000
Vitamin D (IU/mcg)	70	1000	60	1000
Vitamin C (mg)	5	50	5	50
Vitamin E (mg)	10	1000	10	1000
Zinc (mg)	6.5	45	4.6	45
Selenium (mcg)	38	400	33	400
Protein (g) 19-29 years old	63.26	94.875	48.25	73.375
Protein (g) 30-50 years old	70.125	90.75	46.75	60.5

Table 3.2: Daily Nutritional Guide Pyramid
Source: DOST-FNRI

DAILY PYRAMID CONSTRAINT		
	Lower	Upper
FATS & OILS	25.2	33.5
SUGAR/SWEETS	21	33.5
FISH, SHELLFISH, MEAT & POULTRY, DRIED BEANS & NUTS	340.2	453.6
EGG	50	
MILK & MILK PRODUCTS	250	
VEGETABLES	225	
FRUITS	160	240
RICE, RICE PRODUCTS, CORN, ROOT CROPS, BREAD, NOODLES	400	480

Data from the Philippine Statistics Authority, 2018 Family Income, and Expenditure Survey showed the Total and Average Family Income and Expenditure by Family Size and by region: 2018 which indicated the total average and family income of Filipino citizens in the year 2018. The researchers utilized the average annual income of a family with 5 members from the National Capital Region, which is Php 480,000, according to the Philippine Statistics Authority. It has also been reported that Filipino families who belong in the bottom 30 percent by income spend 58.2% of their salary for food expenditures while the upper 70 percent take 39.5% from their annual income. Given these data, the researchers have identified the daily food expenditure of Php 150.20 per person daily.

4. Data Collection

The participants of this study were surveyed through a questionnaire that identified the participants' age, gender, height, weight, and food intake. Participants who met the criteria for healthy adults were invited to participate in the second phase of the study. The Food Frequency Questionnaire (FFQ) and 24-hour Food Recall Record in an editable PDF were distributed through email to identify their long-term dietary habits and daily food intake, respectively. The various food items and their respective nutritional components, specifically the select micronutrient and macronutrient, were obtained from NutritionistPro and were proportioned to the edible portion to acquire the cost. A data cleaning and standardization was done for the creation of raw data. Collected data were analyzed using different statistical software. Statistical Package for the Social Sciences (SPSS) program version 24 was used for the descriptive analysis by obtaining the mean, percentage, and standard deviation of the socio-demographic data and food diet record. Lingo was used to synthesize all available data. The linear programming model was formulated using this software.

5. Results and Discussion

5.1 Numerical Results

5.1.1 Socio-demographic data

A total of 121 survey respondents were the initial participants of the study. Informed consent and data privacy consent were deployed to the initial participants to which one respondent didn't consent, and 120 respondents consented. A majority of the 120 survey respondents who participated in the initial data gathering process were 83 females constituting 69.2 percent, and 37 males with 30.8 percent. 89 out of the 120 survey respondents were aged 19-24 years old, constituting the majority of the respondents with 74.2 percent. 15 (12.5%) out of the 120 respondents were aged 25-30 years old, six (5%) respondents were aged 31-36 years old, five (4.2%) respondents were aged 37-42 years old, three (2.5%) respondents aged 43-48 years old, and one respondent was aged 49-50 years old (0.8%). One survey respondent who was not between 19-50 years old was eliminated in the second part of the initial survey due to the age of interest in this study. 120 respondents who participated in the initial data gathering process were asked if they were

currently located in the National Capital Region. 17 participants who were not from the National Capital Region were eliminated from the pool of respondents, leaving 103 qualified participants in total.

5.1.2 Anthropometric data

The final qualified, healthy 20 participants consisted of 14 females (70%) and the remaining of six males (30%). A majority of the females and males, accounting for 85.71% and 83.33%, respectively, were between 19-24 years old. The female and male participants' mean height was 156.26 ± 4.1 cm and 168.4867 ± 7.3 cm, respectively. The mean weight of the female and male participants was 53.8714 ± 4.5 cm

5.1.3 Results of the 24-hour Food Recall

The study used a 24-hour food recall in an editable PDF form, in which participants were asked about their food intake during the previous 24 hours. The food items collected in the 24-hour food recall was consolidated, and the researchers used Nutritionist ProTM software to determine the selected nutrient content of the final food items, specifically the Vitamin A, Vitamin D, Vitamin C, Vitamin E, Zinc, Selenium (micronutrients), and Protein (macronutrient). The nutritional intake and protein intake per day were analyzed through SPSS. The 24-hour food recall was conducted to analyze whether respondents met their daily micronutrient and protein requirements. 71.43 percent did not reach the recommended daily vitamin A intake, 78.57 percent lacked vitamin D intake, 85.71 percent of female respondents lacked daily vitamin C intake, 64.29 percent lacked daily E, 35.7 percent lacked daily zinc intake, 28.57 lacked daily selenium intake, and 30.77 percent of the 19-29-year-old female respondents did not reach the recommended daily protein intake. 83.33 percent of male respondents did not meet the recommended vitamin A intake. 66.67 percent of male respondents did not meet the recommended vitamin D, C, and E intake, and 40% of male respondents did not meet the recommended protein intake. The micronutrient intake of Vitamin E, Zinc, Selenium, and Protein was inadequate. These findings demonstrated that the respondents' daily nutritional intake does not correspond to the amount required to strengthen their immune system. The results of the 24-hour food record are summarized in Table 5.2.

Table 5.1 Average Micronutrient and Protein intake of participants with recommended and percentage within the range

	Average intake ± SD of Female participants (N =14)	Recommendation	% Of subjects achieving Recommendation	Average intake ± SD of Male participants (N =6)	Recommendation	% Of subjects achieving Recommendation
Vitamin A (RE) (mcg)	465 ± 519.44	600-3000	28.57%	462± 417.40	700-3000	16.67%
Vitamin D (IU/mcg)	24 ± 61.12	5-50	21.43%	19±31.20	70-1000	33.33%
Vitamin C (mg)	72 ± 156.96	60-1000	14.29%	50±48.18	5-50	33.33%
Vitamin E (mg)	18 ± 32.90	10-1000	35.71%	22±38.94	10-1000	33.33%
Zinc (mg)	14 ± 8.02	4.6-45	64.30%	14 ± 8.38	6.5-45	100%
Selenium (mcg)	110 ± 108.77	33-400	71.43%	63±19.03	38-400	100%
Protein (g) 19-29 years old: Female(N = 12), Male (N=5)	152 ±129.19	48.75-72.375	69.23%	477± 222.23	63.26-94.875	60%
Protein (g) 30-50 years old: Female (N=2), Male (N=1)	104±3.15	46.75-60.5	0%	102.175	70.125-90.75	0%

5.1.4 Optimal Solutions

Table 5.2 Summary of cost of the formulated meal plans of males and females (both aged 19-29 and 30-50 years old)

Cost per day	Male (19-29 years old)	Male (30-50 years old)	Female (19-29 years old)	Female (30-50 years old)
Day 1	₱68.75	₱69.08	₱71.13	₱82.57
Day 2	₱85.12	₱86.12	₱91.86	₱119.37
Day 3	₱99.59	₱103.09	₱130.33	Infeasible
Day 4	₱123.38	₱133.68	Infeasible	Infeasible
Day 5	Infeasible	Infeasible	Infeasible	Infeasible
Day 6	Infeasible	Infeasible	Infeasible	Infeasible
Day 7	Infeasible	Infeasible	Infeasible	Infeasible

Table 5.2 above shows the summary of cost of the formulated meal plans of males and females (both aged 19-29 and 30-50 years old). As shown, the meals until the fourth day for males is within the food allocation expense of a Filipino individual which is Php 150.25 while the days beyond are already infeasible. On the other hand, the meal plans for females aged 19-29 years old are feasible until the third day while for those aged 30-50 years old are feasible only until the second day. The optimal food plan for the age group per day will be shown in Table 5.3-5.6.

Summary of One week Meal Plan

In summary, the one-week meal plan for males (aged 19-29 and 30-50 years old) and females (aged 19-29 and 30-50 years old) can be seen in the tables 5.3 - 5.6.

Table 5.3 Summary of Food Items of the Formulated Meal Plans of Males aged 19-29 years old

	Day 1		Day 2		Day 3		Day 4	
Cost	₱68.75		₱85.12		₱99.59		₱123.38	
Gender & Age Group	Recommended food items	Total amount (g)	Recommended food items	Amount (g)	Recommended food items	Amount (g)	Recommended food items	Amount (g)
Male (19-29 years old)	Quail (Pugo)	50	Duck, whole (Pato, buo) egg	50	Chicken, whole, (Manok, buo) egg	50	Duck, unfertilized (Penoy)	50
	Sunflower Oil (langis ng mirasol)	17	Palm Oil (langis ng anahaw)	25	Fish oil, cod liver	25.2	Canola oil	34
	Fish oil, cod liver	5	Anchovy, long-jawed (Dilis)	104	Sardines, in tomato sauce (Sardinas sa tomato sauce)	340.2	Carp (Karpa)	244
	Liver: pork, beef, carabeef, chicken (Atay)	3	Pork ear, barbeque (Tenga, baboy, barbecue)	236	Soy bean curd, tofu	5.98	Catfish, freshwater (Hito)	61
	Tripe: beef (Goto)	337	Banana, latundan (Saging, latundan)	160	Banana, saba (Saging, saba)	160	Soy bean curd, tokwa	27
	Pineapple (Pinya)	160	Milk, skim (Gatas, skim)	250	Milk, cow (Gatas, baka)	95.65	Swordfish (Malasugi/Espada)	8
	Milk, carabao (Gatas, kalabaw)	250	Rice prep, kalamay, with coconut curd topping (Kalamay, may latik)	400	Milk, evaporated, filled (Gatas, evaporada, filled)	40.38	Papaya, ripe (Papaya, hinog)	1
	Corn on cob: yellow, white (Mais sa busal: dilaw, puti)	308	Sugar, crude (pakaskas, panocha)	21	Milk, recombined (Gatas, recombined)	113.97	Pear (Peras)	159
	Taro (Gabi)	92	Bottle gourd/white squash, fruit (Upo, bunga)	27	Rice prep: glutinous, with grated coconut topping (Suman marwekos, may niyog)	394.49	Milk, low fat (Gatas, low fat)	250
	Sugar (Asukal muscovado, pula, puti)	21	Carrot	23	Sweet potato: yellow purple, white (Kamote: dilaw, murado, puti)	5.51	Banana, saba, boiled (Saging, saba, nilaga)	209
	Mushroom, fresh (Kabuti, sariwa)	92	Sweet potato, leaves (Kamote, dahon)	119	Nata de coco/nata de piña, sweetened	21	Plantains	86
	Mustard, leaves (Mustasa, dahon)	27	Taro, leaves (Gabi, dahon)	57	Coconut Shoot (Ubod, niyog)	211.57	Rice cake, brown (Puto, brown)	105
					Swamp cabbage, leaves (Kangkong, dahon)	13.43	Coconut meat, grated, sweetened (Bukayo)	21
							Tomato (Kamatis)	225

Table 5.4 Summary of Food Items of the Formulated Meal plans of Males aged 30-50

	Day 1		Day 2		Day 3		Day 4	
Cost	₱69.08		₱86.12		₱103.09		₱133.68	
Gender & Age Group	Recommended food items	Total amount (g)	Recommended food items	Amount (g)	Recommended food items	Amount (g)	Recommended food items	Amount (g)
Male (30-50 years old)								
	Corn oil (langis ng mais)	21	Fish oil, cod liver	11	Canola oil	2	Margarine	5
	Sunflower Oil (langis ng mirasol)	4	Palm Oil (langis ng anahaw)	14	Oil, marine (Aseyte)	23	Catfish, freshwater (Hito)	35
	Liver: pork, beef, carabeef, chicken (Atay)	4	Anchovy, long-jawed (Dilis)	79	Sardines, in tomato sauce (Sardinas sa tomato sauce)	280	Soy bean curd, tokwa	70
	Tripe: beef (Goto)	337	Pork ear, barbeque (Tenga, baboy, barbecue)	261	Soy bean curd, tofu	60	Squid (Pusit)	50
	Pineapple (Pinya)	160	Banana, latundan (Saging, latundan)	160	Banana, saba (Saging, saba)	160	Swordfish (Malasugi/Espada)	20
	Milk, carabao (Gatas, kalabaw)	250	Milk, skim (Gatas, skim)	250	Milk, cow (Gatas, baka)	123	Pear (Peras)	95
	Corn on cob: yellow, white (Mais sa busal: dilaw, puti)	232	Rice prep, kalamay, with coconut curd topping (Kalamay, may latik)	400	Milk, recombined (Gatas, recombined)	127	Milk, low fat (Gatas, low fat)	250
	Taro (Gabi)	168	Sugar, crude (pakaskas, panocha)	21	Rice prep: glutinous, with grated coconut topping (Suman marwekos, may niyog)	382	Banana, saba, boiled (Saging, saba, nilaga)	65
	Sugar (Asukal muscovado, pula, puti)	21	Bottle gourd/white squash, fruit (Upo, bunga)	23	Sweet potato: yellow purple, white (Kamote: dilaw, murado, puti)	18	Plantains	40
	Mushroom, fresh (Kabuti, sariwa)	92	Sweet potato, leaves (Kamote, dahon)	23	Nata de coco/nata de piña, sweetened	21	Rice cake, brown (Puto, brown)	50
	Mustard, leaves (Mustasa, dahon)	22	Taro, leaves (Gabi, dahon)	179	Coconut Shoot (Ubod, niyog)	220	Rice prep: glutinous, with yam (Kalamay, ube)	60
	Sweet potato, leaves (Kamote, dahon)	111			Swamp cabbage, leaves (Kangkong, dahon)	5	Coconut meat, grated, sweetened (Bukayo)	20
							Tomato (Kamatis)	40

Table 5.5 Summary of Food Items of the Formulated Meal Plans of Females aged 19-29 years old

	Day 1		Day 2		Day 3	
Cost	₱71.13		₱91.86		₱130.33	
Gender & Age Group	Recommended food items	Total amount (g)	Recommended food items	Amount (g)	Recommended food items	Amount (g)
Female (19-29 years old)	Quail (Pugo)	55	Chicken, whole, (Manok, buo)	50	Duck, fertilized (Balut)	50
	Fish oil, cod liver	5	Corn oil (langis ng mais)	17	Palm Oil (langis ng anahaw)	34
	Liver: pork, beef, carabeef, chicken (Atay)	30	Sunflower Oil (langis ng mirasol)	8	Chicken White meat (Laman)	33
	Tripe: beef (Goto)	85	Pork ear, barbeque (Tenga, baboy, barbecue)	272	Sardines, in tomato sauce (Sardinas sa tomato sauce)	124
	Pineapple (Pinya)	80	Soy bean curd, tofu	68	Soy bean curd, tokwa	184
	Milk, carabao (Gatas, kalabaw)	200	Banana, latundan (Saging, latundan)	160	Pear (Peras)	160
	Milk, cow (Gatas, baka)	200	Milk, low fat (Gatas, low fat)	250	Milk, recombined (Gatas, recombined)	250
	Milk, skim (Gatas, skim)	250	Rice prep, kalamay, with coconut curd topping (Kalamay, may latik)	400	Banana, saba, boiled (Saging, saba, nilaga)	108
	Taro (Gabi)	100	Sugar, crude (pakaskas, panocha)	21	Rice prep: glutinous, with grated coconut topping (Suman marwekos, may niyog)	292
	Sugar (Asukal muscovado, pula, puti)	5	Carrot	9	Nata de coco/nata de piña, sweetened	21
	Bottle gourd/white squash, fruit (Upo, bunga)	40	Mushroom, fresh (Kabuti, sariwa)	75	Tomato (Kamatis)	225
	Sweet potato, leaves (Kamote, dahon)	40	Mustard, leaves (Mustasa, dahon)	23		
			Taro, leaves (Gabi, dahon)	119		

Table 5.6 Summary of Food Items of the Formulated Meal Plans of Females aged 30-50

	Day 1		Day 2	
Cost	₱82.57		₱119.37	
Gender & Age Group	Recommended food items	Total amount (g)	Recommended food items	Amount (g)
Female (30-50 years old)	Chicken, whole, (Manok, buo)	50	Duck, fertilized (Balut)	50
	Fish oil, cod liver	25	Corn oil (langis ng mais)	9
	Liver: pork, beef, carabeef, chicken (Atay)	23	Sunflower Oil (langis ng mirasol)	16
	Liver: pork, beef, carabeef, chicken (Atay)	118	Chicken White meat (Laman)	29
	Liver: pork, beef, carabeef, chicken (Atay)	220	Pork ear, barbeque (Tenga, baboy, barbecue)	311
	Pineapple (Pinya)	160	Banana, latundan (Saging, latundan)	160
	Milk, cow (Gatas, baka)	107	Milk, low fat (Gatas, low fat)	250
	Milk, cow (Gatas, baka)	143	Tapioca pearls (Sago, tapioca)	400
	Taro (Gabi)	400	Sugar, crude (pakaskas, panocha)	21
	Sugar (Asukal muscovado, pula, puti)	21	Carrot	22
	Bottle gourd/white squash, fruit (Upo, bunga)	4	Eggplant (Talong)	68
	Sweet potato, leaves (Kamote, dahon)	221	Mushroom, fresh (Kabuti, sariwa)	76
			Sponge gourd, fruit (Patola, bunga)	60

5.3 Proposed Improvements

For further studies, the researchers recommend a larger sample size or available data which accurately represents the specific food items and daily micronutrient and protein intake of the National Capital Region. Additionally, it is recommended to distribute the survey materials to equal respondents considering the gender and age groups to avoid bias in the data. Future researchers can also reduce the age bracket to have a more focused and precise age group study. The food items must be reduced into more common household needs/food items widely available in every market/grocery in Metro Manila. To consider the staple Filipino household food, a constant variable such as plain rice can be added to the formulation of the model and can be retained per model run or day of the meal plan. This would result in more accurate data and be available for all consumers that wanted to avail themselves of the food items indicated in the optimal solution on the daily food items that the typical Filipino household intake. An alternative to the variables and approaches can also widen the scope of knowledge relevant to the study. The data analysis for further studies can integrate additional constraints resulting in varying food items with staple Filipino adding a binary constraint to accurately represent the edible portion based on the Food Frequency Questionnaire (FFQ). It can also be recommended to use data analysis software other than LINGO to have a more profound understanding and utilization of the acquired raw data in the study. Additionally, using a different sampling technique for the project to have a more established population representation.

6. Conclusion

The identification of food items that will minimize the total cost and provide the recommended micronutrients and protein daily recommended intake can be optimized using a mixed-integer linear programming approach. The models provided all required micronutrient and protein intake which can be capable of combating COVID-19. Through this study, the researchers were able to obtain the anthropometric and socio-demographic factors of the participants for descriptive analysis and identify the average daily intake of selected micronutrients and macronutrients of the 20 participants through the 24-hour Food Recall Record. With the usage of the Recommended Nutrient Intake (RNI) of the chosen micronutrient and macronutrient intake per day from Food Composition Tables (FCT) found at the PhilFCT FNRI DOST website, it was identified that 71.43 percent did not reach the recommended daily vitamin A intake, 78.57 percent lacked vitamin D intake, 85.71 percent of female respondents lacked daily vitamin C intake, 64.29 percent lacked daily E, 35.7 percent lacked daily zinc intake, 28.57 lacked daily selenium intake, and 30.77 percent of the 19-29-year-old female respondents did not reach the recommended daily protein intake. 83.33 percent of male respondents did not meet the recommended vitamin A intake. 66.67 percent of male respondents did not meet the recommended vitamin D, C, and E intake, and 40% of male respondents did not meet the recommended protein intake. Based on the 24-hour food record, the female respondents did not reach the recommended daily intake for Vitamin A, Vitamin D, Vitamin C, Vitamin E, Zinc, Selenium, Protein. The male respondents did not get the recommended daily intake for Vitamin A, Vitamin D, Vitamin C, Vitamin E, Protein. The 24-hour food recorded results showed the high demand for an optimal meal plan that would satisfy the recommended daily intake of selected micronutrients and

proteins that help combat COVID-19. A total of four models for Male (19-29 years old), Male (30-50 years old), Female (19-29 years old), and Female (30-50 years old) were formulated for the meal plan of seven days with varying food items.

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Biography

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Krizia Mile Joy Yu is currently taking up BS Industrial Engineering and a penultimate student from University of Santo Tomas. In her secondary, she graduated from Makati Science High School and was awarded with the Exemplary Leadership Award. She is an active youth volunteer in one of the oldest and biggest youth organizations in the world; the Young Men's Christian Organization (YMCA). She was involved in various international camps and conferences to represent her country. In 2018, she joined the International Youth Winter Camp as a Philippine Delegate held in South Korea. She also participated at Asia and Pacific Alliance of YMCAs (APAY) 4th Youth Assembly (in Tokyo, Japan) and APAY 20th General Assembly (in Tozanso, Japan). In 2020, she remained proactive despite the COVID-19 pandemic. She joined the virtual Youth-led Solution Summit 2020 and proposed a youth-led social project called Ykalakalikasan which received the highest funding among 50 countries. She is the President of Operations Research Society of the Philippines - UST for two years; an academic organization in her faculty which advocates the mathematical tool Operations Research. A change of leadership has been her response to lead the organization in the new normal. In her journey as a college student, she was recognized as Fr. Roque Ruano Leadership Awardee and a Dean's Lister in her department. Being an advocate of Operations Research, she is conducting a study to create a meal plan through a mathematical model that will boost the immune system as a supplemental response to COVID-19.

Gabriel C. Bucu is a candidate for a Master of Science in Industrial Engineering at De La Salle University-Manila. He earned his Bachelor of Science in Industrial Engineering at the University of Santo Tomas (UST). Presently, he is

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