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Research Article

Optimization of Food Expenditures in Nigeria: A Case Study of Lafia, Nasarawa State

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Abstract: Currently, the prices of commodities in Nigeria are consistently rising owing to several variables, including economic conditions, political influences, and technical progress. Consequently, the cost of essential items, including food, has risen significantly. Consequently, they often disregard nutritious dietary habits and fail to obtain adequate daily nutrients. This will lead to several repercussions, including diseases, disorders, and less vitality for daily activities. Meeting daily fundamental nutritional requirements has become a considerable challenge in Nigeria, where the average individual earns around N3,500 per day. The simplex method, an iterative algorithm in linear programming, is utilized to identify and select the most cost-effective food items from a range that includes orange, maize, rice, goat meat, eggplant, palm oil, cassava, beniseed, bean cake, ogbonoh, bread, beans, banana, chicken, carrot, and catfish. These foods provide vital elements like calories, lipids, proteins, carbohydrates, calcium, iron, potassium, salt, vitamin A, thiamin, riboflavin, and vitamin C, fulfilling the required daily dietary standards for the average individual in Lafia, Nasarawa State. The data was structured into an objective function and constrained by limitations. The matrices generated were computed using MATLAB code throughout eight iterations. Recent studies reveal that a typical Nigerian in Lafia need N1,904.54 daily from the N3,500 earned to meet fundamental nutritional needs at little cost. This may be accomplished using a food basket consisting of rice, eggplant, cassava, benniseed, and carrot. Given the ideal value of food, some commodities such as oranges, maize, goat meat, palm oil, cassava, bean cake, ogbonoh, beans, bananas, chicken, and catfish have been reported to have detrimental consequences resulting from excessive nutrient intake. A typical individual would allocate 54.42 percent of their daily income to food, based on this food basket and the projected food expenditure. A sensitivity analysis was conducted to assess the robustness of the results.

Keywords: Optimization, Expenditures, Simplex Method, Linear Programming

Introduction

Linear Programming (LP) is an optimization technique employed to address issues in which the objective function and constraints are expressed as linear functions of the decision variables. Numerous real-world problems, when formulated as linear programming models, encompass multiple variables and thus necessitate a more efficient approach to get optimal solutions for these challenges (Divya, 2016). This study illustrates the utilization of linear programming to minimize meal expenses while fulfilling health and diversity requirements. The cost of basic food items required for the sustenance of an average Nigerian family rose by 17.5 percent to N48, 151.5 in January 2023, compared to N40, 980 during the same period last year, according to the 2023 Minimum Wages study. Nigerian Price (2024) stated that food prices in Nigeria increased by 39.53 percent in July 2024 compared to July 2023. This is just behind the 40.87 percent increase recorded in June 2024, which was the highest ever measured. The National Bureau of Statistics (2022) documented a 17.21 percent rise in the composite food index in November 2021 compared to the previous year. Moreover, the average price of 1kg of loose rice rose by 134.81 percent in February 2024 compared to February 2023. The expected average monthly salary in Nigeria ranges from 80,000 to 150,000 Nigerian Naira. This figure represents the median income, signifying that half of the workforce earns below this level, while the other half earns above it. A myriad of factors affect health issues. The principal aspect that is highly adaptable and controllable is diet and nutrition (Nur *et al*., 2019). The diet encompasses the whole of food consumed, supplying essential nutrients and significantly influencing an individual's physical, cognitive, and social functioning. Nutrition is crucial for overall well-being, since various dietary choices may lead to bad decisions, fostering unhealthy behaviors and its associated consequences (Lindbladh and Lyttkens, 2002).

Nasarawa State is recognized for its agricultural potential; however, the industry faces challenges such as inadequate irrigation systems, substandard road networks, and limited access to financial facilities, leading to reduced crop yields and increased costs. The burgeoning population and urbanization of Lafia have led to a heightened demand for food, particularly processed and imported goods, resulting in inflated prices. The demand for food in Lafia is elevated, propelled by an expanding population and the existence of many institutions, notably the Federal University. Nonetheless, the availability of food, especially perishable goods, may be inconsistent, resulting in price volatility.

Food prices in Lafia may vary significantly depending on the season. During the rainy season, the prices of essential commodities like maize and rice may decrease due to increased local production. In contrast, prices may rise during the dry season when local production declines. These challenges are interconnected and can have a compounding impact on food prices in Lafia.

The objective of any dietary issue is to identify the most economical assortment of meals that satisfies an individual's basic daily nutritional needs. To get the ideal answer in the dietary problem, comprehensive nutritional information for each food item must be available, along with the individual's dietary limits. The objective function represents the cost per serving of each food product, while the restrictions pertain to the minimum dietary nutrients (including calories, fat, vitamins, carbs, etc.) that must be satisfied. Pratibha *et al*. (2020) assert that many nutrients, including carbs, proteins, fats, vitamins, and minerals found in food items such as wheat, rice, milk, carrots, and groundnuts, are beneficial for the maintenance, growth, reproduction, and health of humans. Their study aimed to identify the optimal solution and assess its sensitivity to the dietary issues of sedentary and moderately active women in India. They resolved this issue by employing the linear programming solver feature of MS Excel. Linear Programming optimization was employed in the study by Sultana *et al*. (2022) to determine the minimal cost and number of food products necessary for selecting an appropriate diet that provides adequate nutritional elements throughout a week for three distinct age groups.

The relative contributions of animal and plant food sources to sustained, healthy human diets remain unclear. The nutritional quality and cost of meals are Critical elements for sustainable food production. Chungchunlam *et al*. (2021) utilized Linear Programming (LP) to ascertain the composition of nutritionally adequate meal patterns at minimal cost. The hypothesis investigated was that animal-sourced foods will be incorporated into the most economical diets due to their high content of essential nutrients. The linear programming model was based on dietary patterns, retail food costs from 2020, and the daily energy requirements (11,150 kJ, 2,665 kcal) together with essential nutrient needs (29 nutrients in total) for a reference adult in New Zealand. The linear programming modeling approach is publicly accessible and freely available to efficiently demonstrate changes in dietary profiles and daily diet expenses, simulating variations in energy and nutritional needs, as well as price swings among food categories. Leticia *et al*. (2023) argued that eating provides the vital elements necessary for optimal growth and development. Nonetheless, meeting essential dietary needs while considering environmental sustainability may be challenging and complex. Previously, product development relied on trial-and-error procedures, which are intricate and time-consuming. Mathematical methodologies, such as linear programming, provide an alternative and expedited way for product development that incorporates nutritional or sustainability factors. This methodology has been extensively employed in dietary optimization; nonetheless, it inadequately resolves dietary issues involving several target functions.

Mushtak and Karrar (2023) presented a mathematical model of linear programming related to the diet problem, utilized to alleviate hypertension. This strategy was employed to mitigate hypertension in males aged 31 to 50 years. The model included foods that are low in fat but high in potassium, calcium, magnesium, iron, and vitamin E, as well as fiber and protein, which help reduce hypertension and harmful cholesterol levels, thus decreasing the risks of cardiovascular disease. Alaini *et al*. (2019) indicate that poor dietary habits are identified as a risk factor for cancer in various epidemiological studies. A healthy and balanced diet is crucial for reducing cancer risk.

The projected average monthly wage in Nigeria ranges from 80,000 to 150,000 Nigerian Naira (Timecamp, 2024). This statistic represents the median income, signifying that half of the workforce earns below this level, while the other half earns above it. This study estimates the daily earnings of an average Nigerian at N3, 500. Multiple sources, such as the World Bank and Nigeria's National Bureau of Statistics (NBS, 2022), report that the average Nigerian household dedicates approximately 60 percent of its income to food expenditures. This research seeks to identify a cost-efficient combination of food items that meets the nutritional requirements of the average Nigerian in Lafia, Nasarawa State.

Materials and Methods

Approach

The simplex method algorithm is employed to create an optimum linear programming diet model that identifies the most cost-effective assortment of food products meeting the necessary daily nutritional needs for the ordinary Nigerian in Lafia, Nasarawa. It is a linear programming algorithm extensively employed to address large-scale issues. It is an iterative strategy that progressively converges to an optimal solution for linear programming problems. This approach was deemed best suitable for the study since it provides an accurate result for the data reflecting the incurred costs. Linear programs are problems that may be formulated as follows:

$$Optimise\ c^T x$$
$$subectto:$$
$$Ax \geq b$$
$$Ax = b$$
$$x_{j\geq 0\ \ j=1,2,\ldots n}$$

Where the choice variables are delineated, the coefficient of the objective function is represented, a known matrix of coefficients is denoted, and a constant-valued vector is specified. The expression to be minimized is referred to as the objective function (in this instance). The equations and Ax = constitute the constraints that define a convex polytope for the optimization of the objective function.

Data Collection

The principal aim of the study is to ascertain the minimal dietary expenditure for an average Nigerian in Lafia, Nasarawa State, while conforming to the requisite daily nutritional standards, encompassing essential requirements for energy, fats, protein, carbohydrates, calcium, iron, potassium, sodium, vitamin A, thiamin, riboflavin, and vitamin C, utilizing the following food items: Orange, maize, rice, goat meat, eggplant, palm oil, cassava, beniseed, bean cake, ogbonoh, bread, beans, banana, chicken, carrot, and catfish. This study utilizes secondary data obtained from FitNigerian (2023) and the Nutrition Facts label (2023). Due to inflation rates in Nigeria and the study's timeframe, the prices of the specified food goods were acquired during the first and second quarters of 2024. The newly established markets, Kasuwan Koro, Modern Market, and Kasuwan Tomato, situated in Lafia, Nasarawa State, Nigeria, were examined during this period to assess the food goods offered (See Appendix).

Results and Discussion

The model has 16 variables and 12 constraints, yielding a solution to the issue, whereby the coefficients of the food, left-hand side constraint inequalities, and right-hand side constants are represented in matrix form as $Ax = b$. The simplex algorithm was written using MATLAB software. The code executed correctly with eight repetitions. The model indicates that N1, 904.5365 is the best answer for the linear programming diet problem.

It therefore represents the minimum daily expenditure required for an ordinary Nigerian to meet essential nutritional needs. To attain the least daily food cost, the "level column" in Table 2 indicates that the food basket must have 1.2699 g of rice, 4.8746 g of eggplant, 1.3025 g of cassava, 4.0726 g of beniseed, and 0.8889 g of carrots.

The "marginal column" in Table 2 reveals that several dietary products, including orange, maize, goat meat, palm oil, bean cake, ogbonoh, beans, banana, chicken, and catfish, have exhibited negative consequences associated with excessive intake of certain nutrients. Establishing the upper and lower thresholds for each nutrient in the aforementioned food items, which are widely produced and eaten in Lafia, will contribute to enhancing the minimal cost of food inside the food basket. The intake of any aforementioned food items would elevate food costs, since they are comparatively more expensive than the components of the food basket proposed by the model. To mitigate the risk of certain chronic diseases, we advise restricting the consumption of foods including oranges, maize, goat meat, palm oil, bean cake, ogbonoh, beans, bananas, chicken, and catfish, as these items have demonstrated adverse effects associated with excessive nutrient intake (Centers for Disease Control and Prevention, 2020). Excessive Vitamin C or zinc may lead to nausea, diarrhea, and abdominal cramps, while an overabundance of fats can result in heart disease, stroke, and diabetes. Excessive calcium is connected with the production of kidney stones. Elevated vitamin A levels correlate with hair loss, bone discomfort, and xerosis (Darko *et al.*, 2013).

Table 2: Optimal values of food items

Food Items	Lower	Level	Upper	Marginal
Orange	0	0	+∞	239.40
Maize	0	0	+∞	1.00
Rice	0	1.2699	+∞	0
Goat meat	0	0	+∞	17.70
Egg Plant	0	4.8746	+∞	0
Palm Oil	0	0	+∞	1.00
Cassava	0	1.3025	+∞	0
Beniseed	0	4.0726	+∞	0
Bean Cake	0	0	+∞	11.00
Ogbonoh	0	0	+∞	1.00
Bread	0	0	+∞	0
Beans	0	0	+∞	51.90
Banana	0	0	+∞	158.42
Chicken	0	0	+∞	4.00
Carrot	0	0.889	+∞	0
Catfish	0	0	+∞	74.70

Table 3 demonstrates that the upper and lower restrictions for calories, fat, protein, iron, vitamin A, thiamine, and riboflavin are non-binding within the model. The model's binding constraints encompass minimal requirements for carbohydrates, calcium, potassium, sodium, and vitamin C. Table 3 indicates that, despite these restrictions being obligatory, a unit increase on the right-hand side of any of them will not substantially elevate food expenses. An increase in the minimum limitations for carbohydrates, calcium, and potassium will elevate food expenses by ₦1.1455, ₦0.5799, and ₦0.0644, respectively. An increase of one unit in the minimal amounts of salt and vitamin C will raise the food cost by ₦0.1877 and ₦1.1241, respectively.

Table 4 displays the findings of the sensitivity analysis. Overall, there were little variances in the optimal solution when assessing the prices of the food goods enumerated in Table 1. A minor adjustment in the price of a food item is necessary to effect a change in the composition of the optimal food basket. If the price of a food basket component decreases (increases) somewhat, the elements of the food basket and the solution will remain unchanged, but the overall cost of food will decrease (increase). If a price increase surpasses the limits delineated in the "lower" and "upper" columns of Table 4, the quantity of that food item in the food basket will increase. Nonetheless, if the reduction transpires beyond the designated duration, the worth of the food item will decline. Should the decline be significant, the value will diminish to zero (the constituents of the food basket would alter).

Sensitivity analysis graphs of the linear programming diet model were created to illustrate how the ideal solution fluctuates as parameters are altered. Figure 1 illustrates a price sensitivity study for three food items: Rice, eggplant, and cassava, depicting the variations in their cost according to quantity (per 100g). The pricing patterns indicate that cassava prices are elevated at lower quantities but stabilize as quantities grow.

It signifies less price volatility, implying consistent pricing irrespective of quantity. The prices of eggplants exhibit a gradual decline as the quantity grows. It signifies increased price sensitivity, with prices falling markedly as bigger volumes are acquired. The prices of rice have experienced the most significant decline as the quantity rises. It indicates a very competitive market or bulk purchasing incentives resulting in significant price reductions. Consequently, based on these price patterns, rice is the most price-sensitive commodity in our research, exhibiting the greatest significant price reduction per unit of quantity. Eggplant exhibits moderate price sensitivity, characterized by significant yet incremental price reductions. Cassava exhibits the lowest sensitivity, sustaining very constant pricing.

Market insights reveal that items experiencing significant price reductions, such as rice, may suggest competitive market conditions or promotional pricing schemes aimed at stimulating bulk purchasing

Table 3: Optimal nutrient requirement values

Nutrients	Lower	Level	Upper	Marginal
Energy	2400	2400	+∞	0
Fat	78	78	+∞	0
Protein	50	50	+∞	0
Carbs	130	275	+∞	1.1455
Calcium	1300	1300	+∞	0.5799
Iron	8	18	+∞	0
Potassium	26	47	+∞	0.0644
Sodium	23	25	+∞	0.1877
Vit A	900	900	+∞	0
Thiamin	1.2	1.2	+∞	0
Riboavin	1.1	1.3	+∞	0
Vit C	90	90	+∞	1.1241

Table 4: Sensitivity analysis of food Items

Food Items	Lower	Current	Upper
Orange	110	130	+∞
Maize	130	140	+∞
Rice	130	135	+∞
Goat meat	200	250	+∞
Egg Plant	120	130	+∞
Palm oil	120	135	+∞
Cassava	120	130	+∞
Beniseed	180	200	+∞
Bean Cake	140	160	+∞
Ogbonoh	100	120	+∞
Bread	170	190	+∞
Beans	170	190	+∞
Banana	145	150	+∞
Chicken	230	250	+∞
Carrot	120	130	+∞
Catfish	190	200	+∞

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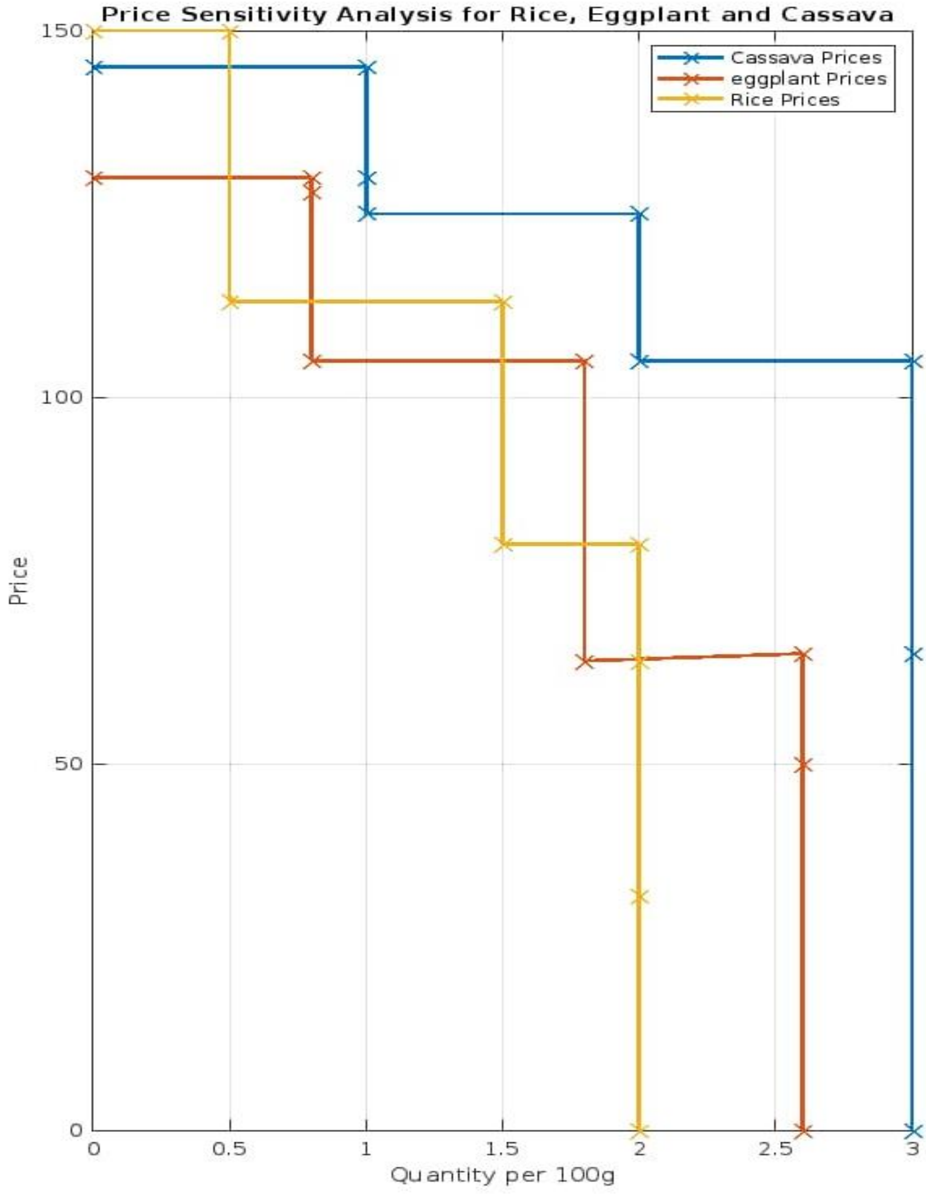

Fig. 1: Sensitivity of cassava, eggplant, and rice to price fluctuations

Stable pricing, such as those of cassava, may indicate reduced competition or steady demand. This research elucidates the variation in costs of certain food products relative to quantity, aiding consumers and sellers in comprehending market patterns and pricing tactics. Figure 2 illustrates a price sensitivity study for three distinct food items: Beniseed, Bread, and Carrots, demonstrating the variation in their pricing according to quantity (per 100 g). The price patterns indicate that beniseed prices start at an elevated level and maintain relative stability as quantity escalates, with a significant decline observed at bigger quantities. It indicates little price fluctuation until bulk volumes are attained. Bread prices demonstrate incremental reductions, reflecting a progressive sensitivity to price as supply rises. The costs of carrots exhibit the most pronounced and substantial decrease as quantity grows. It indicates that carrots exhibit significant price sensitivity, possibly affected by bulk buying incentives or competitive pricing strategies. Consequently, based on these pricing trends, carrots exhibit the highest price sensitivity, since their prices decline swiftly with larger quantities. Bread has modest price elasticity, with prices decreasing incrementally. Beniseed exhibits minimal price sensitivity, sustaining generally steady pricing over reduced volumes.

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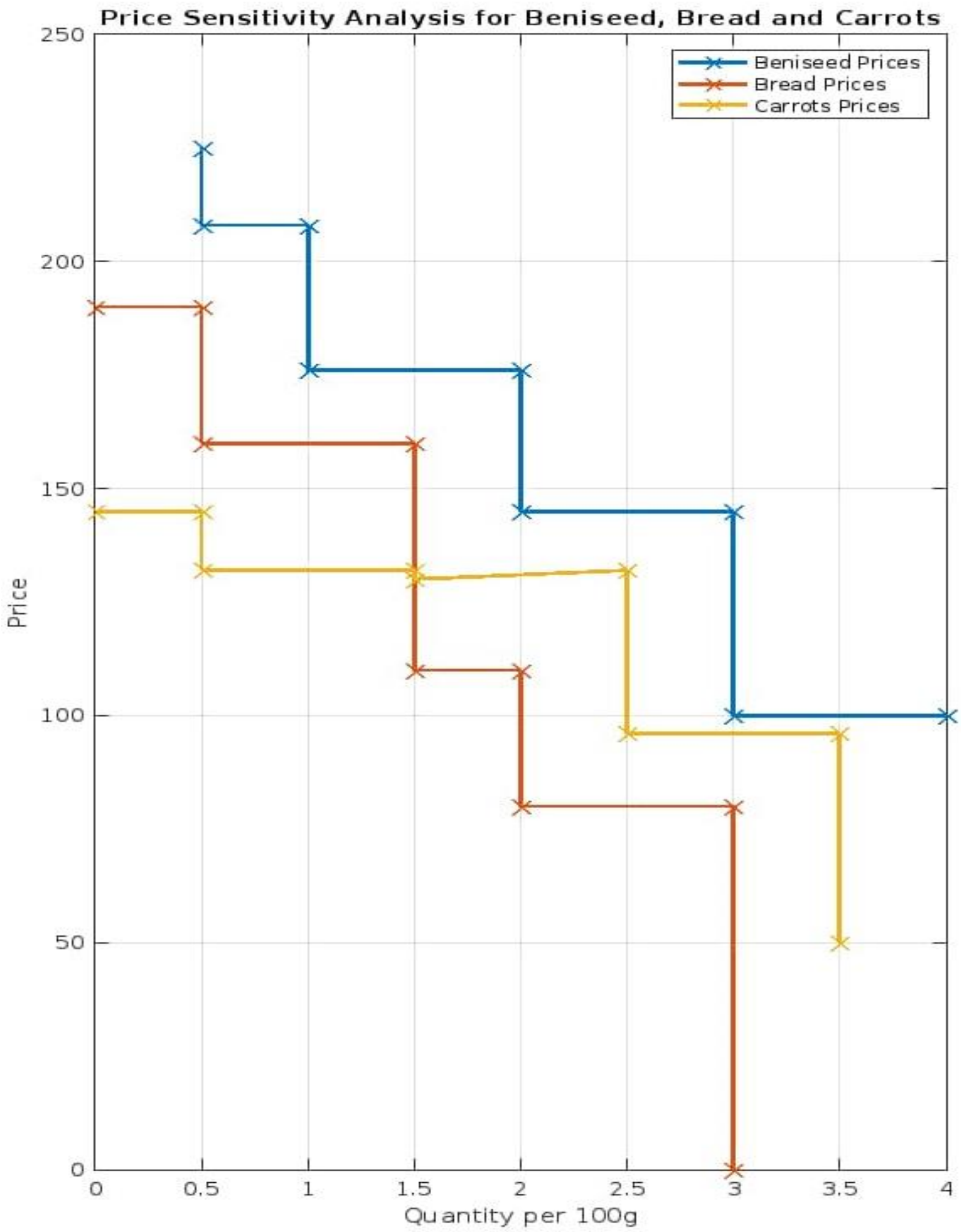

Fig. 2: Price variation to sensitivity of beniseed, bread, and carrots

The market insights indicate that carrots exhibit significant sensitivity, suggesting competitive marketplaces or volume-based discounts. The mild price drop of bread may indicate typical economies of scale in manufacturing and sales tactics. The constant prices of beniseed suggest less competition, demand, or a diminished reliance on bulk sales. This research elucidates the variation in pricing of beniseed, bread, and carrots in relation to quantity. It underscores price stability for beniseed, incremental reductions for bread, and substantial bulk pricing benefits for carrots, offering essential insights.

Conclusion

This study identifies the optimal expenditure on food in Nigeria, particularly in Lafia, Nasarawa State, where meeting daily nutritional needs has emerged as a considerable difficulty. The study utilizes secondary data to formulate and address a linear programming dietary problem using the simplex technique. The model has sixteen decision variables pertaining to the food selection, twelve constraints addressing the nutritional content of the diverse food items, and an objective function representing the meal costs. The problem was addressed using a Matlab method that executed eight iterations. The model simulation for the least cost diet determined that an average Nigerian may devote ₦1,904.5365 per day for nutritional requirements. The findings reveal that within the selected daily earnings of ₦3,500, the average Nigerian allocates at least ₦1,904.54 per day to meet their prescribed dietary requirements. A sensitivity analysis was conducted to illustrate the robustness of the results.

The study also emphasizes the most effective method to fulfill daily nutritional requirements from a selection of meals at least expense. The use of linear programming for cost minimization was utilized to determine the optimal mix of food products that may be acquired at the lowest expense while satisfying the essential nutritional needs of the ordinary Nigerian in Lafia, Nasarawa State. This study reveals that the typical Nigerian allocates 54.42 percent of their daily income to food expenditure, which is below the 60 percent benchmark established by the World Bank and the National Bureau of Statistics for 2022. The optimal value of ₦1,904.5365 constitutes 54.42 percent of the average daily income of Nigerians, which is ₦3,500 (National Bureau of Statistics, 2022), and is comparatively elevated in relation to developing countries, where average household expenditure on food ranges from 20 to 30 percent of income. The elevated proportion in Nigeria arises from many issues, including soaring food costs (inflation), restricted access to credit and financial services, low-income levels, significant reliance on food imports, and inefficient food supply systems. This proportion may fluctuate based on variables such as geographic location (urban or rural), income bracket, and household composition. To fulfill the daily nutritional requirements, it is advised to consume at least 1.2699 g of rice, 4.8746 g of eggplant, 1.3025 g of cassava, 4.0726 g of beniseed, and 0.8889 g of carrots.

This study enhances personalized nutrition by developing a linear programming model that optimizes eating patterns based on individual nutritional needs and health goals. Identifying diet-related health issues informs policies, interventions, and educational programs to promote healthy eating habits, as detailed in the research. Moreover, examining the psychological aspects of eating patterns and food choices contributes to the development of effective counseling and therapeutic strategies. The sensitivity analysis in this linear programming dietary problem evaluates how fluctuations in nutritional requirements, food prices, or availability affect optimal solutions. These contributions enhance the comprehension of cost reduction in food budgets via linear programming, promoting more efficient food budgeting, enhanced nutritional outcomes, superior decision-making, heightened food security, and diminished food waste. Through the application of Linear Programming for food budgeting, the researcher devises optimal solutions to reduce food costs while meeting an individual's nutritional needs in Lafia, Nasarawa State, thereby promoting healthy eating habits, preventing illness, and improving overall well-being.

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Authors Contributions

Olusola Collins Akeremale: Was responsible for the MATLAB code and final edited

Imam Akeyede: Carried out the analysis.

Ishaku Audu: Conceived the idea and was also responsible for the typed.

Adekemi O. Akeremale: Was responsible for the literature review.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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Appendix

Table 1: Prices and nutritional composition of 100 grams of food products

5.5	Price (N)	Energy (Kj)	Fat (g)	Protein (g)	Carbs (g)	Calcium (mg)	Iron (mg)	Potassium (mg)	Sodium (mg)	VitA (μg)	Thiamin (μg)	Riboflavin (μg)	Vit C (μg)
Orange	130	239.37	0.12	0.94	11.75	40	0.1	181	0	11	0.09	0.04	51.9
Maize	140	1584.23	3.95	9.26	74.69	17.21	2.4	355	30.5	0	0.38	0.16	5.7
Rice	135	1536.59	1.59	8.18	78.04	42	1.22	249	27.75	0	0.11	0.07	0
Goat meat	250	435.67	2.31	20.6	0	13	2.83	385	82	0	0.11	0.49	0
Egg plant	130	148	0.15	1.57	6.4	9	2.14	698	373	1	0.04	0.04	2.2
Palm Oil	135	3679	99.45	0	0	0	0.01	0	0	5720	0	0	0
Cassava	130	621.10	0.29	1.04	34.42	22	1.24	201.4	222.1	1	0.09	0.05	20.6
Beniseed	200	2475.78	46.84	17.42	22.43	281.1	9.19	106.7	23.55	0	0.79	0.25	0
Bean Cake	160	436.64	4.89	6.52	8.43	6.87	0.66	0.63	3.3	1.02	0	0	1.5
Ogbonoh	120	294.45	67.9	7.7	16.45	145	3.4	0	2	0	0.19	0.10	0
Bread	190	1191.325	4.01	8.82	51.76	89.84	4.07	172.73	350.16	0	0.3	0.06	0
Beans	190	623.86	0.50	11.61	21.52	6.19	1.24	0.91	6.7	0	0.17	0.04	0.2
Banana	150	439.82	.33	1.09	22.84	5	0.26	358	1	3	0.03	0.07	8.7
Chicken	250	565.1	5.9	20.4	0	11	1.1	276	84	17	0.09	0.16	0
Carrot	130	209.95	0.24	0.93	9.58	33	0.3	320	69	16706	0.07	0.06	59
Cat fish	200	439.58	3.05	18.2	0.61	166.43	10.66	0	0	3	0	1.85	18.01
Daily requirements		2400	78	50	275	1300	18	4700	2300	900	1.2	1.3	90