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Optimization of Feed Ration Cost in Dairy Cattle by Genetic Algorithm

Sağmal İneklerde Yem Rasyonu Maliyetinin Genetik Algoritma ile Optimizasyonu

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ABSTRACT

Feeding animals is one of the important problems of those dealing with livestock breeding. In order for animals to live a healthy life, they need to have adequate and balanced nutrition. Providing nutrients from cheaper sources has an important place in animal husbandry. In this study, it was aimed to prepare low-cost feed rations for dairy cattle with Genetic Algorithm (GA). In the experiments, a milk yield of 20 and 25 Kg with 3.5% fat was targeted, taking as reference dairy cattle with a body weight of 450 to 600 Kg in the 10th lactation week. The results of the proposed model were compared to the National Dairy Council's raw milk production cost in June 2023, yielding an approximately 20% gain in feed cost. In addition, the proposed model is compared with Particle Swarm and Ant Colony optimization algorithms and the results are discussed.

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ÖZET

Havyan besleme, besicilik ile uğraşanların önemli sorunlarından biridir. Hayvanların sağlıklı bir yaşam sürebilmesi için yeterli ve dengeli beslenmeleri gerekir. Besin öğelerinin daha ucuz kaynaklardan sağlanması hayvancılıkta önemli bir yer tutmaktadır. Bu çalışmada, süt sığırları için Genetik Algoritma (GA) ile düşük maliyetli yem rasyonlarının hazırlanması amaçlanmıştır. Deneylerde, 10'uncu laktasyon haftasındaki 450 ile 600 Kg vücut ağırlığına sahip süt sığırları referans alınarak %3,5 yağlı 20 ve 25 Kg süt verimi hedeflenmiştir. Önerilen modelin sonuçları, Ulusal Süt Konseyi'nin 2023 Haziran ayındaki çiğ süt üretim maliyeti ile karşılaştırılmış ve yem maliyetinde yaklaşık %20'lik bir kazanç sağlanmıştır. Buna ek olarak önerilen model, Parçacık Sürüsü ve Karınca Kolonisi optimizasyon algoritmaları ile karşılaştırılmış ve sonuçları tartışılmıştır.

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1. INTRODUCTION

Animal production, one of the two main production areas of agriculture, aims primarily at the economic production of basic nutrients such as meat, milk and eggs, which ensure the survival of humankind and are indispensable elements of a balanced diet. Animal products are relatively expensive products that contain all the nutrients that humans need, especially protein, vitamins and minerals, in appropriate proportions, are easy to digest, have a unique taste and are relatively expensive. Therefore, the most important indicator of individual and social development is the production and consumption of animal products in sufficient quantities [1, 2].

The most important expense in animal production is feed and it constitutes approximately 70% of the total input. This indicates that for economical animal production, people working in this field must have sufficient knowledge about feeds [3, 4]. Increases in compound feed prices in our country, due to reasons such as the fact that feed raw material prices are above the world average, insufficient working capital and stock, the contractual raw material production model has not been developed, and the price formation according to quality, also pose an obstacle to the development of the compound feed industry [5].

In the nutrition of dairy cattle, emphasis should be placed on providing rough and concentrated feed, while providing cheap and high quality feed, and on the other hand, preparing a balanced nutrition program. Features such as the animal's breed, age, live weight, target milk yield and fat rate, lactation periods and general condition of the animal constitute important elements in determining nutritional requirements [6]. Today, animal production has made it necessary to develop solution-oriented projects not only in the fields of food, agriculture and mechanical engineering, but also in the fields of electronics and software. Various methods are used to meet the feed needs in animal production at low costs.

In our country, programs purchased from abroad to prepare feed rations cause high feed costs. At the same time, it increases the total cost by re-claiming usage fees every year. On the other hand, due to regional differences in feed raw materials, it appears that imported software does not fully meet the needs of animals consuming these feeds [7].

While traditional methods such as trial and error, Pearson Square method and algebraic calculation are used in the preparation of an optimal feed ration, with the development of technology, computer-aided methods and metaheuristics have also begun to be used. Additionally, linear and non-linear programming techniques are used in many studies in this field: A linear programming model was developed to reduce the total feed costs for dairy farm [8], dairy cattle feeding and feed calculator developed as a mobile application [9], mixed feed ration optimization using the GA [10], development of ration formulation for buffalo breeding [11], hybrid evolution strategies, and linear programming for beef cattle feed optimization [12]. Existing studies have demonstrated the benefits of using optimization problems to achieve stated goals. Milani et al. [13] stated that one of the most important points in animal nutrition is the preparation of appropriate rations. They reported that proper feeding of animals in terms of cost and production can significantly increase the productivity of livestock farming enterprises. They state that preparing an ideal feed ration is about accurately determining the animal's nutritional needs. They reported that feed ration preparation can be considered a NP (*Non-polynomial*) problem due to the presence of various parameters and many constraints after the animal's needs are met. Fatyanosa et al. [12] stated that the biggest obstacle faced by cattle breeders is the high-cost of feed. Livestock breeders have stated that cattle feed should be formulated that meets the nutritional requirements of cattle and minimizes feed costs. They also stated that this type of problems belongs to the constrained optimization class. They reported that various heuristic and deterministic algorithms were used to solve constrained optimization problems and applied to feed composition. However, they state that while it can consistently discover solutions that are truly close to the global optimum of the problem, there is still some instability in finding an essentially reliable technique.

The GA, one of the metaheuristic methods, is used in engineering, economics, mathematics, chemistry, physics, etc. it is widely used in many fields of science and technology [14, 15]. It is a well-known optimizer that has proven itself with its strong methodology in various types of scientific research. Studies on the preparation of cattle feeds show that the GA can be used to prepare low-cost feed rations [16].

There are many scientific studies in the literature aimed at preparing low-cost animal nutrition programs. Some of them are as follows: Wijayaningrum and Mahmudy [10] reported that determining feed ingredients is a difficult process and that various constraints such as minimizing the total cost of feed ingredients and maximizing the nutritional needs of farm animals must be taken into account simultaneously. They proposed a modified GA model to solve the problem. They reported that the change was made by applying numerical methods in creating the initial population in the GA. In their test results, they reported that the optimal parameters that can be used to produce a solution are the population size of 300, the number of iterations of 400, the crossover rate of 0.2 and the mutation rate of 0.6. They reported that the modified GA provided an average fitness value of 0.142357, while the classical GA provided an average fitness value of 0.094354. They proved that their proposed method provides a better result with a higher fitness value compared to classical GA. In their study, Guo and Zhang [17] proposed a feed formulation preparation method based on the principle of Differential Evolution (DE) algorithm to increase the feeding efficiency of lactating dairy cows and reduce feed costs. They used the NRC-2001 basic nutrient requirement prediction model of dairy cows and the common feed data of dairy cows in the Chinese Feed Database, and performed the feed formulation experiment for lactating dairy cows by analyzing the feed formulation with the DE algorithm. They reported that their method provided better performance in feed formulation results compared to the Linear Programming method. Juan et al. [18], in beef cattle; they reported that nutritional requirements vary according to live weight and live weight gain targets. They reported that it may be harmful for breeders because the live weight gain target cannot be achieved with an inappropriate feed ration and feed funds are spent inappropriately. They reported that the solutions produced by GA are close to the values needed by beef cattle and can be used to search for feed ration solutions. Hassani et al. [19] proposed in their study an intelligent and automatic model to optimize durability and sustainability in industrial dairy farms. They reported that to obtain the best result, they measured the model with both GA and PSO. Although both algorithms gave similar results, validation tests revealed the superiority of the genetic algorithm. Based on the results, they reported that the proposed model can increase the durability and sustainability of production on dairy farms and reduce environmental degradation caused by the production process. Uyeh et al. [20] in their study, they formulated a multi-purpose feed ration problem consisting of two objects; is to minimize feed cost and minimize deviation from stated requirements. They reported that the problem was solved using the population-based evolutionary multi-objective optimization algorithm NSGA-II, which resulted in an optimal set of comprehensive solutions in a single run. They reported that the availability of the full set of solutions included facilitates understanding of the relationship between different nutritional requirements and cost, thus leading to a more efficient decision-making process. They reported that they demonstrated the applicability of their proposed method by performing experimental simulations on several dairy and beef cattle feed ration problems. Kuntal et al. [21] in their study, they proposed a GP model that produces 10 liters of milk with 6% fat content for a non-pregnant buffalo weighing 450 kg and takes into account the standard nutrient requirement on a dry matter basis. Das and Mallik [22] stated in their study that it triggered the need for efficient evolutionary algorithms to find feed mix with minimum cost and maximum shelf life for dairy cattle. They reported that an attempt was made to introduce the self-adaptive multi-population approach with the recently proposed Quadratic Approximation-based Jaya (JaQA) algorithm. Also, they reported that the performance of this approach was tested on problems on the benchmark set of the Congress on Evolutionary Computation (CEC) 2006. According to their results, they reported that the proposed technique was more successful than some new algorithms. They then incorporated this approach into two real-life case studies to optimize feed costs for dairy cattle. The improved results under the applicable area indicated that the proposed method is farmer-friendly.

In this study, it was aimed to prepare a low-cost feed ration that provides the targeted milk yield in cattle by using the GA, one of the well-known metaheuristic methods. The developed GA-based feed ration model uses a dataset consisting of roughage, concentrated feed and minerals. For the targeted milk productivity, the proposed method was tested in three different experiments consisting of cattle with 450 and 600 kg body weight. Source code of the proposed model and dataset publicly available at GitHub (https://github.com/abdullahelen/FeedRationOptimizer).

2. NUTRIENT REQUIREMENTS OF DAIRY CATTLE

Dairy cattle need nutrients such as water, carbohydrates, protein, fat, vitamins and minerals in order to survive and obtain high productivity from them. All substances containing organic and inorganic nutrients that can be safely fed to animals in order to meet these requirements are called feed. The feed mixture that fully meets the nutritional requirements of an animal in its daily life is called a ration. Meeting survival and productivity needs requires consumption of sufficient amounts of nutrients (energy, protein, minerals, vitamins and water) [23]. The ration that meets all these needs is called a balanced ration. In other words, it is a feed mixture that meets the animal's daily nutritional requirement in an appropriate ratio and amount. The amount of feed containing the basic nutrients needed by an animal that is resting or not productive to maintain its live weight and normal body temperature and maintain its vital functions is called survival ration. The daily feed given to animals in addition to the survival rate ration in order to obtain animal productivity is called the yield ration [24]. In addition, nutrient needs of animals vary according to their physiological periods. For this reason, nutritional and energy needs were calculated based on productivity functions such as survival, growth, development, pregnancy, lactation and wool according to the animal species. These calculated values are considered nutritional standards. Therefore, feeding standards must be taken into consideration in the preparation of feed rations [25].

In order to achieve the targeted productivity in dairy cattle, improving environmental conditions is an important issue, in addition to the balanced and regular nutrition mentioned. The main condition for ensuring optimum efficiency is to calculate the animal's survival rate and productivity rate completely and accurately in terms of energy and nutritional needs and to feed it according to this principle. In terms of high milk productivity, it is essential to prepare an appetizing ration for dairy cattle with protein, fat, carbohydrates, vitamins, and minerals such as Ca, P and salt [26]. The daily dry matter rates that dairy cattle can consume vary depending on live weight and targeted milk productivity. NRC-2001 [27] estimates the dry matter intake (DMI) of lactating cows. The DMI equation is a combined combination of two published equations [28, 29]. The formulation in Eq. (1) is universal in that it can be applied at all stages of lactation in dairy cattle [30].

$$DMI = \frac{372}{1000} FCM + \frac{968}{10000} BW^{0.75} \times \left(1 - e^{\left[-\frac{192}{1000} \times \left(WOL + \frac{367}{100}\right)\right]}\right) \tag{1}$$

where FCM (fat-corrected milk) refers to the amount of fat-corrected milk, BW (body weight) refers to body weight of the animal, and WOL (week of lactation) refers to the lactation week of the dairy cattle. The amount of fat-corrected milk is calculated as shown in Eq. (2).

$$FCM_{\%} = 0.4Y_M + 15F_M \tag{2}$$

where Y_M refers to the amount of milk in kg and F_M refers to the amount of fat in milk in kg. For the F_M value here, 3.5% to 4% of the milk amount in Holstein cows is used. The F_M can take may vary for dairy cattle of different breeds. Calculating dry matter intake gives more accurate results, especially when calculations are made taking into account the Neutral Detergent Fiber (NDF) found in roughage [28]. However, less than 1% variation is seen in calculating the dry matter intake of dairy cows fed high-energy feeds containing 25-42% NDF dry matter [29].

All farm animals require energy for the maintenance of body functions, control of body temperature and productivity. Feed needs of farm animals; It is divided into two: maintenance and yield. The reason for this is that animals use some of the feed they eat to survive and some to produce productivity. The amount of energy required by dairy cows for daily living is given in Eq. (3) according to NRC-1989 [31].

$$\begin{aligned} NE_M &= 0.08\, BW^{0.75}\, Mcal/day \\ ME &= 0.133\, BW^{0.75}\, Mcal/day \end{aligned} \tag{3}$$

The NRC reported the net energy requirement for maintenance (NE_M) as 0.073 Mcal/Kg metabolic body weight, and by adding 10% as activity, it was defined as 0.08 Mcal NE_M. These requirements are for adult dairy cattle. Since young dairy cattle are still developing, 20% more is taken for dairy cattle in the first lactation and 10% more for cows in the second lactation.

The energy requirement for productivity in dairy cattle is calculated based on the energy content of the milk. In addition, the energy content of milk also varies depending on the amount of fat. NRC-1989 reported that 0.74 Mcal NE_L is required for 1kg of milk with 4% fat. Depending on the milk fat content, the energy amounts required for 1kg of milk according to different energy systems are as in Eq. (4).

$$\begin{aligned} NE_L &= 0.3512 + 0.0962f \;\; (Mcal/kg\ milk) \\ ME &= 0.577 + 0.165f \;\; (Mcal/kg\ milk) \end{aligned} \tag{4}$$

One of the issues that dairy cattle breeders attach importance to is providing adequate nutrition corresponding to the energy needed in the early period of lactation. To overcome this problem, energy density of the ration must be increased. Daily protein needs of a dairy cattle are expressed in digestible Crude Protein (CP) and its unit is gram. This is also the sum of maintenance and yield margin. The formulation given in Eq. (5) is used to determine the CP requirement in dairy cattle.

$$CP = 3.7\, BW^{0.75} + 85\, Y_M \tag{5}$$

where CP refers to the crude protein requirement of the dairy cattle in grams, $BW_{0.75}$ refers to the metabolic body weight and Y_M refers to the milk yield in Kg.

Minerals are elements necessary for the health and productivity of the animal. Minerals are typically classified as metal elements, which are inorganic compounds essential for many different body functions, from structure to nerve impulses to osmotic balance. Minerals are divided into two categories: macro minerals (Ca, P, Mg, K, Cl, Na and S) and micro minerals (Cu, I, Fe, Mn, Mo, Zn, Se). While the amount required for macro minerals is in grams, micro minerals are in mg or µg [32]. Minerals that should be included in the rations of dairy cows; They are Calcium (Ca), Phosphorus (P), Magnesium (Mg), Sodium (Na), Chlorine (Cl), Sulfur (S) and Potassium (K). Sodium and Chlorine are added to rations as salt. Another important issue here is the Ca/P ratio. With the onset of lactation, the need for Ca and P increases significantly. Because milk contains significant amounts of Ca and P minerals [33]. It is essential that calcium and phosphorus are present in certain proportions in the rations of dairy cows. This ratio (Ca/P) should be between $1/1 \sim 2/1$. Ca requirement in dairy cattle can be calculated with the formulation in Eq. (6).

$$Ca = 0.0154\, BW^{0.75} + (1.22\, FCM) \div 0.38 \tag{6}$$

Here, Ca refers to the calcium requirement of dairy cattle in grams, BW refers to the body weight of the dairy cattle, and FCM refers to the amount of fat-corrected milk. Additionally, the value of 0.38 in this equation shows the absorption efficiency of calcium in animal feed. P requirement in dairy cattle can be calculated with Eq. (7).

$$P = 0.143\, BW^{0.75} + (0.99\, FCM) \div 0.5 \tag{7}$$

Here, P refers to the phosphorus requirement of dairy cattle in grams, BW refers to the body weight of dairy cattle, and FCM refers to the amount of fat-corrected milk. The recommended amount of Na for lactating cows is 0.18% and the amount of Cl is 0.25%. These amounts are 80% more than requirement of dairy cattle in dry period [33].

Fats contain more energy than concentrated feeds and therefore can be preferred in preparing high-energy rations for dairy cattle [34]. 1kg of fat contains approximately 2-2.5 times more energy than 1kg of carbohydrates. If fat is used instead of some of the carbohydrates in the diet, the energy efficiency of the diet will increase. Thus, problems such as high starch content in the feed ration and insufficient roughage will be eliminated. Feeding recommendations typically state that no more than 8% fat in total dry matter should be fed [32].

3. MATERIAL AND METHOD

In this section, technical details are given about dataset we used in feed ration preparation and, the constraint and fitness function designed for the proposed GA model.

3.1. Dataset

The dataset is included in the book published in 2001 by the NRC (National Research Council) in the USA under the name "*Nutrient Requirements of Dairy Cattle*" [27]. The tables in the Nutrient Compositions of Feeds section in the book have been examined, and the relevant values containing the nutritional and mineral compositions of some feedstuffs commonly used in dairy cattle have been created from these tables as reference.

Table 1. Roughages in the ration dataset.

#	Feedstuff	Price (TL/Kg)	DM %	CP %	ME Mcal/kg	NEl Mcal/kg	EE %	NDF %	ADF %	Ash %	Na %	Ca %	P %	Sugar %	Starch %
1	Alfalfa	6.500	90.3	19.2	1.96	1.19	2.50	41.6	32.8	11.0	0.10	1.47	0.28	7.90	1.40
2	Corn silage	2.600	35.1	8.80	2.33	1.45	3.20	45.0	28.1	4.30	0.01	0.28	0.26	1.42	27.0
3	Wheat straw	2.400	92.7	4.80	1.44	0.82	1.60	73.0	49.4	7.60	0.12	0.31	0.10	0.70	2.60
4	Wheat silage	2.000	33.3	12.0	1.91	1.16	3.20	59.9	37.6	8.60	0.07	0.38	0.29	1.60	4.40

Table 2. Concentrate feeds in the ration dataset.

#	Feedstuff	Price (TL/Kg)	DM %	CP %	ME Mcal/kg	NEl Mcal/kg	EE %	NDF %	ADF %	Ash %	Na %	Ca %	P %	Sugar %	Starch %
1	Barley	6.400	91.0	12.4	2.92	1.86	2.20	20.8	7.20	2.90	0.02	0.06	0.39	2.43	52.34
2	Canola meal	8.250	90.3	37.8	2.75	1.76	5.40	29.8	20.5	7.40	0.07	0.75	1.10	8.20	8.30
3	Corn gluten meal	13.50	86.4	65.0	3.66	2.38	2.50	11.1	8.20	3.30	0.05	0.06	0.60	1.58	18.12
4	DDGs	8.700	90.2	29.7	3.03	1.97	10.0	38.8	19.7	5.20	0.30	0.22	0.83	4.44	7.78
5	Maize	6.300	88.1	9.40	3.12	2.01	4.20	9.50	3.40	1.50	0.02	0.04	0.30	1.54	71.86
6	Cotton bagasse	5.700	90.5	44.9	2.70	1.71	1.90	30.8	19.9	6.70	0.07	0.20	1.15	2.12	0.33
7	By-pass FCS	42.00	95.3	0.00	6.27	5.02	84.5	0.00	0.00	15.5	0.00	12.0	0.00	0.00	0.00
8	Molasses	5.650	77.9	8.50	2.88	1.84	0.20	0.10	0.10	11.4	1.48	0.15	0.03	68.0	0.00
9	Rice bran	7.800	90.6	15.5	3.09	2.05	15.2	26.1	13.1	10.4	0.03	0.07	1.78	0.57	21.46
10	Soybean meal	12.70	89.5	53.8	3.41	2.21	1.10	9.80	6.20	6.40	0.03	0.35	0.70	11.3	3.77
11	Soybean hull	6.300	91.0	43.0	4.0	2.72	19.0	22.1	14.7	5.00	0.01	0.26	0.64	10.4	2.80
12	Sunflower meal	7.500	92.2	28.4	2.24	1.38	1.40	40.3	30.0	7.70	0.04	0.48	1.00	7.35	8.27
13	Wheat bran	5.600	89.1	17.3	2.55	1.61	4.30	42.5	15.5	6.30	0.04	0.13	1.18	4.73	21.79
14	Wheat	6.700	89.4	14.2	3.10	1.99	2.30	13.4	4.40	2.00	0.01	0.05	0.43	2.12	65.1

The dataset we use in experimental studies is divided into three main categories: roughages, concentrated feeds and minerals. As shown in Table 1, there are alfalfa, wheat straw, corn and wheat silage in the roughage category, and the nutritional values and unit prices of these feeds in kg are also included. Similarly, nutrients in the concentrated feed category are listed in Table 2, and nutritional values of minerals and unit prices in kg are listed in Table 3. Abbreviations in the columns of tables (Table 1, Table 2 and Table 3): dry matter (DM), crude protein (CP), metabolic energy (ME), net energy of lactation (NEl), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), sodium (Na), calcium (Ca) and phosphor (P). In addition, DDGs in Table 2 stands for dried distillers grains with soluble; MCP and DCP in Table 3 stand for Monocalcium phosphate and Dicalcium phosphate, respectively. The kg values of all feedstuffs in the tables are for 2023 and are in Turkish Lira.

3.2. GA-based Feed Ration Model

In our GA-based model, we designed a fitness function considering the key requirements used in development and implementation of the NRC feeding programs for dairy cattle. The goal in solving the problem is the lowest cost feed ration that can provide dairy cattle's needs in a balanced way (taking into account nutritional standards). The four main elements that need to be known when preparing a ration are as follows: Nutrient requirements of dairy cattle, nutrient contents, restrictive features and raw material costs.

The first stage of the developed model is to transform the attributes of various types of food resources into a computable table. The dataset (v), which we used in experimental studies and shown divided into separate nutrient categories in Table 1, Table 2 and Table 3, was converted into a single data model consisting of 23 rows and 16 columns for ease of calculation of costs and constraints. Thus, the content of a feedstuff in i-th row is defined as

Table 3. Minerals in the ration dataset.

#	Feedstuff	Price (TL/Kg)	DM %	CP %	ME Mcal/kg	NEl Mcal/kg	EE %	NDF %	ADF %	Ash %	Na %	Ca %	P %	Sugar %	Starch %
1	Calcium carbonate	0.475	100	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	34.0	0.02	0.00	0.00
2	MCP	32.00	97	0.00	0.00	0.00	0.00	0.00	0.00	97	0.00	16.4	21.6	0.00	0.00
3	DCP	35.00	97	0.00	0.00	0.00	0.00	0.00	0.00	97	0.00	22.0	19.3	0.00	0.00
4	Sodium chloride	2.250	100	0.00	0.00	0.00	0.00	0.00	0.00	100	39.34	0.00	0.00	0.00	0.00
5	Sodium bicarbonate	13.50	100	0.00	0.00	0.00	0.00	0.00	0.00	100	27.0	0.00	0.00	0.00	0.00

shown below:

- $v_{i,1}$: Type of nutrient (1: roughage, 2: concentrated feed, 3: mineral)
- $v_{i,2}$: Amount of nutrients used in the ration.
- $v_{i,3}$: Price per kilogram of the nutrient in ₺
- $v_{i,4}$: Dry Matter (DM) ratio
- $v_{i,5}$: Crude Protein (CP)
- $v_{i,6}$: Metabolic Energy (ME)
- $v_{i,7}$: Net Energy of Lactation (NEl)
- $v_{i,8}$: Ether-extract (EE)
- $v_{i,9}$: Neutral Detergent Fiber (NDF)
- $v_{i,10}$: Acid Detergent Fiber (ADF)
- $v_{i,11}$: Ash ratio
- $v_{i,12}$: Sodium (Na)
- $v_{i,13}$: Calcium (Ca)
- $v_{i,14}$: Fosfor (P)
- $v_{i,15}$: Sugar
- $v_{i,16}$: Starch

In the GA-based feed ration model, a chromosome is represented as shown in Fig. (1). The gene values represented on the chromosome include amounts in grams of the 23 nutrients in the dataset. The value range for each gene is from 0 to DMI given in Eq. (1), converted to grams ($DMI \times 1000$). In the GA model, the roulette wheel selection method and the double-point crossover method were used. Crossover and mutation rates were determined as 85% and 1%, respectively.

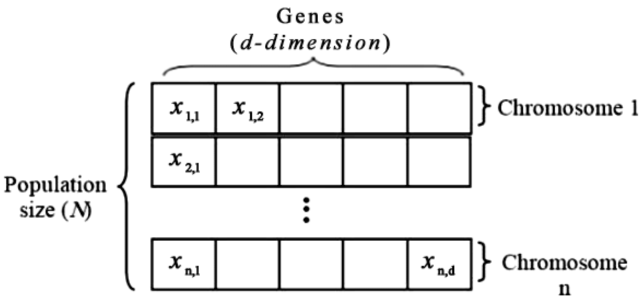

Figure 1. Representation of chromosomes and genes in the population.

Accordingly, for a possible solution, genes with nutrient weights other than 0 will be used in the preparation of the ration. That is, the prepared feed ration may contain 23 different nutrients or less. When calculating the fitness value of chromosomes, minimizing the total feed cost is taken as a basis, and the constraints explained below must also be taken into consideration. The difference between the total dry matter in solution found by the GA and the required minimum dry matter amount (DMI) is as in Eq. (7). Accordingly, if the GA solution contains a value below the DMI, a penalty coefficient equal to the difference will be applied.

$$f_{DMI}(i) = DMI - min\left(DMI, \sum_{j=1}^{d} x_{i,j} \cdot \frac{v_{i,4}}{100}\right) \tag{7}$$

Where $v_{i,4}$ is the dry matter ratio of the j-th food and $x_{i,j}$ is the amount of nutrient represented by the j-th gene of the i-th chromosome. Similarly, the difference between required minimum crude protein (CP) amount and the GA solution is calculated as in Eq. (8).

$$f_{CP}(i) = CP - min\left(CP, \sum_{j=1}^{d} x_{i,j} \cdot \frac{v_{i,5}}{100}\right) \tag{8}$$

Where $v_{i,5}$ is the crude protein ratio of the j-th food. The constraint function where ash rate in the feed ration is desired to be a maximum of 10% of the dry matter amount is as in Eq. (9).

$$f_{Ash}(i) = max\left(\sum_{j=1}^{d} x_{i,j} \cdot \frac{v_{i,11}}{v_{i,4}},\ 0.1\right) - 0.1 \tag{9}$$

Where $v_{i,4}$ and $v_{i,11}$ represent the dry matter and ash ratios of the j-th food, respectively. The desired constraint function for sugar rate in the feed ration to be a maximum of 8% of the dry matter amount is as in Eq. (10).

$$f_{Sugar}(i) = max\left(\sum_{j=1}^{d} x_{i,j} \cdot \frac{v_{i,15}}{v_{i,4}},\ 0.08\right) - 0.08 \tag{10}$$

Where $v_{i,4}$ and $v_{i,15}$ represent the dry matter and sugar ratios of the j-th food, respectively. The constraint function where starch rate in the feed ration is desired to be a maximum of 35% of the dry matter amount is as in Eq. (11).

$$f_{Starch}(i) = max\left(\sum_{j=1}^{d} x_{i,j} \cdot \frac{v_{i,16}}{v_{i,4}},\ 0.35\right) - 0.35 \tag{11}$$

Where $v_{i,4}$ and $v_{i,16}$ represent the dry matter and starch ratios of the j-th food, respectively. The desired constraint function for the ether extract (EE) ratio in the feed ration to be a maximum of 6% of the dry matter amount is as in Eq. (12).

$$f_{EE}(i) = max\left(\sum_{j=1}^{d} x_{i,j} \cdot \frac{v_{i,8}}{v_{i,4}},\ 0.06\right) - 0.06 \tag{12}$$

Where $v_{i,4}$ and $v_{i,8}$ are the dry matter and ether-extract ratios of the j-th food, respectively. The constraint function that ensures that roughage ratio in the feed ration is not less than 40% is as in Eq. (13).

$$f_{Roughage}(i) = 0.4 - min\left(\frac{\left(\sum_{j=1}^{d}\begin{cases} x_{i,j}, & v_{i,1}=1 \\ 0, & otherwise\end{cases}\right)}{\sum_{j=1}^{d} x_{i,j},}\ \ 0.4\right) \tag{13}$$

The constraint function that the amounts of calcium (Ca) and phosphorus (P) in the ration should not be less than the value determined according to Eq. (6) and (7) is as in Eq. (14).

$$\begin{gathered} f_{Ca}(i) = Ca - min\left(\sum_{j=1}^{d} x_{i,j} \cdot v_{i,13},\qquad Ca\right), \\ f_P(i) = P - min\left(\sum_{j=1}^{d} x_{i,j} \cdot v_{i,14},\ P\right) \end{gathered} \tag{14}$$

Where $v_{i,13}$ and $v_{i,14}$ are the calcium and phosphorus ratios of the j-th food, respectively. The constraint function for which the amount of salt in the feed ration should be between 50 and 75 grams is as in Eq. (15).

$$\begin{gathered} f_{NaCl}(i) = 50 - min\left(\sum_{j=1}^{d}\left(x_{i,j} \cdot v_{i,13}\right), 50\right) + max\left(\sum_{j=1}^{d}\left(x_{i,j} \cdot v_{i,13}\right), 75\right) - 75, \\ f_{\mathrm{NaHCO_3}}(i) = 50 - min\left(\sum_{j=1}^{d}\left(x_{i,j} \cdot v_{i,14}\right), 50\right) + max\left(\sum_{j=1}^{d}\left(x_{i,j} \cdot v_{i,14}\right), 75\right) - 75 \end{gathered} \tag{15}$$

Up to this point, mathematical notations of constraint functions designed according to the NRC's recommendations have been explained. In the next stage, we define the fitness function that is included in the constraints. The sum of feed costs and penalty points calculated for all chromosomes in the population is shown in Eq. (16).

$$F(i) = \sum_{j=1}^{d} x_{i,j} \cdot v_{i,3}\begin{pmatrix} 1 + D \cdot f_{DMI}(i) + \frac{3}{2}\left(f_{CP}(i) + f_{Roughage}(i)\right) + \\ f_{Ash}(i) + f_{Sugar}(i) + f_{Starch}(i) + \frac{f_{Ca}(i) + f_P(i)}{10}\end{pmatrix} \tag{16}$$

In order to solve the low-cost feed ration problem with the GA, a fitness function was prepared by taking into account the above-mentioned constraints and a limited range of chromosome values. The fitness function given in Eq. (17) aims to find the minimum penalty score, taking into account nutritional standards.

$$fitness = min\{i | i \in \{0,1,\ldots,n\}, F_i\} \tag{17}$$

Where n is the population number. Accordingly, the fitness function finds the chromosome with the lowest penalties in the population at each iteration. The smallest fitness score of all time is found by Eq. (18).

$$fitness_{Best} = \begin{cases} fitness_t & fitness_t < fitness_{Best} \\ fitness_{Best} & otherwise \end{cases},\ t | t \in \{0,1,\ldots,T\} \tag{18}$$

Where T is the number of iterations. Accordingly, if the fitness value at the t-th iteration is less than the best value, the current fitness is determined as the best. This process is repeated continuously at each iteration until the algorithm is terminated.

4. EXPERIMENTAL RESULTS

In all our experimental studies, crossover and mutation rates of the GA are 85% and 1%, respectively. The number of iterations was determined as 500. Roulette-wheel was used for chromosome selection and two-point technique was used for crossover.

In the first experiment, the target was to produce 20kg of milk with 3.5% fat content from a cow in its 10th lactation week with a body weight of 450 kg. Table 5 lists the expected values of nutrient requirements for targeted milk productivity and the values found by the GA. When the results obtained are compared, it is seen that the GA significantly provides the expected nutritional requirement values in terms of zoo-technics. In addition, the values found in nutritional requirements; It was observed that results above expected values were obtained in CP, ME, NEl, Ca and P.

Table 5. Expected nutritional requirements and GA results for 20 kg of milk with 3.5% fat at 450 kg BW.

#	Nutrient requirements	Expected value	GA result
1	Amount of Dry Matter (DM)	15.16 Kg	15.16 Kg
2	Crude Protein (CP)	2061.5 g	2884.85 g
3	Metabolic Energy (ME)	36.08 Mcal	45.85 Mcal
4	Net Energy (NEl)	21.8 Mcal	28.7 Mcal
5	Crude Ash Ratio	10% ≤	7.32%
6	Sugar Ratio	8% ≤	9.09%
7	Starch Ratio	35% ≤	22.29%
8	Ether-extract (EE) Ratio	6% ≤	2.58%
9	Roughage Ratio	40% ≥	48.78%
10	Neutral Detergent Fiber (NDF) Ratio	25% >	46.84%
11	Amount of Calcium (Ca)	82.43 g	69.4 g
12	Amount of Phosphorus (P)	49.47 g	70.81 g

The feed ration solution found by the GA is given in Table 6. Considering the feed ingredients and food types according to the test results, feed ration containing the animal's daily nutritional requirements; It is seen that a total of 15 different feed ingredients are used, including four types of roughage, six types of concentrated feed and five types of minerals. Total weight in the feed ration is 19,11 Kg and feed cost is 103,57 TL. In the proposed feed ration solution, wheat straw and wheat silage were mainly used in roughage, and barley and molasses were used in concentrated feeds. Also, it is seen that the amount of sugar in the feed ration is 1% high in meeting nutritional requirements, but it meets other requirements at ideal rates.

In the second experiment, a dairy cattle with a body weight of 600 kg in the same lactation week (10th) is aimed to yield 20 kg of milk with a fat content of 3.5%. Table 7 shows the expected values of nutrient requirements for the targeted milk productivity and optimal results obtained with the GA. When the optimal results are compared,

Table 6. Feed ration prepared with the GA for 20 kg of milk with 3.5% fat at 450 kg BW.

#	Animal food ingredients	Type of nutrient	Amount (g)
1	Alfalfa	Roughage	1385
2	Corn Silage	Roughage	1130
3	Wheat Straw	Roughage	4606
4	Wheat Silage	Roughage	2198
5	Barley	Concentrate Feed	2014
6	Corn Gluten Meal	Concentrate Feed	1446
7	Dried Distillers Grains (DDGs)	Concentrate Feed	1040
8	Maize	Concentrate Feed	1464
9	Molasses	Concentrate Feed	2031
10	Wheat	Concentrate Feed	1591
11	Calcium Carbonate	Mineral	2
12	Monocalcium Phosphate (MCP)	Mineral	53
13	Dicalcium Phosphate (DCP)	Mineral	23
14	Sodium Chloride (NaCl)	Mineral	72
15	Sodium Bicarbonate ($NaHCO_3$)	Mineral	50
		Total Price:	**103.57 TL**
		Total Feed Weight:	**19.11 Kg**

it is seen that GA significantly provides the zoo-technically expected nutrient requirement values. According to the first experiment, it was observed that there was an increase in the need for DM as the body weight of the animal increased from 450 Kg to 600 Kg. When the expected DM values for dry matter intake of NRC 2001 in Eq. (1) were compared, it was seen that the results were valid.

The feed ration solution found by the GA is given in Table 8. When the feed ingredients and types are examined according to the test results, the feed ration containing the daily nutritional requirements of dairy cattle; It is seen

Table 7. Expected nutritional requirements and GA results for 20 kg of milk with 3.5% fat at 600 kg BW.

#	Nutrient requirements	Expected value	GA result
1	Amount of Dry Matter (DM)	17.27 Kg	16.66 Kg
2	Crude Protein (CP)	2148.55 g	2689.09 g
3	Metabolic Energy (ME)	39.21 Mcal	47.84 Mcal
4	Net Energy (NEl)	23.68 Mcal	30.46 Mcal
5	Crude Ash Ratio	10% ≤	7.02%
6	Sugar Ratio	8% ≤	1.93%
7	Starch Ratio	35% ≤	20.38%
8	Ether-extract (EE) Ratio	6% ≤	6.43%
9	Roughage Ratio	40% ≥	47.18%
10	Neutral Detergent Fiber (NDF) Ratio	25% >	54.01%
11	Amount of Calcium (Ca)	88.5 g	126.39 g
12	Amount of Phosphorus (P)	53.76 g	93.61 g

that a total of 15 different feed ingredients are used, including three types of roughage, seven types of concentrated feed and five types of minerals. The total weight in the feed ration is 20,04 Kg and feed cost is 117,36 TL. In the proposed feed ration solution, mainly wheat straw and wheat silage were used in roughage, and dried distillers grains and corn were used in the concentrated feed. According to the first experiment, it is seen that the DM requirement resulting from the 150 Kg increase in body weight is met by wheat straw, which is predominantly from the roughage category.

Table 8. Feed ration prepared with the GA for 20 kg of milk with 3.5% fat at 600 kg BW.

#	Animal food ingredients	Type of nutrient	Amount (g)
1	Corn Silage	Roughage	761
2	Wheat Straw	Roughage	6688
3	Wheat Silage	Roughage	2006
4	Barley	Concentrate Feed	1050
5	Dried Distillers Grains (DDGs)	Concentrate Feed	2699
6	Maize	Concentrate Feed	2547
7	Cotton Bagasse	Concentrate Feed	1145
8	By-pass FCM	Concentrate Feed	609
9	Wheat Bran	Concentrate Feed	1377
10	Wheat	Concentrate Feed	965
11	Calcium Carbonate	Mineral	3
12	Monocalcium Phosphate (MCP)	Mineral	41
13	Dicalcium Phosphate (DCP)	Mineral	13
14	Sodium Chloride (NaCl)	Mineral	71
15	Sodium Bicarbonate ($NaHCO_3$)	Mineral	63
		Total Price:	**117.36 TL**
		Total Feed Weight:	**20.04 Kg**

In the third and last experiment, the target was to produce 25 kg of milk with a fat content of 3.5% from a dairy cow with a body weight of 600 kg and in the 10th week of lactation. Table 9 shows the expected values of nutrient

Table 9. Expected nutritional requirements and GA results for 25 kg of milk with 3.5% fat at 600 kg BW.

#	Nutrient requirements	Expected value	GA result
1	Amount of Dry Matter (DM)	18.86 Kg	18.74 Kg
2	Crude Protein (CP)	2573.55 g	4510.45 g
3	Metabolic Energy (ME)	44.99 Mcal	52.12 Mcal
4	Net Energy (NEl)	27.18 Mcal	32.7 Mcal
5	Crude Ash Ratio	10% ≤	8.67%
6	Sugar Ratio	8% ≤	4.12%
7	Starch Ratio	35% ≤	14.16%
8	Ether-extract (EE) Ratio	6% ≤	3.75%
9	Roughage Ratio	40% ≥	45.71%
10	Neutral Detergent Fiber (NDF) Ratio	25% >	48.04%
11	Amount of Calcium (Ca)	104.55 g	144.41 g
12	Amount of Phosphorus (P)	62.91 g	174.78 g

requirements for targeted milk productivity and the optimal results obtained with the GA. When the experimental results are compared, it is seen that the GA significantly meets zoo-technically expected nutrient requirements. Additionally, when the targeted amount of milk was increased, there was an increase in Ca and P requirements. When the amounts of Ca and P at the optimal result of the GA were evaluated according to the recommendations of NRC-2001 given in Eq. (5) and (6), it was seen that they were 40 g and 112 g more, respectively. In addition, with the increase in milk amount, DM, CP, ME, NEl requirements also increased.

The feed ration solution found by GA is given in Table 10. When the feed ingredients and types are examined according to the test results, the feed ration containing the daily nutritional requirements of the animal; It is seen that a total of 17 different feed ingredients are used, including three types of roughage, nine types of concentrated feed and five types of minerals. The total weight in the feed ration is 22,02 kg and the feed cost is 134,77 TL. In the recommended feed ration solution, the roughages are mainly wheat straw and alfalfa, and the selected concentrated feeds are on average close to each other. Compared to the previous experiment, the total feed weight difference required for a five kg increase in the targeted milk amount is two kg.

Table 10. Feed ration prepared with the GA for 25 kg of milk with 3.5% fat at 600 kg BW.

#	Animal food ingredients	Type of nutrient	Amount (g)
1	Alfalfa	Roughage	3385
2	Corn silage	Roughage	2263
3	Wheat straw	Roughage	4417
4	Barley	Concentrate Feed	1379
5	Canola meal	Concentrate Feed	694
6	Corn gluten meal	Concentrate Feed	1066
7	Dried distillers grains (DDGs)	Concentrate Feed	1453
8	Cotton bagasse	Concentrate Feed	1007
9	Soybean hull	Concentrate Feed	1057
10	Soybean meal	Concentrate Feed	1664
11	Wheat bran	Concentrate Feed	1834
12	Wheat	Concentrate Feed	1374
13	Calcium Carbonate	Mineral	1
14	Monocalcium Phosphate (MCP)	Mineral	254
15	Dicalcium Phosphate (DCP)	Mineral	31
16	Sodium Chloride (NaCl)	Mineral	66
17	Sodium Bicarbonate ($NaHCO_3$)	Mineral	71
		Total Price:	**134.77 TL**
		Total Feed Weight:	**22.02 Kg**

5. CONCLUSION AND DISCUSSION

In this paper, use of the GA in feed ration cost optimization in dairy cattle is discussed. Finding the feed ration ingredients with low-cost is goal of the optimization algorithm. Based on this, the developed model was coded in the MATLAB environment as an optimization problem with determined objective function and constraints. The performance of the model was tested with dairy cattle samples with a body weight of 450 and 600 Kg for 20 Kg milk with 3.5% fat. In three different experiments we have conducted, it has been observed that the expected values in NRC's nutrient requirements are largely compatible with the results found by the GA. Experimental results show that GA can be a useful tool for feed ration cost optimization. As a concrete example, the ration solution obtained with the GA for the yield of 20 kg milk (3.5% fat content) of cattle with a body weight of 600 kg costs 117.36 TL. The daily feed cost amount in the June 2023 Raw Milk Cost Table of the National Milk Council [35] is stated as 143.70 TL. Thanks to the proposed method, a feed ration with approximately 20% lower cost was prepared.

Table 11. Expected nutritional requirements and GA results for 20 kg of milk with 3.5% fat at 450 kg BW.

#	Nutrient requirements	Expected	GA	PSO	ACO_R
1	Amount of Dry Matter (DM)	15.16 Kg	15.16 Kg	16.14 Kg	15.54 Kg
2	Crude Protein (CP)	2061.5 g	2884.85 g	2993.54 g	3712.6 g
3	Metabolic Energy (ME)	36.08 Mcal	45.85 Mcal	45.39 Mcal	47.61 Mcal
4	Net Energy (NEl)	21.8 Mcal	28.7 Mcal	29.09 Mcal	29.57 Mcal
5	Crude Ash Ratio	10% ≤	7.32%	6.93%	8.16%
6	Sugar Ratio	8% ≤	9.09%	3.25%	4.74%
7	Starch Ratio	35% ≤	22.29%	20.42%	10.8%
8	Ether-extract (EE) Ratio	6% ≤	2.58%	6.62%	1.92%
9	Roughage Ratio	40% ≥	48.78%	40.24%	67.18%
10	Neutral Detergent Fiber (NDF) Ratio	25% >	46.84%	43.5%	59.74%
11	Amount of Calcium (Ca)	82.43 g	69.4 g	125.02 g	121.65 g
12	Amount of Phosphorus (P)	49.47 g	70.81 g	77.34 g	65.47 g
		Total Price:	103.57 TL	126.75 TL	107.42 TL
		Total Feed Weight:	19.11 Kg	17.78 Kg	20.95 Kg

The results of the experimental studies were compared with Particle Swarm Optimization (PSO) and Ant Colony Optimization for Continuous Domains (ACO_R) algorithms, which are well known in the literature. Comparative results of the first, second and third experiments are given in Table 11, Table 12 and Table 13, respectively. While the proposed GA model found the lowest cost feed ration in the first and third experiments, the ACO_R algorithm achieved the best result in the second experiment.

Table 11 shows that the sugar content in the feed ration obtained by GA is 1.09% higher than expected, while the PSO algorithm contains 0.62% more Ether-extract. The ACO_R algorithm met all of the expected values. Table 12 shows that the Ether-extract content in the feed ration obtained by GA was 0.43% higher than expected. The PSO and ACO_R algorithms met all the expected values. In Table 13, all three optimization algorithms met all expected values.

Table 12. Expected nutritional requirements and GA results for 20 kg of milk with 3.5% fat at 600 kg BW.

#	Nutrient requirements	Expected	GA	PSO	ACO_R
1	Amount of Dry Matter (DM)	17.27 Kg	16.66 Kg	18.32 Kg	17.83 Kg
2	Crude Protein (CP)	2148.55 g	2689.09 g	3031.33 g	4430.95 g
3	Metabolic Energy (ME)	39.21 Mcal	47.84 Mcal	73.09 Mcal	52.92 Mcal
4	Net Energy (NEl)	23.68 Mcal	30.46 Mcal	46.72 Mcal	33.22 Mcal
5	Crude Ash Ratio	10% ≤	7.02%	5.76%	7.54%
6	Sugar Ratio	8% ≤	1.93%	7.96%	4.69%
7	Starch Ratio	35% ≤	20.38%	34.71%	10.52%
8	Ether-extract (EE) Ratio	6% ≤	6.43%	5.56%	4.06%
9	Roughage Ratio	40% ≥	47.18%	50.8%	62.15%
10	Neutral Detergent Fiber (NDF) Ratio	25% >	54.01%	50.55%	57.22%
11	Amount of Calcium (Ca)	88.5 g	126.39 g	134.61 g	113.14 g
12	Amount of Phosphorus (P)	53.76 g	93.61 g	83.36 g	71.18 g
		Total Price:	117.36 TL	148.94 TL	116.79 TL
		Total Feed Weight:	20.04 Kg	27.89 Kg	22.41 Kg

Those exceeding the expected value in the feed ration of optimization algorithms are negligible. Since the main focus here is on feed-cost, the highest penalty coefficient in the fitness function is applied to the total cost of feed. It is also possible to obtain different results by changing these coefficients.

As a result, the fitness function in the proposed model can be easily adapted to other metaheuristic methods. The results obtained can be used in the nutrition of dairy cattle to save on feed costs.

Table 13. Expected nutritional requirements and GA results for 25 kg of milk with 3.5% fat at 600 kg BW.

#	Nutrient requirements	Expected	GA	PSO	ACO_R
1	Amount of Dry Matter (DM)	18.86 Kg	18.74 Kg	19.95 Kg	19.61 Kg
2	Crude Protein (CP)	2573.55 g	4510.45 g	6872.56 g	5516.3 g
3	Metabolic Energy (ME)	44.99 Mcal	52.12 Mcal	62.72 Mcal	53.64 Mcal
4	Net Energy (NEl)	27.18 Mcal	32.7 Mcal	39.48 Mcal	33.73 Mcal
5	Crude Ash Ratio	10% ≤	8.67%	7.51%	7.89%
6	Sugar Ratio	8% ≤	4.12%	7.45%	4.43%
7	Starch Ratio	35% ≤	14.16%	7.06%	9.73%
8	Ether-extract (EE) Ratio	6% ≤	3.75%	2.41%	4.02%
9	Roughage Ratio	40% ≥	45.71%	54.41%	62.66%
10	Neutral Detergent Fiber (NDF) Ratio	25% >	48.04%	45.33%	46.41%
11	Amount of Calcium (Ca)	104.55 g	144.41 g	108.54 g	136.43 g
12	Amount of Phosphorus (P)	62.91 g	174.78 g	96.06 g	81.37 g
		Total Price:	134.77 TL	180.23 TL	143.14 TL
		Total Feed Weight:	22.02 Kg	24.75 Kg	22.22 Kg

Author's Contributions

Ertuğ ATICI contributed to the implementation of the research, analysis of the result, and writing, and Abdullah ELEN provided support for the coding part of the study and review of the manuscript.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

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