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A LINEAR PROGRAMMING APPROACH TO MINIMIZING BROILER RATION COSTS: THE CASE OF BROILER FARMS IN AL-AHSA, SAUDI ARABIA

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Abstract

The paper aims to estimate the least-cost ration of a sample of broiler farms in Al-Ahsa, Saudi Arabia. The farms were divided into three groups based on their production capacity. The linear programming technique was used to estimate the least-cost ration using the three-stage feeding system (starter, grower, and finisher). The results show that the optimal ration would save broiler farms in Al-Ahsa, on average, SAR 234,100, and their profit would increase by 47%, compared to their present situation. Furthermore, the optimal solution showed that the cost per bird would decrease by 7.3% if broiler farms adopted the recommended ration.

Key words*: *linear programming, least-cost, poultry ration

INTRODUCTION

The broiler industry is considered to be one of the main agricultural industries in Saudi Arabia (KSA) due to its return on investment and nutritional value. The main nutritional characteristics of chicken are that it is rich in protein and not expensive compared to other meat items in Saudi Arabia. In 2017, broiler farms in Saudi Arabia reached 917 farms with production capacity of 10,850,000,000 birds/year (Annual Agricultural Bulleting, 2017) [8]. The aggregate broiler projects in eastern province of Saudi Arabia represent 9.6% of the total KSA broiler projects, and its production capacity represents 4.9% of the total KSA production capacity. Poultry ration is very important due to its impact on the quantity and quality of produced chicken. Minimizing ration costs is important because it helps broiler farms to minimize their production costs and obtain greater return on their investment. Since feed cost represents almost 70% of total broiler variable production cost (Oladokun and Johnson, 2012) [7], this paper aims to estimate the least-cost ration of broiler farms in Saudi Arabia by focusing on the three-stage feeding system. In the three-stage feeding system, the birds are classified as starter (ages one day to three weeks, grower stage (one month), and finisher (over five weeks).

(Chen, 1973) [3] used a quadrating programming technique to estimate the least cost feed formulation for poultry. The author indicated that the quadratic programming is not efficient for the case of large problems. Miller et al., (1986) [5] used quadratic programming to estimate finishing broiler ration and stated that the savings from using the optimal ration can reach to $120 million per year. D'Alfonso et al., (1992) [4] used linear programming (LP), LP with marginal safety method, and stochastic programming (SP) to estimate the least-cost ration for poultry. The authors stated that ration obtained using the LP method was least-cost ration, and SP method produced lower ration costs compared to the LP with the marginal safety method. Al-Deseit (2009) [1] used the LP method to estimate the least-cost broiler ration for starter and finisher feed. Oladokun and Johnson (2012) [7] used the LP method to estimate the least-cost broiler ration in Nigeria. The author showed that the optimal

LP solution resulted in 9% reduction in feed costs.

This paper adds to the literature by applying the LP method to estimate least-cost ration on a sample of broiler farms in Al-Ahsa, Saudi Arabia, which are divided into three groups based on their production capacity. Also, the paper demonstrates how the optimal solution would reduce the cost of the sample of study, and how ration delivery can affect ration costs. Moreover, the paper conducts a sensitivity analysis to show which component of broiler ration has the greater price variability.

MATERIALS AND METHODS

The data is cross-sectional data that was collected from 33 broiler farms, which represent 35.9% of the total 92 broiler farms in the eastern province (Saudi Ministry of Environment, Water, and Agriculture Bulletin, 2017) [8]. The farms were classified into three groups based on their production capacity. The first group has a production capacity of less than 150,000 birds, the second category has a production capacity ranging from 150,000 to less than 300,000 birds, and the third category has a production category of more than 300,000 birds.

In order to achieve the purpose of this paper, this paper will use linear programming (LP) techniques to estimate the least-cost rations for broiler chicken in Al-Ahsa. The objective function represents the cost function of broiler rations that we aim to minimize. The model is expressed below (Al-Deseit, 2009; Almasad et al., 2011) [1, 2]:

$$\text{Minimize} \rightarrow Z = \sum C_{ij} X_j \rightarrow \text{Objective Function}$$

where Z is the total ration costs, C is the feed item cost, and X is the quantity of feed used in broiler farms.

The following are the required constraints to obtain the optimal broiler's ration:

$$X_1 + X_2 + X_3 + \cdots + X_n = b_1 \rightarrow \text{Ton}$$

$$a_1 X_1 + a_1 X_2 + \cdots + a_i X_n = b_2 \rightarrow \text{Protein\%}$$

$$a_2 X_1 + a_2 X_2 + \cdots + a_i X_n = b_3 \rightarrow \text{ME/kcal kg}$$

$$a_3 X_1 + a_3 X_2 + \cdots + a_i X_n = b_4 \rightarrow \text{Fiber\%}$$

$$a_4 X_1 + a_4 X_2 + \cdots + a_i X_n = b_5 \rightarrow \text{Fat\%}$$

$$a_5 X_1 + a_5 X_2 + \cdots + a_i X_n = b_6 \rightarrow \text{Ca\%}$$

$$a_6 X_1 + a_6 X_2 + \cdots + a_i X_n = b_7 \rightarrow \text{P\%}$$

$$a_7 X_1 + a_7 X_2 + \cdots + a_i X_n = b_8 \rightarrow \text{Lysine\%}$$

$$a_8 X_1 + a_8 X_2 + \cdots + a_i X_n = b_9 \rightarrow \text{Methionine\%}$$

$$a_9 X_1 + a_9 X_2 + \cdots + a_i X_n = b_{10} \rightarrow \text{Methionine+Cysteine\%}$$

a *is t*echnical coefficients of nutrient components as suggested by the National Research Council (1994) [6] and b is ration constraints. The model constraints provide the bird with the necessary protein, vitamins, antioxidants, etc. that are necessary for bird growth and health.

RESULTS AND DISCUSSIONS

The determinants of the objective function were obtained from the questionnaire of broiler farms in Al-Ahsa. Table 1 shows broiler feeding requirements based on the three-stage feeding system according to the information we obtained from the sample of study.

Table 1. Broiler feeding requirements based on the three-stage feeding system

Item	Constraints	Feeding Requirements		
		Starter	Grower	Finisher
Raw Protein	=	23.00	21.00	19.00
Energy (kilo calorie/kg)	=	3100	3100	3200
Dietary fiber	≤	2.430	2.410	2.310
Fats	≤	5.050	5.450	5.650
Calcium	=	1.000	0.900	0.850
Phosphorus	≥	0.500	0.450	0.450
Lysine	≥	1.380	1.200	1.100
Methionine	≥	0.550	0.540	0.510
Weight in kg	=	988.0	988.0	988.0

Source: Obtained from the sample of study.

On the other hand, the solution of the LP, as shown in Table 2 and Table 3, show that the fat percentage in Table 1 exceeds bird nutrients requirements.

Table 2. Determinants of broiler feeding requirements based on LP solution

Item	Starter	Grower	Finisher
Raw Protein	23.00	21.00	19.00
Energy (kilo calorie/kg)	3100	3100	3200
Dietary fiber	2.430	2.410	2.310
Fats	4.730	4.250	5.290
Calcium	1.000	0.900	0.850
Phosphorus	0.500	0.450	0.450
Lysine	1.380	1.200	1.100
Methionine	0.550	0.540	0.510
Weight in kg	988.0	988.0	988.0

Source: Own results.

The growth rate was by approximately 0.32%, 1.2%, and 0.36% higher for starter, grower, and finisher stages, respectively. However, the remaining feeding items matched the LP optimal solution.

Table 3. Minimum and maximum feeding requirements based on the LP solution

Item	Starter		Grower		Finisher	
	Min	Max	Min	Max	Min	Max
Raw Protein	23.00	0.000	21.00	0.000	19.00	0.000
Energy (kilo calorie/kg)	0.000	3100	0.000	3100	0.000	3200
Dietary fiber	0.000	2.430	0.000	2.410	0.000	2.310
Fats	0.000	4.730	0.000	4.250	0.000	5.290
Calcium	0.000	1.000	0.000	0.900	0.000	0.850
Phosphorus	0.000	0.500	0.000	0.450	0.000	0.450
Lysine	0.000	1.380	0.000	1.200	0.000	1.100
Methionine	0.000	0.550	0.000	0.540	0.000	0.510

Source: Own results.

Tables 4, 5, and 6 show components and costs of broiler chicken optimal ration for starter, grower, and finisher, respectively. The tables show that the total costs for optimal rations are SAR 1359, SAR 1287, and SAR 1313 for starter, grower, and finisher, respectively. Thus, the most expensive feeding stage is the starter and the least expensive stage is the grower. We can also see that the optimal ration shows that maize has the greatest percentage in broiler ration in all development stages. As a result, maize's total cost represents 30%, 35%, and 36% of the total cost in starter stage, grower stage, and finisher stage, respectively.

Table 4. Optimal ration components for starter stage

Ration Component	Quantity (KG)	% Ton	Actual Price	Cost
Maize	582.4	58.24	0.7	407.68
Soybean	269.4	26.94	1.15	309.81
Maize Gluten	75.50	7.550	2.063	155.76
Vegetable oil	21.00	2.100	5.000	105.00
Methionine	1.500	0.150	35.00	52.500
Lysine	3.500	0.350	21.00	73.500
Monocalcium Phosphate	18.30	1.830	1.50	27.45
Limestone	16.40	1.640	0.075	1.2300
Vitamins and Minerals	4.000	0.400	24.00	96.000
Premix	1.000	0.100	20.00	20.000
Anticoccidials	0.500	0.050	100.0	50.000
Antifungal	2.000	0.200	30.00	60.000
Sodium Chloride Salt	4.500	0.450	0.300	1.4000
Total	1,000	100.0	-	1,358.93

Source: Collected and calculated from LP solution using 2019 market prices.

Table 5. Optimal ration components for grower stage

Ration Component	Quantity (KG)	% Ton	Actual Price	Cost
Maize	639.7	63.97	0.7	447
Soybean	236.5	23.65	1.15	271.98
Maize Gluten	61.70	6.170	2.063	127.87
Vegetable oil	14.60	1.460	5.000	73.000
Methionine	1.700	0.170	35.00	59.500
Lysine	2.700	0.270	21.00	56.700
Monocalcium Phosphate	16.10	1.610	1.50	24.150
Limestone	14.90	1.490	0.075	1.1180
Vitamins and Minerals	4.000	0.400	24.00	96.000
Premix	1.000	0.100	20.00	20.000
Anticoccidials	0.500	0.050	100.0	50.000
Antifungal	2.000	0.200	30.00	60.000
Sodium Chloride Salt	4.500	0.450	0.300	1.4000
Total	1,000	100.0	-	1,287.32

Source: Collected and calculated from LP solution using 2019 market prices.

Table 6. Optimal ration components for finisher stage

Ration Component	Quantity (KG)	% Ton	Actual Price	Cost
Maize	679.0	67.9	0.7	475.3
Soybean	189.0	18.9	1.15	217.35
Maize Gluten	61.00	6.10	2.063	125.84
Vegetable oil	24.10	2.41	5.000	120.50
Methionine	1.700	0.17	35.00	59.500
Lysine	3.000	0.30	21.00	63.000
Monocalcium Phosphate	16.50	1.65	1.5	24.75
Limestone	13.70	1.37	0.075	1.0300
Vitamins and Minerals	4.000	0.400	24.00	96.000
Premix	1.000	0.100	20.00	20.000
Anticoccidials	0.500	0.050	100.0	50.000
Antifungal	2.000	0.200	30.00	60.000
Sodium Chloride Salt	4.500	0.450	0.300	1.4000
Total	1,000	100.0	-	1,313.27

Source: Collected and calculated from LP solution using 2019 market prices.

According to Tables 4, 5, and 6 the average ration cost per ton, if it was made in the farm, is SAR 1320. Table 7 shows the average ration cost per ton according to the sample of study. Table 7 also shows the cost based on the broiler farm production capacity, as stated earlier in the paper. We can see that the average cost per ton when ration is delivery to the farm gate is SAR 1700, and the average cost per ton when the ration is obtained directly from the manufacturer is SAR 1570. Consequently, there is SAR 130 profit in every ton that goes to a third party, such as a delivery company or courier. Thus, we can see that the broiler farms in Al-Ahsa would save, on average, SAR 380 and SAR 250 if they mix the optimal ration ingredients in their farms compared to farm gate deliveries and direct receiving from factories, respectively.

Table 7. Average ration cost per ton according the sample of study

Delivery type	Average cost per ton according to production capacity			Average Cost
	First group less than 150,000 bird	Second Group 150,000-300,000 birds	Third Group over 300,000 birds	
Farm Gate	1,809	1,707	1,583	1,700
Receives from factory	1,633	1,569	1,507	1,570
Third party profit	176	138	76	130

Source: Own results.

We then conducted a sensitivity analysis to reveal the sensitivity of the components of broiler rations based on changes in market prices. This helps us to know which item in the ration has greatest price volatility and which item has the least price volatility.

Table 8 shows the results of the sensitivity analysis for ration components that are required in starter stage, grower stage, and finisher stage, respectively.

Table 8. Sensitivity analysis of ration components' prices

Optimal Ration Component	Price in SAR per kg			% Price decrease	% Price increase
	Actual	Minimum	Maximum		
Maize	0.7	0.222	1.77	68.29	152.86
Soybean	1.15	-	1.38	-	20.00
Maize Gluten	2.063	1.70	5.01	17.60	142.85
Vegetable oil	5.000	-	7.710	-	54.200
Methionine	35.00	4.720	156.4	86.51	346.86
Lysine	21.00	4.710	208.5	77.57	892.86
Monocalcium Phosphate	1.50	0.03	∞	98.00	∞
Limestone	0.075	-	9.820	-	12,993

Source: Calculated using LP solution using 2019 market prices.

Table 8 shows that soybean, vegetable oil, and limestone are not subject to any reduction in price. Monocalcium phosphate, methionine, lysine, and maize reveal the greatest percentage decrease in price. Thus, decision makers in broiler farms should utilize the reduction in these ration component prices by supplying their farm needs when prices drop and reducing the impact of future price increases. This will reduce their total cost and help them to maximize their prices during the high-price season. Furthermore, limestone, lysine, methionine, maize, and maize gluten show the largest percentage increase in price. As a result, decision makers in broiler farms should try as much as possible to mitigate the effect of price increase in these components by either purchasing a large quantity when prices drop or utilize future markets. The infinity sign (∞) attached to monocalcium phosphate indicates that there is no limit for price increase and that the component is very necessary, according to bird biological needs, regardless of any future increases in price.

Tables 9 (in appendix) shows the average cost and revenue of the study sample and Table 10 (in appendix) shows the reduction in broiler farms' costs if they adopted the suggested optimal ration. We can see that the broiler farms in Al-Ahsa would save, on average, SAR 234,100. As a result, the average broiler farms' profit would increase from SAR 494,000 to SAR 728,100, which indicates that the percentage increase in their profit is 47%. Also, the average cost per bird would decrease by 8%, which will translate to a 56% increase in profit per bird.

Table 9. Sample average cost and revenue

Production capacity	**Number of birds**	Ration quantity per ton	Ration cost per ton	Ration total cost	Average sample total cost	Average sample revenue	Average sample net profit	Cost per bird	Profit per bird
First Group	119	338.2	1,809	611.8	1,721	1,845	124.7	14.6	1.1
Second Group	234	665.7	1,707	1,136.3	3,140	3,564	423.6	13.4	1.8
Third Group	374	1,062.2	1,583	1,681.5	4,849	5,783	933.6	12.9	2.5
Average	242	688.7	1,700	1,143.2	3,237	3,731	494	13.6	1.8

Note: Birds and values are in thousands SAR.

Table 10. Saving in average sample cost after optimal ration application

Production Capacity	Number of birds	Ration quantity per ton	Ration cost per ton	Ration total cost	Reduction in ration total cost	Average sample total cost after reduction in ration cost	average sample net profit after cost reduction	Cost per bird	Profitper bird
First Group	119	338.2	1,320	446.4	165.4	1,555.6	289.4	13.1	2.4
Second Group	234	665.7	1,320	878.7	257.6	2,882.4	681.6	12.3	2.9
Third Group	374	1,062.2	1,320	1,402.1	279.4	4,569.6	1,213.4	12.2	3.2
Average	242	688.7	1,320	909.1	234.1	3,002.9	728.1	12.5	2.8

Note: Birds and values are in thousands SAR.

CONCLUSIONS

The paper uses the LP technique to estimate the optimal least-cost ration for a sample of broiler farms in Al-Ahsa, Saudi Arabia. The sample represents 35.9% of total broiler farms in the eastern province. The farms were divided based on their production capacity into three groups. The first group has a production capacity that does not exceed 150,000 birds, the second group has a production capacity of 150,000 to 300,000 birds, and the third group has a production capacity of over 300,000 birds. The paper applied the LP technique by focusing on the three-stage feeding system (i.e. starter, grower, and finisher). The results show that the most expensive feeding stage is the starter and the least expensive stage is the grower. The paper also revealed that broiler farms would save more if they mix broiler ration components inside their farms rather than buying them from third parties. Sensitivity analysis reveals that limestone, lysine, methionine, maize, and maize gluten show the largest percentage increase in price. Thus, the decision makers of broiler farms are urged to supply as much as possible of their needs from these materials during the seasons of low prices or to use future markets to mitigate the risk of price uncertainty. This paper shows that if broiler farms in Al-Ahsa adopted the recommended optimal ration mix, they would save, on average, SAR 234,100 and their profit would increase by 47%.

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