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Ration Preparation of Dairy Cows with an Innovative Method: A Multi-Objective Optimization Approach

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Abstract: Abstract: The livestock industry, particularly in dairy farming, is actively engaged in diverse research endeavors aimed at addressing economic challenges and refining feeding strategies. Ration preparation in this sector involves meticulous planning to meet the daily nutritional needs of animals and optimize their performance. This planning considers various factors, including animal characteristics, physiological conditions, productivity levels, and environmental influences. The crucial task of selecting and determining the quantity of feeds significantly impacts animal health, efficiency, and economic viability. The application of artificial intelligence, specifically the multi-objective optimization method, proves highly effective in addressing these intricate challenges. This method aims to formulate optimal rations by simultaneously considering diverse objectives, such as different nutrients and cost factors. This article introduces a feeding strategy in the livestock sector utilizing Multi-Objective Particle Swarm Optimization (MOPSO), a noteworthy multi-objective optimization method, to generate cost-effective rations. Comparative analyses with existing systems consistently highlight the notable effectiveness of the proposed method.

Keywords: Livestock, ration preparation, feeding strategies, multi-objective optimization, MOPSO, artificial intelligence, cost

Süt İneklerinin Yenilikçi Bir Yöntemle Rasyon Hazırlanması: Çok Amaçlı Bir Optimizasyon Yaklaşımı

Özet: Hayvancılık sektörü, özellikle süt sığırcılığında karşılaşılan ekonomik zorluklarla baş etmek ve besleme stratejilerini geliştirmek amacıyla çeşitli araştırmalara odaklanmaktadır. Bu sektörde rasyon hazırlama süreci, hayvanların günlük besin ihtiyaçlarını karşılamayı ve optimal verim elde etmeyi amaçlayan kapsamlı bir planlamayı içermektedir. Bu süreç, hayvanların özellikleri, fizyolojik durumları, verim düzeyleri ve çevresel faktörler dikkate alınarak gerçekleştirilir. Rasyon hazırlama sürecinde kullanılacak yemlerin seçimi ve miktarı, hayvan sağlığı, verimliliği ve ekonomik etkinlik açısından kritik öneme sahiptir. Yapay zekanin çok amaçlı optimizasyon yöntemi, bu tur problemlerini çözmek için özellikle etkilidir. Bu yöntem, farklı besin maddeleri ve maliyet faktörleri gibi çeşitli amaçları gözeterek, optimal rasyonları oluşturmayı amaçlar. Bu makalede çok amaçlı optimizasyon yöntemlerinde biri olan MOPSO ile hayvancılık sektöründe bir besleme stratejisini geliştirerek, maliyeti etkin rasyonlar oluşturmaktadır. Geliştirilen yöntem birkaç mevcut sistem ile karşilaştirildiğinda önerilen yöntemin etkili olduğu gözukmektedir.

Anahtar Kelimeler hayvancılık, rasyon hazırlama, besleme stratejileri, çok amaçlı optimizasyon, MOPSO, yapay zeka, maliyet

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1. INTRODUCTION

Livestock is pivotal in addressing fundamental nutritional requirements, not only by providing animal-based nutrition but also by making substantial contributions to agricultural economies. Animal-derived sources like meat, milk, and eggs play a vital role in human

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nutrition, furnishing essential nutrients crucial for growth and development. This significance of the livestock sector has been underscored by the escalating demand for animal products, driven by both population growth and shifts in dietary patterns.

Nutrition stands out as a paramount and intricate challenge within the livestock sector. Given that feed expenses constitute a substantial portion of a business's overall costs, the feeding strategies adopted for animals play a pivotal role in determining the long-term success of enterprises. Dairy farming, in particular, grapples with economic challenges stemming from the considerable costs associated with animal feed. This scenario has ushered in an era where businesses are increasingly directing their focus toward novel strategies for feeding animals more efficiently and cost-effectively. Numerous studies have been conducted on this subject. For example, Buryakov researched on the impact of incorporating varying levels of protein concentrate into the rations of Ayrshire dairy cows, examining effects on rumen microbiota, reproductive characteristics, and economic performance [1].

Certain studies have explored the economic and environmental dimensions of the subject by investigating diverse feeds. Lee addressed the evaluation of insects as a new source for animal feed, emphasizing their economic, eco-friendly, and nutritious qualities [2]. Gasco stressed the need for alternative protein sources in feed formulations for the sustainable development of the animal production sector. They highlight that by-products from human, fisheries, and aquaculture represent optimal alternatives for protein sources [3]. Hristov and colleagues provide a comprehensive assessment of plant-based proteins, covering aspects such as nutritional quality, cost-effective extraction and processing technologies, impact on nutrition, utilization of various food wastes as alternative sources, and their environmental effects [4].

However, it is crucial to use the right ration to ensure the productivity and healthy growth of animals. In this regard, formulating rations that contain the necessary nutrients for animals in the most cost-effective way is the key to economic success in the livestock sector. Dumas and his colleagues have provided a comprehensive review spanning a century, exploring the evolution of modeling concepts in animal feeding and highlighting the contributions of pioneers in this field [5]. There are other research studies in this area [6-8].

Modern animal production relies heavily on models designed to predict the nutritional needs and responses of animals [9]. While various systems have been developed in this field [10-12], each comes with its set of strengths and weaknesses. Specifically, while amino acid requirements for pigs and poultry can be fairly well-defined, data in this regard remains limited for ruminants due to the complexity of the ruminal digestion process. The efficacy of these models needs continuous assessment and scrutiny [13]. Future research should strive to improve and validate these systems further, employing cutting-edge tools. Additionally, certain studies have explored the optimization of ration formulation [14], with some approaches incorporating artificial intelligence, such as swarm intelligence optimization methods [15-17].

This article aims to provide a detailed examination of optimizing animal feeding strategies and developing cost-effective rations. Specifically focusing on dairy farming, a method based on the Multi-Objective Particle Swarm Optimization (MOPSO) technique is proposed. MOPSO is a multi-objective optimization method that addresses both cost and requirements, making it particularly relevant to the context of dairy cattle nutrition.

2. RATION PREPARATION

The process of ration formulation constitutes a systematic and scientific approach to addressing the daily nutritional requisites of animals, with the overarching objective of optimizing productivity. This comprehensive approach takes into consideration various factors, including the animal's live weight, physiological state (whether pregnant, lactating, or in a dry period), productivity levels, and environmental factors like temperature and wind. The overarching objective is to ensure animal health, enhance productivity, and optimize costs.

Central to this procedure is the discerning selection and quantification of feeds in rations, a critical determinant of animal health, productivity, and economic efficacy. Balancing the cost-effectiveness of concentrated feeds with the conformity of forages to stringent quality standards, the ration is intricately designed to be economically viable and nutritionally optimal. Principally, this involves maintaining roughage at a minimum of 40% of the dry matter content and ensuring an optimal mineral balance, particularly for pivotal elements such as calcium (Ca) and phosphorus (P).

Within the context of dairy cow nutrition, the focus narrows down to comprehending the specific nutritional demands during the lactation period and customizing the ration accordingly. This process mandates a nuanced evaluation of the animal's distinct life and productivity phases. Moreover, from a scholarly perspective, it is imperative to underscore that sheep and goats generally necessitate more protracted feeding periods than dairy cows. Additionally, ruminant animals necessitate the consumption of roughage for stomach development, while poultry rations conventionally incorporate grain feeds.

3. RATION PREPARATION SYSTEM AND METHODS

Ration formulation systems and methodologies constitute a diverse array of approaches designed to imbue animal feeding processes with effectiveness and scientific rigor. These systems are broadly categorized into three main classes: manual, semi-automatic, and automatic. In this section, we will elucidate certain prevalent methods utilized in ration calculation programs and scrutinize computer-based techniques for their application in this domain.

3.1. Traditional Methods:

- **Trial-and-Error Method:** In an effort to balance the content of rations, feeds and nutrients are adjusted through the trial-and-error method. This approach is practical and experiential, though its accuracy is occasionally constrained.
- **Algebraic Method**: Ration formulation is accomplished by leveraging binary or multiple equation systems. Nevertheless, the management of equations and the quantity of unknowns can prove to be intricate.
- **Pearson Square Method:** The balance of nutrients is adjusted based on the proportions of energy and protein. However, dealing with intricate processes may be necessary.
- **Pearson Double Square Method**: Nutrient adjustments for ration balancing are conducted in binary mixtures. In instances with multiple nutrients, the Pearson square method is iteratively applied.
- **Matrix Solution Method**: This method is employed when the number of raw materials is high. The matrix solution method presents different mixtures in the ration, with the equation matching the number of unknowns.

3.2. Computer Aided Methods:

- **Manual Computer Aided Method:** The manual entry of animal characteristics and nutritional data using programs like Excel is a prevalent practice, albeit one associated with potential drawbacks such as time consumption and susceptibility to errors.
- **Automatic Computer Aided Method**: Ration calculations are automatically executed based on pre-established parameters. While this method may entail costs, it affords time-saving benefits.

Among these techniques, computer-aided methods offer distinct advantages, including time savings, error reduction, and heightened operational efficiency. Nevertheless, it is imperative to acknowledge that each method bears its own set of advantages and disadvantages. In an academic framework, a thorough assessment of the applicability and effectiveness of each approach becomes crucial.

4. MULTI-OBJECTIVE OPTIMIZATION

The Multiple Objective Particle Swarm Optimization (MOPSO) algorithm was developed by Dr. Carlos A. Coello in 2004 [18]. This algorithm operates by leveraging the paradigms of swarm intelligence based on Particle Swarm Optimization. Swarm intelligence is grounded in the principle of individuals collaborating to achieve common objectives. Solving multi-objective optimization problems proves to be a more intricate process compared to single-objective problems, particularly when faced with conflicting objectives. The complexity of the challenge further intensifies as the algorithm endeavors to minimize one objective while simultaneously maximizing another [19].

Multi-objective optimization problems are investigated in the literature through three primary approaches. Firstly, the implementation of methods directly solving multi-objective optimization problems stands out. The second approach involves methods that solve multi-objective optimization problems after transforming them into single-objective optimization problems. The third approach aims to solve multi-objective optimization problems based on the Pareto optimality principle. In this approach, a vector containing all objectives and the concept of dominance, allowing for preference among solutions, play a significant role. However, research on solving multi-objective optimization problems using the Pareto optimization technique is more limited compared to other methods.

The MOPSO (Multiple Objective Particle Swarm Optimization) algorithm is inspired by an evolutionary algorithm rooted in genetic algorithms and based on Pareto dominance. In fact, the II-PESA algorithm initially included a genetic algorithm; however, the MOPSO algorithm has been developed by removing this genetic algorithm section and replacing it with PSO (Particle Swarm Optimization).

Multi-objective optimization is recognized as a sub-discipline within the realm of "Multi-Criteria Decision Making." This field grapples with the concurrent consideration of distinct and complementary objective functions within a given mathematical optimization problem. Even for ostensibly straightforward multi-objective optimization problems, the prospect of attaining an optimal solution that simultaneously optimizes all objective functions is notably improbable. The objective functions delineated in multi-objective optimization problems typically harbor conflicting attributes. Consequently, the concept of "Pareto Optimal Solutions" becomes pivotal for a multi-objective optimization problem, where theoretically, an infinite number of Pareto optimal solutions may exist. Figure 1 illustrates the Pareto optimal solutions for a two-objective problem.

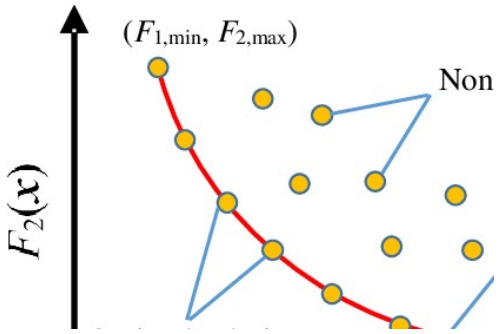

Figure 1. The Pareto optimal solutions for a two-objective problem

The MOPSO (Multiple Objective Particle Swarm Optimization) algorithm is an evolutionary algorithm developed to address multi-objective optimization problems. The fundamental steps of this algorithm are outlined as follows:

I. **Initialization**: Parameters crucial for the effective operation of the algorithm are defined, including the maximum number of iterations, population size, weight factors (γ, β, c1, c2), and the repository size.

II. **Population Generation:** Utilizing the specified parameters, an initial population is generated, consisting of potential solution candidates.

III. **Identification of Non-Dominant Solutions and Repository Augmentation:** Non-dominant solutions within the population are discerned and subsequently added to the repository. The repository functions as a repository, preserving non-dominant solutions for use in various evolutionary steps.

IV. **Construction of the Objective Space:** A table representing the objective space of various solutions discovered by the algorithm is established.

V. **Particle Movement and Leader Selection:** Each particle selects a leader from the repository and moves under the guidance of that leader. This step involves updating the particles' velocities and positions.

VI. **Optimal Personal Memory Update:** The optimal personal memory of each particle is updated. If the new state surpasses the personal memory, an update ensues; otherwise, no adjustments are made.

VII. **Repository Update:** New non-dominant solutions are added to the repository, and if necessary, outdated members of the repository are removed.

VIII. **Iteration of the Algorithm:** The steps are repeated until the maximum iteration count is reached.

In multi-objective optimization scenarios featuring restricted repository capacities, special attention is directed towards the ramifications of leader selection and its influence on the solution set. The strategy involving leader movement to eliminate a solution reflects a counteraction of the repository's capacity impact on optimal solutions. This underscores the importance of calibrating the leader's influence on the solution set in a repository-sensitive manner.

The algorithm iterates until the termination conditions are met. This necessitates dynamic adaptation of the leader and solution set in each iteration, emerging as a crucial strategy for ensuring balanced progress in optimizing the repository capacity.

5. RECOMMENDED METHOD

Developing an effective ration formulation system requires a critical understanding of accurately calculating the nutritional needs of the animals. The precise determination of requirements stands as a foundational step in designing an efficient ration system. This process involves calculations based on the characteristics of the animal and environmental factors. Additionally, assessing how well the needs are met using a hypothetical ration is essential. In this context, methods for establishing relationships that meet the requirements and determining the values of each need have been extensively examined. These insights will provide a fundamental framework for developing an appropriate and effective ration formulation system.

Animals require essential nutrients on a daily basis to sustain their lives. In the ration formulation process, the sum of daily nutrient requirements should align with the amount of feed an animal can consume daily. Failure to meet daily nutrient needs can lead to improper functioning of the animal's digestive system and inadequate nutritional intake. Furthermore, considerations should be given to free-ranging animals that may consume excess feed to fill their rumens, potentially leading to fat accumulation and reduced economic efficiency. Accurate determination of animal needs, precise estimation of nutrient quantities, and maintaining balance are critically important for sustaining the delicate equilibrium in operations [20]. Therefore, enterprises must carefully plan by accurately determining animal needs, managing feed consumption accurately, and maintaining balance. Additionally, attention should be given to the varying nutrient requirements of animals during different physiological periods (heifer, pregnancy, dry period, and lactation period).

The proposed method aims to accurately determine the needs of dairy cows. Dairy cows are typically divided into four different periods, each with distinct characteristics. Calculating needs for each period is accomplished by utilizing biological variables based on the period the animal is in and various environmental factors. Functions developed in the JavaScript programming language calculate the desired needs based on the animal's characteristics and environmental factors. The obtained needs are stored in output variables defined for use in other sections of the study. The study determines parameters used for the needs of dairy cows in different periods, followed by an algorithmic explanation of the method for calculating the needs of cows. This research provides a detailed examination of the different periods of dairy cows in large-scale livestock enterprises as follow:

- **Lactation Period:** This period spans from the initiation of milk secretion in cows and is influenced not only by animal characteristics but also by environmental factors. Ambient temperature plays a crucial role in the calculations during this phase.
- **Dry Period:** In the approximately 45-60 days leading up to calving, when milking ceases, concentrate feed is not recommended, and among environmental factors, only ambient temperature significantly affects calculations.
- **Heifer Period:** This phase encompasses the period when female calf cows are between 1 to 2 years old, and it represents a stage of peak milk production. While it shares similarities with the dry period, the influence of environmental factors is more pronounced.
- **Calf Period:** Emphasizing the period from birth to weaning, this phase underscores the importance of avoiding early cessation of milking to prevent milk burn. Parameters such as body weight and temperature characteristics are crucial in determining needs during this period.

Table 1 illustrates the parameters and characteristics that dairy cows require during various periods.

Table 1. Effective parameters for rationing in different periods of dairy cattle

	Parameter	Lactation Period	Dry Period	Heifer Period	Calf Period
Animal Characteristics	Age	✓	✓	✓	
	Body weight	✓	✓	✓	
	Pregnant Days	✓	✓	✓	
	Status Score	✓	✓	✓	
	Milky days	✓			
	Number of Breastfeeds	✓			
	First calving age	✓	✓	✓	
	Calving interval	✓	✓	✓	
	Desired ADG			✓	
Product	Mature weight	✓	✓	✓	
	Milk production	✓			
	Milk fat	✓			
	Lactose	✓			
Environment	Heat	✓	✓	✓	
	Previous Temperature			✓	
	Wind speed			✓	
	Hair Depth			✓	
	Night Cooling			✓	
calf variable	Body weight				✓
	Heat				✓

In the study, functions developed to calculate the nutritional quantities of selected feeds have been thoroughly examined. The primary objective of the ration system is to determine the list of selected feeds and their respective quantities. Typically, the quantity of each feed in the ration is manually determined by users. However, the primary goal of the study is to establish these values automatically and intelligently using optimization methods.

To effectively manage the process in the study, an application has been developed. The list of feeds and their respective characteristics are stored in the system database. The user selects the desired feeds from the list for ration preparation and then utilizes an interface to input the quantity of each feed in the list (this step is automatically executed by the implemented program). Following this, purpose-built functions come into play, systematically computing the nutrient quantities within the ration, thereby attaining the desired outcomes. These steps are detailed in the flowchart shown in Figure 2.

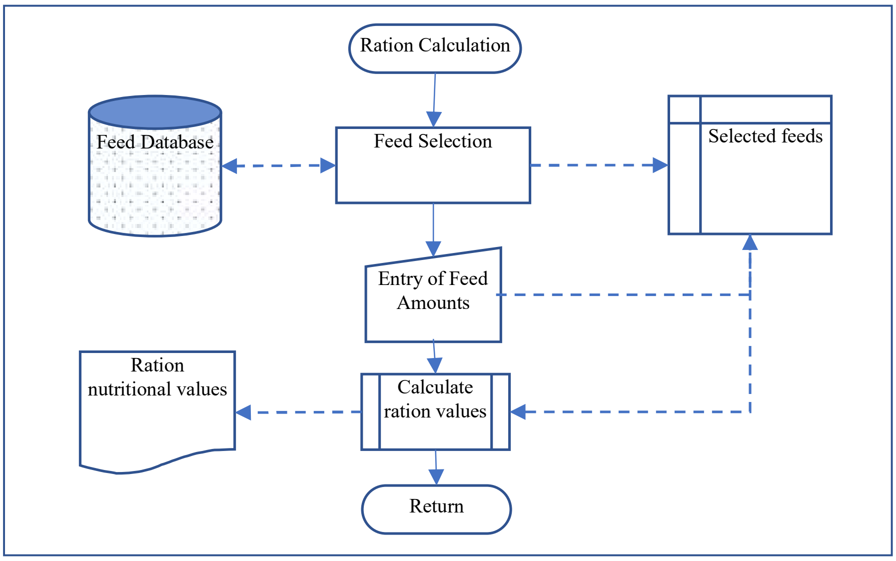

Figure 2. Nutrient values calculation process

In the context of ration formulation, the objective function represents the sum of absolute errors between the nutritional needs of the animals and the predicted values for each need in the ration. Equation 1 illustrates the computation of the objective function for the ration problem in animals.

$$\begin{cases} fitness_1 = \sum_{i=1}^{n} |e_i - d_i| \\ fitness_2 = \sum_{i=1}^{k} C_i * m_i \end{cases} \tag{1}$$

In this equation, n denotes the number of needs to be considered according to the desired ration, d_i represents the required value for a specific need for the animal, e_i represents the corresponding value estimated by the predicted ration, k denotes the number of feed, C_i is cost of i^{th} feed, and m_i is amount of i^{th} feed in ration.

The optimization problem aims to obtain a solution with the lowest value for the objective function. Hence, a fitness value is calculated for each candidate solution, and the relevant optimization algorithm is executed based on this value. Typically, optimization algorithms consider the update of each candidate solution and strive to progress towards the final solution at each stage. In the context of multi-objective optimization, the second objective function is often treated as the cost amount of the ration. This optimization process is crucial for formulating rations that minimize the discrepancies between predicted and actual nutritional needs, contributing to the overall health and productivity of the animals.

6. EXPREIMENTAL RESULTS

In this study, feed and animal information was scrutinized using the NRC-2001 program. To assess the efficacy of the proposed method, specific examples from different periods with a designated cow weight are elucidated in this section. The values obtained using the proposed method are calculated for the given examples and juxtaposed with the results from other systems.

Several examples were formulated using ration samples specified on the website of the Amasya Cattle Breeders Association. These samples were created under specific conditions outlined in the NRC-2001 program, and the results obtained with the proposed method were recorded. Furthermore, results were obtained with the proposed method under the same conditions and compared with the outcomes from other scrutinized systems. The findings indicate that the proposed method is more efficient compared to other examined systems.

In the evaluation of the study, the focus was on Holstein breed and a cow weighing 600 kg in all examples. The following example was taken to assess the performance of the method:

In the examined example, early lactation and non-pregnant conditions were considered, assuming 70 days of nursing. Table 2 list the characteristics of the animal for this example. This approach provides a comprehensive evaluation, emphasizing the method's effectiveness in addressing specific scenarios, showcasing its superiority over alternative systems.

Table 2. List of characteristics for a sample animal

Sample	Type	Race	Weight	Pregnancy Period	Condition Score	Milking Period	Milk Yield	Milk Fat
1	Milk Cow	Holstein	600	0	3	70	31 kg	3.5
2	Milk Cow	Holstein	600	0	3	70	21 kg	3.5
3	Milk Cow	Holstein	600	0	3	70	35 kg	3.5

In Table 2, three sample cows with milk yields of 31, 21, and 35 kg under specific conditions are examined. The characteristics outlined in Table 2 are used in the proposed method to obtain requirements for each item. To effectively compare the proposed system with similar situations, significant and calculable requirements of the systems under comparison have been determined. The values for the selected requirements are shown in Table 3.

Table 3. Nutrient requirement list for the situations in Example

Sample	DM	NEI	Ca	P	K	RDP	RUP
1	20.51	31.1	0.57	0.50	1.94	17.57	17.38
2	17.33	24.2	0.45	0.37	1.60	14.83	11.26
3	21.80	33.9	0.62	0.54	2.08	18.66	19.83

In table 3, DM (Dry Matter), representing the solid content in feed excluding water; NEI is Net Energy for Maintenance and Production and signifying available energy after metabolic losses;Ca (Calcium) and P (Phosphorus), essential minerals vital for bone development and physiological functions; K (Potassium), crucial for fluid balance and muscle function. RDP (Rumen Degradable Protein) is the portion of dietary protein susceptible to microbial degradation in the rumen, while RUP (Rumen Undegradable Protein) or bypass protein is the fraction that bypasses rumen degradation, providing essential nutrients for absorption in the lower digestive tract. These terms collectively guide the formulation of well-balanced diets tailored to diverse animal nutritional needs.

Under the conditions outlined in Table 2, an automatic ration was generated using the NRC-2001 application. The values representing how well the ration obtained by the system meets the requirements in Table 3 have been recorded. Table 4 illustrates the predicted nutrient requirement values in the ration generated by NRC-2001.

Table 4. Nutrient requirement list obtained from the NRC-2001 system for the situations in the example

Sample	DM	NEI	Ca	P	K	RDP	RUP
1	20.50	50.5	1.33	0.69	3.93	28.60	9.51
2	17.3	42.4	1.28	0.63	3.32	21.82	6.23
3	21.80	58.2	1.35	0.71	4.18	29.70	12.03

To assess the effectiveness of the ration systems presented for three different scenarios, we thoroughly examined the first example on the Amasya Province Breeding Cattle Breeders Union website. On this platform, there are various recommended rations for each condition in Table 2. To better understand the subject, we extensively reviewed all the rations provided on this site. Tables 5, 6, and 7 respectively contain the rations for scenarios 1-3 in Table 2.

For each of Tables 5 to 7, we calculated the amounts of requirements that each ration can fulfill using the proposed method. Each ration is capable of providing a value that indicates its suitability based on the specified requirements. Tables 8, 9, and 10 offer a comprehensive breakdown of the values met by each ration from Tables 5, 6, and 7, respectively. The first column in these tables details the individual needs of each section.

Table 5. Ration samples for early lactation (70 days) and non-pregnant 31 kg milk-yielding cows

Feed Ingredients	Rations									
	1	2	3	4	5	6	7	8	9	10
Corn Silage. %30-35 KM	22.00	22.50	21.00	22.00	22.00	22.00	22.00	22.00	22.50	22.50
Clover Dried Grass. End of Bloom	5.50	0.00	0.00	5.65	0.00	0.00	4.00	4.00	0.00	0.00
Vetch Dry Grass	0.00	5.60	6.00	0.00	6.00	4.00	0.00	0.00	2.00	1.25
Oat dried grass. spicate	0.00	0.00	0.00	0.00	0.00	2.00	1.60	1.90	4.00	4.30
Cattle Milk Feed. 19 HP. 2700 ME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.75
Cattle Milk Feed. 21 HP. 2750 ME	6.00	5.20	3.70	5.50	5.00	5.00	6.00	6.00	5.60	0.00
Sugar Beet Pulp, Wet	0.00	0.00	6.00	2.30	5.00	4.00	2.00	0.00	0.00	0.00
Oil. Vegetable	0.35	0.29	0.50	0.38	0.36	0.45	0.37	0.34	0.37	0.43
Soybean Meal %44 HP	2.50	1.80	2.00	3.00	2.66	2.70	2.60	2.70	2.70	3.00
Cottonseed Meal. %32 HP	0.50	1.85	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total weight of the ration. natural. kg	**36.85**	**37.24**	**40.95**	**38.83**	**41.02**	**40.15**	**38.57**	**36.94**	**37.17**	**37.23**

Table 6. Ration samples for early lactation (70 days) and non-pregnant 21 kg milk-yielding cows

Feed Ingredients	Rations									
	1	2	3	4	5	6	7	8	9	10
Corn Silage. %30-35 KM	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	0.00	0.00
Clover Dried Grass. End of Bloom	4.00	0.00	5.00	5.50	5.50	0.00	5.00	3.00	0.00	0.00
Vetch Dry Grass	0.00	4.00	0.00	0.00	0.00	5.00	0.00	0.00	5.50	5.00
Oat Dried Grass. Spicate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Wheat Straw	1.00	2.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Cattle Milk Feed. 19 HP. 2700 ME	6.00	5.00	5.50	5.50	0.00	0.00	6.00	6.50	5.50	6.00
Cattle Milk Feed. 21 HP. 2750 ME	0.00	0.00	0.00	0.00	5.50	5.00	0.00	0.00	0.00	0.00
Barley Grain Crush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Sugar Beet Pulp, Wet	0.00	0.00	0.00	3.00	5.00	5.00	3.00	3.00	0.00	0.00
Sunflower Meal. %32 HP	2.00	2.50	2.50	2.00	1.50	1.50	2.00	1.50	1.50	2.00
Wheat bran	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Bonemeal	0.50	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total weight of the ration. natural. kg	**29.50**	**29.50**	**29.50**	**32.00**	**33.50**	**33.50**	**32.00**	**32.00**	**28.50**	**28.50**

Table 7. Ration samples for early lactation (70 days) and non-pregnant 35 kg milk-yielding cows

Feed Ingredients	Rations									
	1	2	3	4	5	6	7	8	9	10
corn silage. %30-35 KM	22.00	22.00	22.00	24.00	24.00	24.00	24.00	24.00	23.00	23.00
Clover dried grass. end of bloom	0.00	0.00	0.00	0.00	4.00	0.00	3.50	6.00	0.00	0.00
Vetch Dry Grass	5.00	5.70	5.00	4.75	0.00	0.00	0.00	0.00	5.50	5.50
Oat Rried Grass. Spicate	1.50	0.00	0.00	0.00	0.00	5.00	1.20	0.00	0.00	1.00
Wheat Straw	0.00	0.75	1.00	1.00	1.00	0.00	0.00	0.00	0.50	0.00
Cattle Milk Feed. 21 HP. 2750 ME	3.35	3.20	4.00	5.00	6.00	7.00	6.40	4.20	5.00	3.00
Cracked Dry Corn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Sugar Beet Pulp, Wet	6.00	6.00	4.30	0.00	0.00	0.00	0.00	0.00	0.00	4.50
Oil. Vegetable	0.85	0.86	0.79	0.65	0.65	0.60	0.60	0.63	0.60	0.85
Soybean Meal. %44 HP	3.85	3.90	3.70	3.70	3.40	3.00	3.25	3.80	2.40	4.00
Cottonseed Meal. %32 HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00
Wheat Bran	0.00	0.00	1.00	0.50	0.60	0.00	0.70	0.00	0.00	0.00
Bonemeal	0.60	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium Bicarbonate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
Total weight of the ration. natural. kg	**43.15**	**43.16**	**41.79**	**39.60**	**39.65**	**39.60**	**39.65**	**39.63**	**39.00**	**42.05**

Table 8. Nutrient needs met by the rations in Table 5

Nutrient	Need	Rations									
		1	2	3	4	5	6	7	8	9	10
DM	20.51	20.41	20.49	20.35	20.52	20.53	20.50	20.51	20.51	20.45	20.50
NEI	31.1	55.88	57.02	62.41	58.77	62.98	61.22	58.10	55.69	56.15	56.26
Ca	0.57	1.51	1.53	1.50	1.51	1.62	1.43	1.42	1.40	1.25	1.20
P	0.50	0.78	0.86	0.80	0.75	0.75	0.73	0.74	0.75	0.75	0.79
K	01.94	2.64	2.99	3.04	2.74	3.20	3.12	2.75	2.79	3.05	3.01
RUP	17.57	28.53	28.33	27.17	28.71	27.88	26.36	26.97	27.30	25.51	25.50
RDP	17.38	11.51	11.80	11.72	11.57	11.17	11.16	11.32	11.30	11.14	10.91
price	------	16.04	14.79	14.03	15.98	14.48	15.24	16.12	16.33	16.18	17.38
Fitness Error		43.63	44.65	49.06	46.62	50.98	47.41	44.36	42.33	41.33	41.56

Table 9. Nutrient needs met by the rations in Table 6

Nutrient	Need	Rations									
		1	2	3	4	5	6	7	8	9	10
DM	17.33	17.31	17.36	17.31	17.37	17.25	17.28	17.36	17.36	17.38	17.36
NEI	24.2	42.34	42.25	42.57	45.68	48.02	48.74	46.00	45.87	38.37	38.24
Ca	0.45	1.33	1.34	1.38	1.45	1.45	1.46	1.45	1.33	1.61	1.62
P	0.37	0.77	0.75	0.80	0.73	0.65	0.65	0.74	0.72	0.77	0.84
K	01.60	2.11	2.51	2.14	2.12	2.09	2.53	2.09	2.15	3.39	3.39
RUP	14.83	22.62	22.24	24.40	23.25	22.36	21.38	23.33	21.24	24.15	25.27
RDP	11.26	7.49	7.43	7.48	7.56	8.11	7.93	7.68	7.68	8.02	8.35
Price	------	12.65	11.40	12.66	12.51	11.60	10.44	12.71	13.19	10.11	10.14
Fitness Error		31.51	31.50	33.64	35.52	36.35	36.69	35.77	33.47	30.13	30.85

Table 10. Nutrient needs met by the rations in Table 7

Nutrient	Need	Rations									
		1	2	3	4	5	6	7	8	9	10
DM	21.80	21.77	21.78	21.78	21.77	21.80	21.77	21.78	21.77	21.82	21.33
NEI	33.9	67.46	67.69	65.34	62.15	61.25	60.73	61.46	61.10	60.66	65.54
Ca	0.62	1.44	1.48	1.46	1.48	1.42	1.21	1.41	1.32	1.54	1.43
P	0.54	0.80	0.81	0.85	0.85	0.80	0.81	0.87	0.78	0.90	0.75
K	2.08	3.48	3.48	3.38	3.35	2.88	3.01	2.90	2.94	3.18	3.45
RUP	18.66	29.41	29.74	29.67	30.25	29.73	26.68	29.89	30.44	30.18	29.08
RDP	19.83	12.23	12.24	12.16	12.26	12.33	12.33	12.29	12.15	12.87	11.94
Price	------	16.16	15.68	15.73	16.39	17.26	18.24	17.60	17.45	16.10	15.99
Fitness Error		54.42	55.01	52.59	49.88	47.78	44.17	48.29	48.49	47.64	52.81

Following the computation and documentation of details pertaining to the systems for comparison, the ration calculation based on the proposed method was executed. During this phase, the system incorporated input regarding the animal and environmental characteristics, and the method was systematically implemented. Figure 3 illustrates the progressive reduction in the Fitness function throughout the execution of the program and across various iterations.

Following the optimization process, the Fitness function reaches its minimum value, and the ration associated with this minimum is stored in the "globalBest" variable. Table 11 presents a comparison of the calculated nutrient values for the example with the average values from the samples on the Amasya Province Breeding Cattle Breeders Union (ADS) website and the values obtained from the NRC-2001 program.

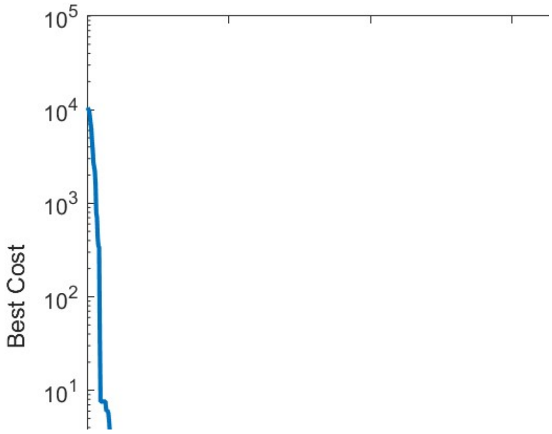

Figure 3. Fitness values for globalBest during program iteration

Table 11. Comparison of nutrient amounts in the sample with different methods

	Method	DM	NEI	Ca	P	K	RUP	RDP	Price	Error
Case 1	ADS Average	20.47	58.44	1.43	0.77	2.93	27.22	11.36	15.651	45.19
	NRC-2001	20.50	50.5	1.33	0.69	3.93	28.60	9.51	---	41.25
	Recommended Method	20.50	49.5	1.48	0.95	3.68	26.33	22.35	14.958	35.24
Case 2	ADS Average	17.33	43.80	1.44	0.74	2.45	23.02	7.77	11.741	33.54
	NRC-2001	17.3	42.4	1.28	0.63	3.32	21.82	6.23	---	33.06
	Recommended Method	17.31	42.03	1.33	0.68	3.15	22.11	6.28	11.525	32.86
Case 3	ADS Average	21.73	63.33	1.41	0.82	3.20	29.50	12.28	16.66	50.10
	NRC-2001	21.80	58.2	1.35	0.71	4.18	29.70	12.03	---	46.14
	Recommended Method	21.79	59.3	0.95	0.75	3.98	29.65	12.14	15.892	46.53

The effectiveness of the proposed method becomes apparent when examining the results presented in the table 11. In order to provide a more comprehensive analysis, several additional examples were scrutinized. These examples, sourced from both the ADS website and the section dedicated to ration samples, encompass Tables 7, 8, and 11. Table 12 provides a detailed breakdown of the characteristics associated with these samples.

Table 12. List of characteristics for a sample animal

Sample	Weight	Pregnancy Period	Condition Score	Milking Duration	Milk Yield	Milk Fat
4	600	60	3	140	18 kg	3.5
5	600	60	3	140	23 kg	3.5
6	600	60	3	140	39 kg	3.5

The application, formulated using the proposed method, was employed to ascertain the requirements for the features outlined in Table 12, mirroring the approach taken in the previous example. Table 13 illustrates the values corresponding to the selected requirements.

Table 13. Nutritional requirement list for the situations in example

Sample	DM	NEI	Ca	P	K	RDP	RUP
4	17.44	22.1	0.041	0.035	0.156	1.495	0.908
5	19.16	25.6	0.047	0.041	0.174	1.641	1.211
6	24.62	36.7	0.067	0.061	0.231	2.107	2.179

To facilitate a comprehensive comparison with other methods, Table 14 succinctly summarizes the errors in the cost function for the ADS site, NRC-2001 program, and the proposed method.

Table 14. Error comparison between methods according to examples

Situation	Errors		
	ADS (average)	NRC-2001	Recommended Method
1	45.19	41.25	35.24
2	33.54	33.06	32.86
3	50.10	46.14	46.53
4	32.80	31.21	31.15
5	41.37	40.29	41.12
6	49.89	45.38	44.98

Based on the comparisons above, it can be demonstrated that the proposed method exhibits higher efficiency compared to the other methods we examined.

7. Conclusions

The livestock industry stands as a crucial component of contemporary economic and social development, demanding effective management practices to enhance economic prosperity and overall societal efficiency. Within this context, the management of feed costs becomes paramount, underscoring the importance of efficient ration formulation processes. A comparison between traditional and computer-based programs reveals the distinct advantages of the latter in achieving greater flexibility and precision. Researchers in the fields of mathematics and computer science are encouraged to devote efforts to optimize computer-based methods in the livestock sector. The development of novel algorithms and the more efficient utilization of existing systems can significantly reduce costs for livestock operations while enhancing overall productivity. Such endeavors are pivotal, not only for ensuring the sustainability of the sector but also for augmenting its economic contribution.

This study focuses on the process of preparing feed rations for dairy cows, providing a detailed examination of a developed optimization method. Customized formulas for requirement calculations were tailored to the specific needs of dairy cows in different stages, and the reliability of these formulas was validated through various examples. As a result, a system capable of obtaining rations tailored to the needs of dairy cows was designed, supported by artificial intelligence optimization principles. Specifically, the optimization method developed based on Multiple Objective Particle Swarm Optimization offers significant advantages in both cost-effectiveness and efficiency.

The results demonstrate the potential of the developed method to provide more economical and efficient solutions for the nutrition of dairy cows. This study provides a guiding framework for researchers, farm owners, and industry experts seeking innovative solutions in the livestock sector. Future research could explore the broader applications of this method and its potential utilization in similar studies.

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