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Interactive livestock feed ration optimization using evolutionary algorithms

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ABSTRACT

The profitability of the livestock industry largely depends on cost-effective feed ration formulation as feed accounts for between 60 and 80% of production costs. Therefore, feed formulation is a recurring problem for breeders. In addition, the presence of linear and non-linear constraints, and multiple possible combinations that are subject to upsurge makes the formulation of feed a Non-deterministic Polynomial-time hard (NP-hard) problem. Generally, feed formulation is done by specifying the nutritional requirements as rigid constraints and an algorithm attempts to find a feasible cost-effective formulation. However, relaxing the constraints can sometimes provide a huge reduction in the cost of feed while not seriously affecting the economic performance of the livestock. This entails the development of a feed formulation software that has an inbuilt mechanism to enable relaxation to the constraints based on the users' necessities. Accordingly, the problem formulation and the optimization algorithm should facilitate this. We modified the conventional problem formulation with a tolerance parameter (as a percentage of the actual value) to accommodate the relaxation of constraints. We solved this problem with differential evolution, a variant of evolutionary algorithms, which are good for handling NP-hard problems. In addition, the relaxation of the constraints was done in an interactive way using the proposed method without penalties. In other words, the proposed method is flexible and possesses the ability to search for a feasible and least-cost solution if available or otherwise, the best solution and finds the suitable feed components to be used in ration formulation at an optimal cost depending on the nutrient requirements and growth stage of the animal.

1. Introduction

Several products with immense benefits to the human wellbeing are derived from livestock. The productivity and the quality of livestock products mainly depend on the animal's diet during different growth stages (Doğan et al., 2000). For cattle, the balanced diet to be provided varies depending on purpose (dairy or beef), age, quality of product desired (preference differs by country or region due to different customs) and the expected productivity (Alan Sutton, 2003; Van Elswyk and McNeill, 2014).

In the livestock industry, feed plays an important role as it accounts for approximately 60–80 % of the production cost depending on breed and growth and reproduction stage of the animal (Abd Rahman et al., 2010; Chagwiza et al., 2016). Therefore, it is essential to provide the best diet at the least possible cost in order to cut down operational costs and subsequently increase profit. Additionally, the aim of feed ration formulation is to choose appropriate ingredients and at the right quantities based on their nutritional characteristics and cost; so that the overall feed cost is reduced while satisfying constraints related to different nutrient requirements of the livestock. Feed management is very important in raising of livestock. It aims to attain the requisite ration that is healthy and safe at a low-cost (Kim et al., 2013; Trillo et al., 2017).

In livestock breeding, feed formulation is a recurring problem with Non-deterministic Polynomial-time hardness (NP-hard) complexity due to the presence of linear and non-linear constraints regarding nutritional requirements such as total dry matter intake, crude protein, total digestible nutrients, roughages, and moisture content. In addition, the presence of these constraints reduce the optimal attainable regions complicating the search process.

Generally, in feed formulation, the minimum nutritional requirements are expressed as rigid constraints to be met. Even a small violation regarding any of the nutritional requirements implies an infeasible solution and the optimization algorithms neglect them in search of feasible solutions. In other words, for a set of given minimum nutritional requirements, the feasible solution obtained may not be

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Nomenclature

Term	Description
Met	methionine
Lys	lysine
Arg	arginine
Thr	threonine
Leu	leucine
Ile	isoleucine
Val	valine
His	histidine
Phe	phenylalanine
Trp	tryptophan
ME	metabolizable energy
MP	metabolizable protein
Ca	calcium
P	phosphorous
DMI	dry matter intake
MC	moisture content
TDN	total digestible nutrients
CP	crude protein
Conc.	concentrates
Rhage	roughages
Tolerance parameter (δ)	limit to which a specific nutritional requirement can vary as a percentage of actual specification
Epsilon (ε) parameter	algorithmic parameter that specifies the amount of overall constraint violation allowed

cost-effective compared to a slightly infeasible solution. In addition, a slight relaxation of one or more nutritional requirements may result in a large reduction of feed cost thus, making the infeasible solution with respect to strict nutritional requirements more viable, since it has been observed (Cline and Richert, 2001; Niemi et al., 2010) that relaxation of some of the constraints would not seriously affect the economic performance of the livestock. Moreover, the possible loss of effectiveness can be compensated for by the reduction in the cost of the ration. Perfectly satisfying all constraints related to the nutritional requirements is not economically viable in some scenarios while the relaxation of some constraints does not impact the health or quality of products derived from the animal. In terms of optimization, the relaxation of the constraints increases the feasible region, which will presumably lead to a reduction in the cost of the ration. In addition, the amount of constraint relaxation depends on the problem at hand. This can be seen in several Cases. For instance, *Bulgogi*, a popular Korean cuisine that requires the beef to possess a particular sensory attribute (in terms of taste, flavor, tenderness and juicy features) which are usually achieved by the type of feed provided to the animal, in this Case; high amounts of concentrates (Park et al., 2012). Therefore, depending on the availability of the constituent materials and economic considerations, farmers would want to reduce operating costs while relaxing the constraints or vice versa. The amount of constraint relaxation will depend on the need of the farmer, feed company and consumer preference of the product. Accordingly, it is essential to develop an interactive platform that when combined with prior technical knowledge, can easily visualize the nutritional requirements that can be relaxed to yield a low-cost but adequate feed formulation for the animal's growth.

Researchers have proposed various methods for feed formulation using linear and nonlinear programming (Abd Rahman et al., 2010; Saxena and Chandra, 2011). Due to the presence of the linear/nonlinear constraints, the feed mix optimization problem is often complex and difficult to solve. Under such conditions, application of standard linear or nonlinear programming techniques and methods to finding least cost formulation has many limitations, which includes complexity in determining the objective function and difficulty in establishing constraints in achieving the given objective. Consequently, population-based algorithms such as evolutionary algorithms have gained significance in solving the feed ration formulation problems. Nevertheless, even though these advanced constraint handling methods are available, researchers still apply the penalty methods to handle constraints where the penalty factor needs to be determined depending on a problem's characteristics.

Interactive feed mix formulation aims at relaxing the excessively rigid specifications of nutrient requirements of livestock rations formulations. In (Rehman and Romero, 1987), the nutritional requirements are treated as goals that may or may not be achieved instead of rigid constraints. Furthermore, a penalty system was coupled with the above goal-programming formulation where the penalty scale operates when the desirable limits or targets are violated. In (Czyzak, 1989), the goal-programming, problems are solved using fuzzy mathematical programming. In (Lara and Romero, 1994), the nutritional requirements are formulated as targets for formulating a multi-goal programming model which is solved in an interactive way. These previous studies highlight one of which requires developing an optimization algorithm that has an inbuilt mechanism to enable relaxation to the constraints based on the users' necessities. In the current work, we modified the conventional problem formulation (Abd Rahman et al., 2010) with a tolerance parameter (as a percentage of the actual value) to provide the user with the flexibility for visualization of nutrient requirements that can be relaxed to yield a low-cost but adequate feed formulation for beef and dairy cattle. Further, the modified problem is solved using differential evolution (DE), a variant of evolutionary algorithms with epsilon (ε) constraint handling method.

2. Materials and methods

2.1. Data

Data on the various feed materials under consideration, their nutritional values and cost was obtained from the Rural Development Administration, Republic of Korea (Korea, 2017). These are summarized in Tables 1 and 2 for dairy and beef cattle, respectively. The nutritional requirements of dairy cattle are arranged as: Met, Lys, Arg, Thr, Leu, Ile, Val, His, Phe, Trp, ME, Ca, and P and that of beef cattle are arranged as: DMI, MC, TDN, CP, Ca, and P. The nutritional requirements of livestock according to the animal species (dairy and beef), age and weight are summarized in Table 3 (Korea, 2017).

2.2. Problem formulation

The general objective and constraint formulation employed in the literature for dairy and beef cattle ration optimization are summarized in Table 4.

In dairy cattle, n is the number of ingredients under consideration (64 variables). The weight in kilograms is w_i and $cost_i$ is the cost (Won/kg) of the material (X_i) as mentioned in Table 1. In Table 1, each column (3–15) represents the amount of respective nutrient values in a kilogram of the particular material (X_i) mentioned in column 1. The variables r, s, t, u, v and z are the nutrient values of MP, Lys, Ca, P, ME and Met, respectively. The requirements change with the age and weight of the cattle.

The objective is formulated as weight (w_i) of selected materials (variables X_i) multiplied by their respective costs ($cost_i$). The aim is to find w_i that minimizes the overall cost while satisfying the constraints. Since the weight and the cost are non-negative, the objective function has a non-negative sign restriction. The first constraint is MP which is a postruminally digested protein and is vital for maintaining the dairy