THE OPTIMIZATION OF RUMINANT FEED WITH LOCAL INGREDIENTS USING LINEAR PROGRAMMING

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ABSTRACT

The high cost of feed is a major factor that reduces profit margins in ruminant farming, primarily due to the reliance on imported feed pellets. However, various locally available ingredients present cost–effective alternatives that can still meet the nutritional requirements of ruminants. This study aims to create a cost–effective goat feed using local ingredients through Linear Programming (LP). The objective is to find the cheapest feed mix that still meets all the nutritional requirements. Eleven local ingredients from Kedah and Perlis were chosen for their availability, cost–effective, and nutritional value. Using Excel Solver, a LP model was formulated and solved to meet key nutrient needs for ruminants, specifically dry matter, crude protein, calcium, and phosphorus. Nutrient composition data for each ingredient were collected from The Malaysian Agricultural Research and Development Institute (MARDI). The results show that a balanced feed can be formulated using local ingredients, reducing reliance on imported feed and supporting sustainable farming in Kedah and Perlis. The LP model found an optimal solution using just two local ingredients, *petai belalang* and napier grass, that fully meet all nutritional needs. This approach resulted in a 72% reduction in feed costs compared to current commercial options. This research offers a practical solution for local farmers, enabling the production of ruminant feed at a lower cost and thereby enhancing profit margins. As a result, this contributes to improved food security, economic resilience in rural communities, and a more sustainable livestock industry.

Keywords: Animal diet, Feed mix, Linear programming, Optimization, Ruminant.

ABSTRAK

Kos makanan yang tinggi merupakan faktor utama yang mengurangkan margin keuntungan dalam penternakan ruminan, terutamanya disebabkan oleh kebergantugan kepada pelet makanan yang diimport. Walau bagaimanapun, terdapat banyak bahan tempatan berpotensi digunakan sebagai alternatif yang kos–efektif dan masih memenuhi keperluan pemakanan ruminan. Kajian ini bertujuan untuk menghasilkan makanan kambing yang kos–efektif dengan menggunakan bahan tempatan melalui Pengatucaraan Linear (LP). Objektif kajian ialah untuk mendapatkan formulasi makanan yang paling murah disamping memenuhi keperluan nutrisi. Sebelas ramuan makanan tempatan dari Kedah dan Perlis telah dipilih berdasarkan ketersediaan ramuan, kos–efektif dan kandungan nutrisi. Menggunakan *Excel Solver,* model LP diformulasikan dan diselesaikan bagi memenuhi keperluan pemakanan penting ruminan, terutamanya bahan kering, protein kasar, kalsium dan fosforus. Data komposisi nutrien untuk setiap bahan dikumpulkan daripada Malaysian Agricultural Research and Development Institute (MARDI). Hasil kajian menunjukkan makanan yang seimbang boleh diformulasikan menggunakan bahan tempatan, yang boleh mengurangkan kebergantungan bahan makanan import dan menggalakkan amalan pertanian mampan di Kedah dan Perlis. Model LP mengenal pasti penyelesaian optimum yang mengurangkan kos makanan dengan hanya menggunakan dua bahan tempatan iaitu petai belalang dan rumput napier bagi memenuhi keperluan pemakanan yang lengkap. Pendekatan ini menghasilkan pengurangan sebanyak 72% kos makanan berbanding pilihan komersil. Kajian ini menawarkan penyelesaian praktikal untuk petani tempatan, membolehkan pengeluaran makanan ruminan pada kos yang lebih rendah dan dengan itu meningkatkan margin keuntungan. Hasil kajian ini, menyumbang kepada peningkatan keselamatan makanan, ketahanan ekonomi dalam komuniti luar bandar, dan industri ternakan yang lebih lestari.

Kata kunci: Diet haiwan, Campuran makanan, Pengaturcaraan linear, Pengoptimuman, Ruminan.

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Table of Contents

List of Tables

List of Figures

CHAPTER ONE

INTRODUCTION

1.1 Ruminant Industry in Malaysia

The livestock farming in Malaysia is an essential and integral part in agricultural sector, providing productive employment for the population with the internal demand for meat, milk and dairy products as well as supplying essential animal-based protein products. The industry's growth would ensure the country's food safety and reduce reliance on meat imports. Livestock farming consists of domesticated ruminants and non-ruminants. Goat, cows, sheep, buffalo and deer are classified under ruminant category, while poultry and swine are classified under non-ruminant category.

Ruminants are mammals, which can obtain nutrients from vegetable intake mainly through microbial activities by fermenting it before digestion in a specific stomach. Their stomach comprises of four compartments: the rumen, reticulum, omasum and abomasum. Additionally, ruminants have a distinctive capacity to transform high-fibre feed into usable nutrient sources for animal maintenance, manufacturing (growth, fattening, lactation) and reproduction compared to other herbivores. According to Dijkstra et al. (2013), ruminants play a crucial role in human food systems. Their unique digestive system, which includes a multi-chambered stomach, allows them to break down and extract nutrients from fibrous plant materials, like grass and other forages, that indigestible among humans. This process converts these otherwise indigestible resources into high-quality, nutrient compressed foods.

Sub-sector ruminants are typically raised by minimum-scaled farmers. The industry was developing slowly in 1996-2002, but in 2005- present, it started to grow steadily because of government efforts and initiatives (Bekhet, 2017). Nevertheless, the self-sufficiency rate for ruminants is still lower than 30%, according to the higher demand than the supply of local producers. To meet at least 50% of the local market needs, Malaysia must increase livestock production (Ariff et al., 2015).

1.2 Issues in Ruminant Feed

The major issue concerning ruminants involved in feed, considerably augmenting the overall cost by 60% to 70% of the total expenditure on imported pellet from other countries. Numerous ingredients, sourced either locally or imported from overseas, can be utilized in formulating quality pellets for ruminants. However, a significant portion of these ingredients is typically imported for ruminant feed, contributing to the high cost of producing the pellets. It is supported that ruminant feed should be composed by using locally available ingredients while still meeting the necessary nutritional requirements for ruminants. Moreover, pellets contribute to maintaining digestive health in ruminants by offering a consistent and controlled diet, minimising the risk of digestive disorders commonly associated with sudden dietary changes. This supplementary feed ensures a steady supply of vital nutrients, fostering healthier growth and enhancing overall productivity among the animals.

Pellet is one of the supplements for ruminant. For the growth of ruminants, pellets must be taken every day. Malaysia, situated near the equator, experiences distinct wet and dry seasons throughout the year. The country encounters rainfall sporadically, making the wet season unpredictable. Typically, breeders provide grass to ruminants in their daily feedings, both mornings and nights. Unfortunately, during the rainy season, breeders face challenges due to a surge in the number of worm eggs within the grass. However, excessive worms in the animal's stomach can lead to infections, potentially causing illness or even death in the ruminant (Love & Hutchinson, 2003).

1.3 Feed Formulation for Ruminant

Feed formulation is a method that combines ration ingredients to provide livestock at distinct phases of manufacturing with the needed nutrition. The formulation of feed should provide all essential nutrients and energy to sustain the needs, reproduction and physiological health of the animals. Feed should be palatable, easily digestible, economical and have less environmental effects (Bocquier & González-García, 2010).

The feed formulation model aims to obtain the optimum combination of the ingredients at the minimum possible price to meet all the animal's dietary demands. In addition, there has been significant attention to animal choice resistant to certain illnesses as choice for enhanced disease control as well as decreasing the need for treatment at risk. Feed is also made to help breeders, especially in rainy season, since green grass cannot be fed to ruminants. The supplement for ruminants is produced to keep each animal's durability while saving on the expense of buying extra supplements as it could prevent the animal from damaging illnesses like diarrhoea (Ban & Guan, 2021).

1.4 Factors Affecting Producing Pellet

There are two main factors that need to be considered in producing good pellets. Firstly, the suitable ingredients in ruminant diet and secondly the required nutrients for ruminant.

1.4.1 The Ingredients in Ruminant Dietary

The appropriate ingredients play an essential role in producing the best pellets. Every animal should consume different diet depending on the body's digestion system. For instance, deer are very selective in choosing green grass compared to other livestock. Therefore, the list of suitable ingredients for ruminants needs to be identified to offer a high-quality mixture of feed for ruminants. Some of the ingredients identified in previous studies are soybean, alfalfa, paddy straw and maize grain. The use of agricultural waste as animal feed is very beneficial in obtaining animal nutrients and in reducing pollution (Bakshi et al., 2016).

1.4.2 Nutrition for ruminant

Australian farmers have identified nutrition as the primary contributor to animal health in farms and is one of the fundamental requirements for all animals (Phillips, 2016). Ruminants should be fed differently to satisfy body requirements depending on their species, age and manufacturing intent. Nutrition provides the essential for nearly all metabolic processes in the body, thereby fulfilling the fundamental requirements for livestock well-being. A study of Australian livestock farms has discovered that although significant dietary advancements are being made, farmers still see the most important social security issue on farms as nutrition is concerned (Phillips, 2016). Nutrients are substances that are generally acquired from feeds that an animal can use when made accessible to its cells, bodies and tissues in an appropriate form. Required nutrients for ruminants include proteins, minerals and vitamins.

1.5 Problem Statement

The major cost in livestock farming is the cost of animal feed from day one until the day of harvest. The main reason is Malaysia relies heavily on imports of livestock feed, especially for the ruminant, poultry, swine, and aquacultural sectors. The most important nutrients are energy and protein-based feeds, respectively, which are derived from maize and soybean meal. The total imported source of feed is around USD 1.6 billion per year (Sharma, 2014), this imported feed has caused instability in prices and led to high production costs.

Particularly, the term within December to February is considered as rainy season. During this period, feeding on grass is discouraged due to the potential presence of worm eggs, which can adversely impact the health and nutrition of the ruminants. Ensuring the nutritional content of ruminant feed is of utmost significance. It must align precisely with the daily dietary requirements of the ruminants. Any shortfall in nutritional value compared to the ruminants' needs increases the susceptibility of the animals to illnesses.

The price of pellets is quite expensive due to the fact that most pellets are imported from overseas. Alqaisi et al. (2011) mentioned that feed consists of 60% to 70% of total production costs, thus any effort to decrease feed costs could lead to a significant reduction in total production costs. In order to minimize costs, farmers suggested to mix pellets with local ingredients. The animal feed industry has just started to use local ingredients. For instance, Universiti Putra Malaysia (UPM) uses pineapple to produce a pellet for cows and goats, meanwhile there are a few farmers who are producing a feed mix for their personal use only. Additionally, many possible local ingredients can be used to produce the cheaper pellet that is able to fulfil the nutrients needed, where simultaneously can fully utilise sources of local plants. The formulation of feed mix using try and error technique does not obtain the optimal solution. in contrast, LP is the technique which has been applied to formulate the optimal feed formulation for ruminant. By using LP technique, it can generate the best feed formulation for ruminant.

Various ingredients contain distinct nutrients, in which every serving is beneficial for specific functions. Therefore, a good combination of ingredients with specific quantities are required to produce a feed that can fulfil nutrients needs. In this case study, the ruminant of focus is the goat since this type of ruminant has a high market demand in Malaysia as highlighted by Kaur (2010).

1.6 Research Questions

i. What are the appropriate ingredients and nutrients for ruminant's feed?

ii. How to obtain the best feed formulation for the ruminant that considers all nutrients needed?

iii. How to evaluate the proposed ruminant's feed formulation model?

1.7 Research Objectives

The main objective of this research is to determine the best combination of ingredients for ruminant's feed through an optimization model. The following specific objectives must be accomplished in order to achieve the target:

i. To identify appropriate local ingredients and nutrients for the ruminant's feed.
ii. To develop an optimal feed formulation for ruminants that fulfil nutrients requirement and ingredients using linear programming approach.
iii. To evaluate the developed model through different scenario.

1.8 Scope of Study

This research involves breeders in Kedah and Perlis. Several interview sessions have been conducted among breeders in Kedah and Perlis to obtain data on animal nutrition, specifically in goats. Goat was selected due to its high market demand in Malaysia.

1.9 Summary of Chapter One

Chapter one presents the details of the problem and focuses on the objectives of the study, as well as discusses the contribution of feed formulation for ruminants.

While in chapter two, it presents an overview of animal feed formulation problems. It includes the list of techniques used to solve problems in feed formulation. Chapter Two also discusses the gap in animal feed formulation problems according to the previous research.

Moving on to chapter three, it describes the methodology used where several procedures in previous research are investigated. This chapter highlights the concept of Optimization Technique using Linear Programming. This would also be the basis for the research contribution.

Next, chapter four demonstrates the implementation of fed mix formulation. This chapter also reveals the result obtained from the mathematical modelling of the feed formulation for goat using the information of the data required in developing the LP model. Apart from that, this chapter also discusses the what-if analysis.

In the final chapter, implication, limitation and assumptions of the study are discussed. Recommendations and the research extension are suggested as well.

CHAPTER TWO

LITERATURE REVIEW

2.1 An Introduction to Ruminant

Ruminants are hoofed mammals with different digestive systems that enable fibrous plant resources to be used more frequently than other herbivores. The examples of this type of ruminants are goats, cows, giraffes and deer. Ruminants possess a digestive system specialized for fermenting feed primarily in the rumen, where microbial fermentation breaks down complex plant materials into simpler compounds that provide essential precursors for energy use by the animals. In contrast, monogastric animals, including pigs and poultry have a simple-chambered stomach that primarily relies on enzymatic digestion, requiring feed that is more easily digestible for efficient energy extraction. Through a better understanding of the digestive system of ruminants, the farmers can understand more about how ruminant animals need to be handled and fed (Forbes, 2007). Ruminants have a complicated digestive system that allows fibrous plant material to be digested (Reddy & Hyder, 2023). Each of these compartments serves a distinct function in the breakdown of feed. Ruminants play a crucial role in Malaysia's livestock sector. The majority of farmers focus on producing either small or large quantities of milk and meat from ruminants for public consumption (Sadiq et al., 2018).

2.2 The Importance of Feed Formulation for Ruminants

Feed formulation is a process that combines different ingredients to provide ruminants with the nutrition required at various stages of production. A feed should provide all the nutrients and energies needed to preserve the vital physiological functions of animal growth, reproduction and health (Nath & Talukdar, 2014). Feed also should be highly digestible and have a much lower environmental impact. The feed formulation model seeks to combine feed ingredients that meet ruminant nutritional needs at the minimum possible cost. Additionally, feed formulation is the total amount of feed given to the animal daily which can be defined as the process by which different ingredients are mixed in a proportion necessary to provide the animal with a proper amount of nutrients needed at a particular stage of production (Olatunde et al., 2008).

Complete feed is a combination of feed ingredients intended to satisfy animals' nutrient requirements that contain drilling, sub-products, cereals, protein sources, fats, minerals and vitamins for ruminants. A mixture of several ingredients permits the use of feed that is more palatable than it is fed individually (Meel et al., 2018). Therefore, the minimal intakes of nutrients required to stabilize the animal are well established (Ritskes-Hoitinga & Chwalibog, 2002).

There are several benefits of complete feed as mentioned by Faraz et al. (2021), which are; it can maintain a balanced diet for animals, managing waste, improving performance and enhancing feed components' starch gelatinization. Additionally, creating water-stable feed and preventing mold growth can enhance animal performance.

Thus, most livestock producers aim to achieve optimal feeding formulation for their farm animals. Conventional algorithms were aimed to achieve optimum feed formulation by minimizing the cost of feeding and satisfying the nutritional requirements of the animal. However, some authors aimed to maximize weight gain, milk yield, profit and nutrient utilization (Saxena & Khanna, 2017). The key to achieving these objectives is to provide a nutritionally balanced diet to the animal. To fulfil the nutrient requirement of animals, diet formulation is the basic need in livestock industry.

2.3 Constraints Related to Ruminant's Feed Formulation

In modelling a ruminant's feed, the difficulty level of the problem increases with the involvement of a variety of decision criteria. These requirements include the type of nutrients ruminants need and the appropriate ingredients they can consume.

2.3.1 Nutrients in Ruminant's Feed

Typically, multiple types of feed may constitute feed rations. The minerals, protein, energy, vitamins, fibre and water are necessary for ruminants. Energy (calories) is usually the most restrictive nutrient, while protein is the most expensive. Excessive and imbalanced supplies of vitamins and minerals can restrict animal production and may cause variety of health problems. Fibre (bulk) is required to maintain rumen health and to prevent it from digestive disorders. The cheapest ingredient in feed is water but it is the most overlooked. According to general rule of thumb, sheep and goats consume 2% to 4% of dry proportion in their feed based on their body weight. Ruminants need a good mineral; salt, calcium and phosphorus are most necessary for ruminant's feed (McDowell & Arthington, 2005). Furthermore, the use of clean fresh water is always required for ruminants. Each day, mature animals consume in between 3½ and 1.5 gallons of water. During late gestation and lactation, the water requirements and consumption increase significantly (Hart & Schauer, 2015).

According to Wadhwa and Bakshi (2013), ruminant requires at least 10% of protein, 65% of total digestible nutrients (TDN), 0.33% of calcium and 0.28% of phosphorus.

Additionally, based on the study from Olugbenga and Abayomi (2015), they proposed to use the nutritional and restricted amounts of metabolizable energy (ME), protein, amino acid restricting, calcium, phosphorus, fibre and fat. Moreover, Thapelo (2018) mentioned that ruminant only requires five essential nutrients which is crude protein, fibre energy, fatty, water-soluble vitamins and minerals. The lack of attention to these main food ingredients has contributed to poor production in various situations. Food additives are additional to these absolute requirements. These are classified as nutritional ingredients providing an adequate response in non-nutritional animals.

Four nutrient which is grouped in dry matter, protein, calcium and phosphorus have been selected based on this study. Each of these four nutrients has unique benefits that should be take consideration while formulating ruminant's feed. First and foremost, dry matter intake will assure that the animal gets adequate nutrients to maintain growth, milk production, daily energy demands and overall health. Secondly, eating protein increases the rumen bacteria productivity and growth. By improving the digestion of fibrous foods, this ensures the best possible absorption of nutrients. Thirdly, calcium is necessary for healthy bones, neuron function, and muscle contractions, it is particularly important for lactating animals. Lastly, phosphorus helps the body transmit energy, which is essential for ruminants to be active and productive.

2.3.2 Ingredients in Ruminant's Feed

Corn, soybean, fish meal, premix, vitamin or mineral, salt, lysine, oyster shell, bone meal, methionine, wheat bran and calcium diphosphate are the most common ingredients used in ration formulation for farmers and broiler feed factories (Olugbenga & Abayomi, 2015).

According to Swecker and Saun (2023), hay tends to be a mild protein and energy source for goats and sheep. The proteins, vitamins and minerals, especially calcium of legume hay, alfalfa, clover and lespedeza seem to be higher than grass hay. The strength and protein content of the hay based on the forage maturity when harvested. In order to maintain the nutritional quality of the hay, proper healing and storage are also needed.

In the U.S. livestock feed industry, corn is the most common grain used for energy. Other grains are sorghum, wheat, barley and oats. The energy provided by starch from these cereals varies greatly depending on the type of feed grains and animal species (Nikkhah, 2012). According to the National Research Council (NRC), the Metabolizable Energy (ME) for sorghum is lower than corn. However, it is still a profitable feed grain since sorghum grain price are usually lower than corn price (Danalatos et al., 2009)

Additionally, as useful sources of livestock, Palm Kernel Cake (PKC) is widely used in animal feed, particularly for ruminants (Zahari & Alimon, 2005). PKC is a widely used ingredient in Malaysia, Germany and the Netherland with constituting about 10% of the dairy feed in Germany and the Netherland, whereas Malaysian dairy farmers utilize more than 50% of the feed (Mohamed & Alimon, 2003).

It is crucial to select the best ingredients for ruminants' health, productivity and overall well-being. Ruminants such as cows, sheep and goats possess a unique digestive system featuring a rumen that ferments food for breakdown. Furthermore, high-quality feed supplies essential nutrient for example carbohydrates, proteins, fats, vitamins and minerals for ruminants to grow, reproduce and efficiently produce milk or meat. Balanced feed also lowers the risk of health problems like acidosis or nutrient deficiencies, helping to maintain the animals' health and productivity. As stated on the website of the Malaysian Agricultural Research and Development Institute (MARDI), there are various types of ingredients that can be utilized. However, MARDI offers 11 specific ingredients for ruminants, including Napier grass, silage, *petai belalang*, rice paddy straw, wheat bran, soybean bran, paddy bran, anchovy head, corn silage, soy dregs and palm fronds. These ingredients were selected because they are easily accessible and available within reach.

2.4 Approaches in Feed Formulation

There are several techniques that have been used previously to solve feed formulation problems. These common solution techniques include the optimization tools which are linear programming and nonlinear programming. In addition, MCDM, heuristics techniques and simulation technique are also used to solve feed formulation problem.

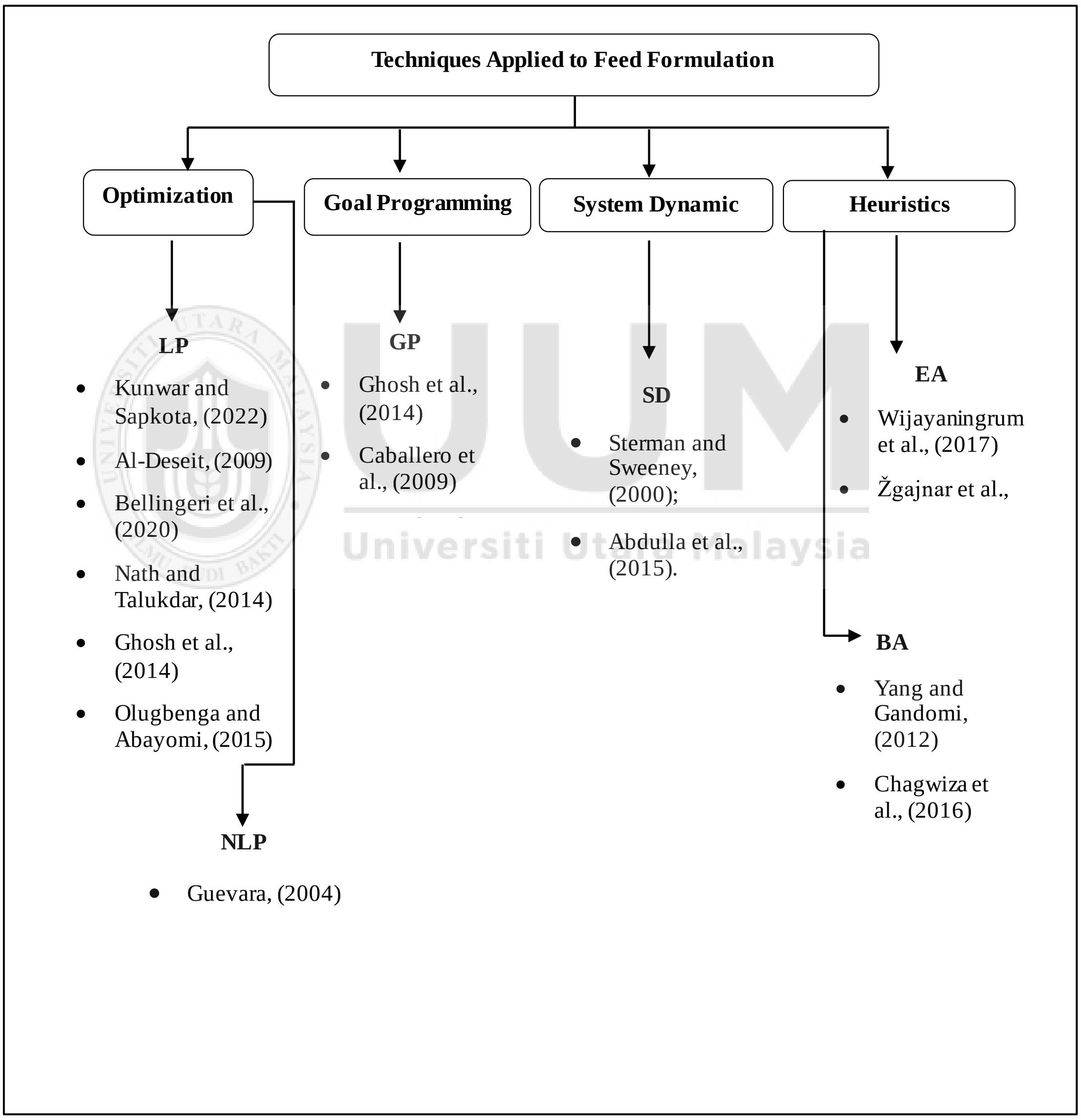

Figure 2. 1. Techniques Applied to Feed Formulation

2.4.1 Optimization

Optimization is the process of finding the best solution to a problem, or optimum is produced. Optimization techniques such as linear programming (LP) and nonlinear programming (NLP) are commonly applied in various problems.

2.4.1.1 Linear Programming

Linear programming (LP) is known as part of a great revolutionary development which has given mankind the ability to state general goals and to lay out a path of detailed decision to take in order to attain the "best" achievement in its goals whilst facing with complexity. LP tools are the ways to formulate real-world problems in detailed mathematical terms (model), techniques for solving the models (algorithms) and engines for executing the steps of algorithms (computers or software) (Kunwar & Sapkota, 2022).

Al-Deseit, (2009) mentioned that LP is the conventional method of Least Cost Feed Formulation, which compares the nutrients provided by the animal with the nutrients supplied by the feed ingredients available and mixes them to achieve a healthy diet at the lowest possible cost. They also mentioned that the LP approach is aimed to formulating feeds, therefore could lead to better performance in this sector as compared to using inefficient approaches such as the try-and-error method.

Bellingeri et al. (2020) mentioned that LP as a tool to optimise human nutrition. A model was developed to represent the efficiency of nutrient use and its relationship to profitability on dairy farms. Thus, Nath and Talukdar (2014), applied linear programming on fish feed formulation. LP is also widely used in feed formulation.

Feed formulation by LP is based on assumptions of linearity between animal yield and nutrient ingredient included in the feed formulation.

In LP, the requirements must be measured and expressed numerically. In order to obtain an LP solution for feed formulation, the necessary information needed are the list of feed ingredients, their availability, costs, nutrient content and species-specific requirements for minimum, maximum or exact quantities.

According to Ghosh et al. (2014), LP in feed formulation assumes a single objective, decision variables representing available ingredients, nutritional requirements changing to these variables and the optimum diet minimizing the objective without disrupting constraints.

Olugbenga and Abayomi (2015) alleged that, for broiler beginners and finishers in their respective fields, the proposed optimal formulation of the LP model showed approximately 7.48% and 9.96% reduction in cost for feed formulations compared to previous formulations. This model decreased the amount of fat in the current ration but the metabolism energy required for the physiological structure was significantly increased by adding more flesh. By reducing the total cost of feed formulation production and making it available to the moderate Nigerian farmer using a standard excel package, the model also achieved the objectives of study.

To achieve a final calving weight of 600 kg as an objective, Tozer (2000) proposed to use mathematical programming to formulate rations for big breed replacement dairy heifers for 11 different weight classes between 50 to 550 kg and daily growth rates of 600,700 and 800. Apart from that, LP has been used widely in modelling feeding problems of pigs, cattle and prawn and another aquaculture. Additionally, Ghosh et al. (2011) mentioned that LP helps nutritionists to make a choice by comparing a range of feedstuff and identify which feedstuffs can be combined to provide the most optimal amount of nutrients without prejudice to other ingredients. LP is a highly suitable method for feed formulation, particularly when aiming to optimize costs while meeting the nutritional requirements of ruminants. LP assists in identifying the least-cost combination of feed ingredients that yet satisfies the animals' nutritional requirements. This is specifically helpful in controlling feed expenditures, which are a significant part of livestock production costs. It also ensures that the formulated feed, meets specific nutrient requirements, such as protein, calcium, dry matter and phosphorus by setting constraints in the mathematical model.

2.4.1.2 Non-linear Programming

Non-linear programming is certainly a useful tool, since so many aspects of our world exhibit non-linear behaviour.

Guevara (2004) conducted a study of maximizing margin over feed cost in broiler feed formulation by using a non-linear programming optimization model. The NLP model identified the optimal feed mix that maximizes profit margin. The study objective is to illustrate the effects of changes in different variables on the optimum energy density, performance and profitability and was compared with conventional linear programming. As a result, non-linear programming can be used in the study for broiler feed formulation because energy level does not need to be set.

2.4.2 Goal Programming

The Goal Programming (GP) is vastly popular for two reasons: it is clear and comprehensible as well as it can be applied as an expansion of the linear programming model for which an efficient solving algorithm is available (Ghosh et al., 2014). GP is a proactive and versatile technique for solving several criteria decision-making problems that pool design needs by having different targets with or without weight, with or without penalty functions of target deviations (Caballero et al., 2009).

Kuntal and Gupta (2018) conducted a study by implementing GP approaches for ration formulation problems for Indian dairy cows. Hence, to meet the nutrient requirement, a model for three categories of dairy cattle weighing 500 kg each and yielding 10 litres of milk with 4% of fat content during 7th, 8th and 9th month of pregnancy has been formulated by dividing the goals into set of priorities which is least cost and dry matter intake.

In conclusion, the reason GP is not suitable for this research is because it allows to handle multiple, potentially conflicting goals by prioritizing or weighting them. It is useful when there have several objectives to achieve and are willing to compromise between them.

2.4.3 Heuristics

Heuristics are methods of problem-solving that employ a practical approach to addressing problems, particularly in situations when identifying the best answer might be challenging or time-consuming. Heuristics seek for a "good enough" solution rather than perfection, frequently depending on educated estimates, rules of thumb, or trial-and-error.

2.4.3.1 Evolutionary Algorithm

Evolutionary algorithms are a subset of artificial intelligence and optimization methods inspired by the process of natural evolution. There use mechanisms such as mutation, selection and crossover to evolve solutions to complex problems over multiple generations.

According to Wijayaningrum et al. (2017), to optimize the cost of poultry and cattle feed mixes, Genetic Algorithms (GA) were used. The optimization involves identifying the minimum cost of ingredients in the feed formulation. In poultry sectors, the results could not be obtained without penalties due to the management of multiple constraints at the same time. However, zero penalty value for the animals was easily solved and maximum outcomes were achieved.

Many restrictions encountered difficulties because of zero penalty tests that were unable to be achieved. Penalty value occurs when violating acceptable limits (Žgajnar et al., 2010). This problem typically arises when nutrient requirement constraints are identified as goals that can or cannot be accomplished. The objectives could be absolutely, partly or mostly could not be met.

2.4.3.2 Bat Algorithms

BA is a swarm intelligence algorithm under meta heuristic technique. Yang and Gandomi (2012) created the Bat algorithm (BA). Based on Bat algorithm, all bats fly spontaneously using echolocation, and that the loudness changes from positive to a constant minimum value.

Chagwiza et al. (2016) applied BA and Cplex solver to find the optimal quantity of Moringa Oleifera being used in the poultry feed ration problem. Without really investigating or visiting the paths, BA can be identified as useless paths of solution. It results in faster optimization in execution time in the algorithm.

In conclusion, heuristics are most useful when speed is crucial, exact solutions are not required, or the problem is too complex for traditional methods. They focus on providing approximate, ‘good enough’ solutions quickly in contrast to research objectives that aim to achieve an optimal solution.

2.4.4 System Dynamic

System dynamics (SD) is a methodology that can be used to study and understand the behaviour of a complex system over time which is characterized by interdependence, mutual interaction, information feedback and circular causality (Sterman & Sweeney 2000; Abdulla et al., 2015).

Abdulla et al. (2016) conducted the study of management of beef cattle in Malaysia. According to their study, simulation models are of great value in decision-making, as they help in understanding the dynamics of complex systems. Therefore, in this study the system dynamics approach is used for analysing beef cattle production. The result of their study is to design a model that can provide better understanding and evaluation of the beef cattle production issues.

In conclusion, system dynamic is useful for analysing dynamic, non-linear, and interconnected systems where the focus is more on understanding the system's behaviour than optimizing a specific goal. Additionally, if the goal is to find the best solution for a clearly defined, static problem, LP is more suitable compared to system dynamic.

2.5 Summary of Chapter Two

From the previous studies conducted by various researchers as discussed in previous section, it can be understood that the feed formulation has been widely studied in the animal feed sector, as it provides the optimal feed mix composition for specific types of animals,

Hence, the most suitable optimization tools in determining the best optimal feed mix for animals is Linear Programming technique. Linear Programming technique was successfully applied in feed formulation for animals either in maximizing profit or minimizing cost. The researcher was motivated to implement the LP technique as the most suitable optimization tool. The implementation of LP technique formulation is discussed in Chapter Three.

In developing feed formulation for ruminant, there are two important factors: nutrition and ingredients. In this research, four nutrients were chosed which are protein, calcium, sodium and phosphorus. Meanwhile, the 11 selected ingredients were Napier grass, silage, *petai belalang*, rice paddy straw, wheat bran, soybean bran, paddy bran, anchovy head, corn silage, soy dregs, palm fronds. This research proposed that these nutrients and ingredients are based on information from the veterinary website regarding suitable components for ruminants.

There are three approaches that have been used by possibly in solving feed formulation for ruminants. LP have been to be used due to the suitability of the problem with four nutrients and 15 ingredients. The major objectives of the feed formulation problem are to minimize the cost of producing pellets that are able to satisfy all the constraints which ruminants need and finding the best combination of ingredients. Therefore, in the next chapter we will discuss the methodology applied in this paper.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discussed the details of methodology related to data collection, model development, mathematical formulations and relevant what-if analysis in achieving all the objectives. Therefore, the research design developed to achieve the objectives of this study is outlined below.

3.2 Research Design

This study is carried out in four phases of research activities in order to accomplish the objectives, which are problem definition, data collection, model development and model evaluation. Data involved in this study were primary and secondary data types. The primary data were gathered via a ruminant expert interview, while secondary data were retrieved from previous studies and product information in the market. The mathematical formulations for ruminants feed formulation were constructed for the objective function and the relevant constraints. The optimization model was generated to meet all constraints in achieving the minimum cost. The optimization model was in the form of LP solution method due to all variables involved in the formulation of the real value type. The proposed model was evaluated through what-if analysis based on various scenarios.

3.3 Research Process

The overall flow of the study is illustrated in Figure 3.1. Subsequently, the discussion for each phase is discussed in following sub-section.

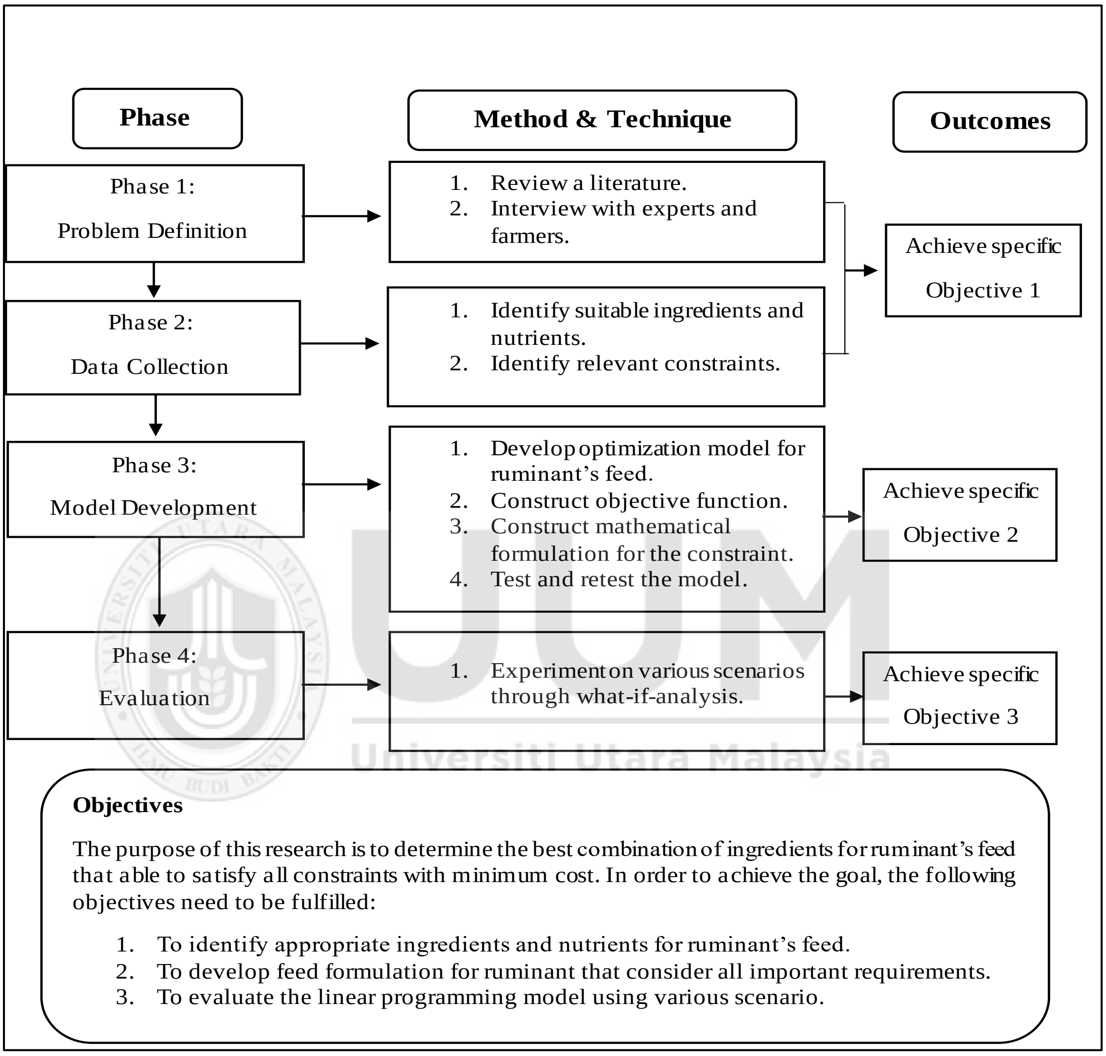

Figure 3. 1. Details of research activities

3.4 Phase 1: Problem Definition

The ruminant diet formulation problem involves various constraints, such as the type of nutrients, the appropriate combination of ingredients to meet nutritional requirements and the cost of pellet processing. Some of this information was obtained from literature reviews and based on interviews with breeders in the northern region of Peninsular Malaysia.

3.5 Phase 2: Data Collection

Primary data and secondary data were collected in this research. Primary data was gathered through interviews with experts from Department of Veterinary Services (DVS) Negeri Kedah, breeders from UiTM Arau, UUM and commercial breeders from Perlis who have many experiences on managing ruminants. Additionally, in this research a questionnaire was distributed to breeders in Kedah and Perlis to explore their requirements for pellet production. The survey findings indicated that the average price preferred by breeders is RM50 for 100 kg of pellets.

Meanwhile, for secondary data, literature reviews and books were used as reference. The required data include the nutrient composition, ingredients for ruminants, and the most essential nutrients suited for ruminant diets. The composition of nutrients in each ingredient and the appropriate ingredients for ruminant were retrieved from MARDI website and literature reviews.

3.6 Phase 3: Linear Programming Model Development

For the purpose of model formulation, relevant data were used to construct the objective function and constraints. The components of the modelling e including variable definitions, the objective function and constraint functions are presented in this section.

3.6.1 Definition of Variables

Various variables were used for the modelling process.

x_i = ingredient of type i in the feed formulation in kg.

where $i = 1,2, \dots, n$;

N_{ki} = amount of nutrient k (%), in ingredient i;

k = Type of nutrient where $k = 1, 2, \dots, t$;

L_k = Lower bound of total value of nutrient k;

U_k = Upper bound of total value of nutrient k;

C_i = Cost of ingredients i per kilogram (kg);

3.6.2 Objectives Function of the Model

The following objective must be accomplished in order to achieve the target.

The objective function of the cumulative feed cost is defined as the summation of the weight of all ingredient's times the cost of one kg for each ingredient:

$$Minimize\ Cost, C = \sum_{i=1}^{n} c_i\, x_i \text{ Where } i = 1,2, \dots, n \tag{1}$$

3.6.3 Constraints Functions

There are several restrictions that must be satisfied to achieve the minimum cost. Therefore, the cost is minimized subject to constraints related to ingredients and nutrients.

i. Cost of producing pellet;

The cost of producing pellet is at most RM 50 for 100kg of feed mix.

$$\sum_{i=1}^{n} c_i \, x_i \leq 50 \quad (2)$$

where $i = 1,2, \dots , n$

ii. Weight of pellet

The weight of the pellet per packaging is 100kg.

$$\sum x_i = 100 \quad (3)$$

iii. Nutrient constraint;

The total nutrients k in the final ration should be within the permitted range of the nutrients.

$$L_k \leq \sum_{i=1}^{n} N_{k_i x_i} \leq U_k$$

Where;

a) The feed mix must contain at least 12% but not more than 35% of dry matter;

$$12 \leq \sum_{i=1}^{11} N_{k1xi} \leq 35 \quad (4)$$

b) The feed mix must contain at least 7% but not more than 20% of protein;

$7 \leq \sum_{i=1}^{11} N_{k2xi} \leq 20$ (5)

c) The feed mix must contain at least 0.30% but not more than 0.80% of calcium;

$0.3 \leq \sum_{i=1}^{11} N_{k3xi} \leq 0.8$ (6)

d) The feed mix must contain at least 0.25% but not more than 0.4% of phosphorus;

$0.25 \leq \sum_{i=1}^{11} N_{k4xi} \leq 0.4$ (7)

iv. Non-negativity constraint;

$x_1, x_2, \dots, x_n \geq 0$ (8)

Therefore, the complete mathematical formulation for feed mix is as follows:

Minimize cost, $C = \sum_{i=1}^{n} c_i \, x_i$ (1)

Subject to:

$c_i x_i \leq 50$ (2)

$x_i = 100$ (3)

$12 \leq \sum_{i=1}^{11} N_{k1xi} \leq 35$ (4)

$7 \leq \sum_{i=1}^{11} N_{k2xi} \leq 20$ (5)

$0.3 \leq \sum_{i=1}^{11} N_{k3xi} \leq 0.8$ (6)

$0.25 \leq \sum_{i=1}^{11} N_{k4xi} \leq 0.4$ (7)

$x_1, x_2, \dots, x_n \geq 0$ (8)

3.7 Phase 4: Model Evaluation

In the stage of model evaluation, actual data obtained from experts was utilized to be compared with the model's output, enabling the observation of its performance. Additionally, what-if analysis was employed to evaluate the model by assessing various scenarios and making judgments on the model inputs. Evaluating the effectiveness of the model output required an examination of its performance, specifically understanding how changes in linear programming parameters impact the optimal solution. Observing fluctuations in the model results is crucial when implementing several amendments to the model input. In this study, the suggested what-if analyses include adding more ingredients to the feed formulation and increasing the price of 100 kg of pellet. Therefore, what-if analysis provides valuable insights into the effects of such changes.

3.8 Summary of Chapter Three

The methodology was divided into four phases: problem definition, data collection, model development and model evaluation. There were two types of data involved in this study: primary data and secondary data. Primary data were collected through interviews with experts in goat farming and veterinary practices. Secondary data were collected from previous studies and books to gather additional information. The study includes various constraints including ingredient and nutrient constraints as mentioned above. Consequently, the results and data analysis are presented in Chapter Four.

CHAPTER FOUR

IMPLEMENTATION AND RESULTS

This chapter starts with discussion on the information of the data required in the development of LP model. Then, the mathematical modelling of the feed formulation for ruminant is developed in the following section. Finally, for the purpose of evaluating the proposed LP model, a set of what-if analysis is carried out.

4.1 Related Information for The Feed Formulation

The relevant information for the feed formulation includes expert input, ingredients requirement, and nutrient requirement for goats.

4.1.1 Expert Information

Some data were obtained through discussions with the experts in ruminants breeding. The three experts consulted initially helped to understand the real problem regarding the feeds suitable for breeding ruminants, such as goats. The first expert was Dr. Norisan who is attached to the Department of Veterinary Services, at Pokok Sena, Kedah. The second expert was Mr Razak Ahmad from the Department of Veterinary Services, Alor Setar and the third was expert Mr Yusof who is the manager of a deer farm owned by UiTM, Perlis located in Arau.

4.1.2 Ingredients Requirement

For the purpose of this study, 11 ingredients and four nutrient compositions were considered, along with their respective prices per kilogram (kg). The ingredients selected were according to Department of Veterinary Services, (DSV) website and the suggestion from the experts. The purpose of this objective function is to minimize the cost for the optimal combination of the recommended ingredients. The price per unit of each ingredient is the coefficient of the respective variables in the objective function. The ingredients with its price per kilogram are shown in Table 4.1.

Table 4. 1

Type of ingredients with its composition of nutrient

Ingredients	**Dry Matter (%)**	**Protein (%)**	**Calcium (%)**	**Phosphorus (%)**	**Cost (RM/Kg)**
Napier grass, x_1	18.4	12.2	0.3	0.24	0.2
Silage, x_2	30	6.6	0.25	0.3	0.4
Petai Belalang, x_3	19.1	40.4	0.37	0.51	0.018
Rice paddy straw, x_4	98.8	6.7	0.1	0.1	1.47
Wheat bran, x_5	88	14.4	0.2	0.68	1.5
Soybean bran, x_6	88.4	45.5	0.33	0.75	1.9
Paddy bran, x_7	91.6	12	0.1	0.49	1
Anchovy head, x_8	34.6	54.7	4	0.43	2.9
Corn silage, x_9	23.2	8.2	0.37	0.86	0.89
Soy dregs, x_{10}	15.5	30.4	0.41	0.32	0.25
Palm fronds, x_{11}	36.4	4.1	0.32	0.1	0.43

Sources: Malaysian Agricultural Research and Development Institute (MARDI), 2019

Table 4.1 shows the ingredients that have been chosen to produce feed formulation for goat. There are 11 ingredients selected. Based on expert interviews, the prevailing recommendation was to utilize ingredients with the highest percentage of dry matter. This is because a higher dry matter content can expedite the drying process of pellets. Additionally, experts suggested choosing for readily available ingredients, such as napier grass, *petai belalang* and rice paddy straws.

4.1.3 Nutrients Requirement

The information of required nutrients such as protein, calcium, phosphorus and dry matter, is used to build the constraints functions of the proposed LP model as presented in Table 4.2.

Table 4. 2

Types of nutrients with its minimum and maximum requirements

Nutrients	Minimum (%)	Maximum (%)
Dry matter, k_1	12	35
Protein, k_2	7	20
Calcium, k_3	0.3	0.8
Phosphorus, k_4	0.25	0.4

Several nutrient requirements must be considered when formulating feed for goat. In this study, we have chosen four nutrients: dry matter, protein, calcium and phosphorus. There have the minimum and maximum percentage of nutrients in the feed. Table 4.2 shows the range of nutrients required for feed formulation. As example, the range of nutrients for dry matter is between 12% to 35%.

4.2 Implementation of The Proposed LP Model

In this study, the objective function is to minimize the cost of feed mix in purpose of producing pellet for goats. The proposed LP model will determine the best combination of ingredients based on the nutrients needed to produce the pellet for goats. Below are decision variables for respective ingredients.

$$Minimize\ Cost, C = \sum_{i=1}^{11} c_i\, x_i$$

x_1 = Weight of Napier grass in kg

x_2 = Weight of Silage in kg

x_3 = Weight of Leucaena leucephala (*Petai belalang*) in kg

x_4 = Weight of Rice paddy straws (*Jerami padi*) in kg

x_5 = Weight of Wheat bran (*Dedak gandum*) in kg

x_6 = Weight of Soybean bran (*Dedak soya*) in kg

x_7 = Weight of Paddy bran (*Dedak padi*) in kg

x_8 = Weight of Anchovy head (*Kepala bilis*) in kg

x_9 = Weight of Corn Silage (*Silaj jagung*) in kg

x_{10} = Weight of Soy dregs in kg

x_{11} = Weight of Palm fronds (*Pelepah sawit*) in kg

k_1 = % of Dry matter

k_2 = % of Protein

k_3 = % of Calcium

k_4 = % of Phosphorus

Minimize cost, $\boldsymbol{C} = 0.2_{x1} + 0.4_{x2} + 0.018_{x3} + 1.47_{x4} + 1.5_{x5} + 1.9_{x6} + 1_{x7} + 2.9_{x8} + 0.89_{x9} + 0.25_{x10} + 0.43_{x11}$

Subject to:

$$\sum_{i=1}^{11} N_{k1}x_i = 18.4x_1 + 30_{x2} + 19.1_{x3} + 98.8_{x4} + 88_{x5} + 88.4_{x6} + 91.6_{x7} + 34.6_{x8} + 23.2_{x9} + 15.5_{x10} + 36.4_{x11} \leq 12$$

$$\sum_{i=1}^{11} N_{k1}x_i = 18.4_{x1} + 30_{x2} + 19.1_{x3} + 98.8_{x4} + 88_{x5} + 88.4_{x6} + 91.6_{x7} + 34.6_{x8} + 23.2_{x9} + 15.5_{x10} + 36.4_{x11} \geq 35$$

$$\sum_{i=1}^{11} N_{k2}x_i = 12.2_{x1} + 6.6_{x2} + 40.4_{x3} + 6.7_{x4} + 14.4_{x5} + 45.5_{x6} + 12_{x7} + 54.7_{x8} + 8.2_{x9} + 30.4_{x10} + 4.1_{x11} \leq 7$$

$$\sum_{i=1}^{11} N_{k2}x_i = 12.2_{x1} + 6.6_{x2} + 40.4_{x3} + 6.7_{x4} + 14.4_{x5} + 45.5_{x6} + 12_{x7} + 54.7_{x8} + 8.2_{x9} + 30.4_{x10} + 4.1_{x11} \geq 20$$

$$\sum_{i=1}^{11} N_{k3}x_i = 0.3_{x1} + 0.25_{x2} + 0.37_{x3} + 0.1_{x4} + 0.2_{x5} + 0.33_{x6} + 0.1_{x7} + 4.0_{x8} + 0.37_{x9} + 0.41_{x10} + 0.32_{x11} \leq 0.3$$

$$\sum_{i=1}^{11} N_{k3}x_i = 0.3_{x1} + 0.25_{x2} + 0.37_{x3} + 0.1_{x4} + 0.2_{x5} + 0.33_{x6} + 0.1_{x7} + 4.0_{x8} + 0.37_{x9} + 0.41_{x10} + 0.32_{x11} \geq 0.8$$

$$\sum_{i=1}^{11} N_{k4}x_i = 0.24_{x1} + 0.3_{x2} + 0.51_{x3} + 0.1_{x4} + 0.68_{x5} + 0.75_{x6} + 0.49_{x7} + 0.43_{x8} + 0.86_{x9} + 0.32_{x10} + 0.1_{x11} \leq 0.25$$

$$\sum_{i=1}^{11} N_{k4} x_i = 0.24_{x1} + 0.3_{x2} + 0.51_{x3} + 0.1_{x4} + 0.68_{x5} + 0.75_{x6} + 0.49_{x7} + 0.43_{x8} + 0.86_{x9} + 0.32_{x10} + 0.1_{x11} \geq 0.4$$

$$x_1, x_2, \ldots, x_{11} \geq 0$$

In order to solve the ruminant feed problem and present the results of the proposed enhanced LP, the data collected were run using Excel Solver in Microsoft Excel version 2019 (MicrosoftCorporation, 2019), ASUS VivoBook laptop of which the processor is Intel ® Core ™ CPU @ 1.60 GHz 1.80 GHz and the memory size of 4.00 GB with Microsoft Windows Professional system.

4.3 Result of The Model

The optimal output of the model is shown in Table 4.3. All related ingredients with the nutrients needed for each ingredient is shown below. The optimal cost from this feed formulation is RM 14.97. Based on the result, all the constraints requirement has been fulfilled. According to the interviews and observation, the cost for the pellet that we get is cheaper in marketplace.

Table 4. 3

The optimal solution for linear programming model

Ingredients	**Dry matter, k_1 (%)**	**Protein, k_2 (%)**	**Calcium, k_3 (%)**	**Phosphorus, k_4 (%)**	$c_i x_i$	**Cost (RM/kg)**
Napier grass, x_1	18.4	12.2	0.3	0.24	72.34	0.2
Petai belalang, x_3	19.1	40.4	0.37	0.51	27.66	0.018
Optimal value	18.60	20	0.32	0.31	100	14.97

Objective function is to minimize the cost of feed formulation for goat using eleven ingredients.

$$Minimize\ Cost, C = \sum_{i=1}^{11} c_i\, x_i$$

$$= (0.2 \times 72.34) + (0.018 \times 27.66)$$

$$= \text{RM } 14.97$$

Nutrients content for the selected ingredients which is;

$$k_1 = (18.4 \times 72.34) + (19.1 \times 27.66)$$
$$= 18.60\%$$
$$k_2 = (12.2 \times 72.34) + (40.4 \times 27.66)$$
$$= 20\%$$
$$k_3 = (0.3 \times 72.34) + (0.37 \times 27.66)$$
$$= 0.32\%$$
$$k_4 = (0.24 \times 72.34) + (0.51 \times 27.66)$$
$$= 0.31\%$$

By using the excel solver, there were two ingredients with their respective weights that were chosen, which was 72.34kg of Napier grass and 27.66kg *petai belalang* with the contains of nutrients 18.6% of dry matter, 20% of protein, 0.32% of calcium and 0.31% of phosphorus. These two ingredients were the most suitable because there were easily accessible in the northern area and more reasonably priced than other ingredients. Additionally, it can help the farmers reduce their reliance on imported feed mix and other imported ingredients.

4.4 Model Evaluation

In this section, model evaluation was performed by comparing the model output in two scenarios. The first scenario was by increasing the percentage of dry matter and the second scenario was by increasing the price of *petai belalang*.

4.4.1 Scenario 1: By Changing the Percentage of Dry Matter

Based on the interview with Mr. Razak from the Department of Veterinary Services, Alor Setar, a higher percentage of dry matter is preferred as it reduces both the cost and time required to produce the pellet. This can be seen from the try and error formulation from Department of Veterinary Services, Alor Setar by using the high percentage of dry matter. Due to that, this scenario is focus on the increment of the dry matter percentage. In original model, the current percentage of dry matter was between 12% to 35%. This scenario focused on increasing the percentage of dry matter which is between 30% to 50%.

Table 4. 4

Result of scenario 1

Ingredients	Dry matter (%)	Protein (%)	Calcium (%)	Phosphorus (%)	$c_i x_i$(kg)	Cost (RM/kg)
Petai Belalang, x_3	19.1	40.4	0.37	0.51	43.37	0.018
Paddy bran, x_7	91.6	12	0.1	0.49	1.99	1
Palm fronds, x_{11}	36.4	4.1	0.32	0.1	54.64	0.43
Optimal Value	30	20	0.3373	0.2856	100	26.2712

Based on this scenario, by using the Excel Solver, there were three ingredients that have been chosen, which was 43.37kg of *petai belalang*(x_3), 1.99kg of paddy bran(x_7) and 54.64kg of palm fronds(x_{11}) with the contains of nutrients 30% of dry matter, 20% of protein, 0.34% of calcium and 0.29% of phosphorus. The cost for this scenario was RM 26.27. The cost for the feed mix was increased RM 11.30 from the optimal cost due to the consideration of highest percentage of dry matter of the ingredients.

4.4.2 Scenario 2: By Changing the Price of *Petai Belalang*.

This research is based in Kedah and Perlis, where *petai belalang* can be retrieved easily. The difficulty in obtaining *petai belalang* outside of Kedah and Perlis has led to a rise as its price is expensive to purchase. In original model, the current price for *petai belalang* was RM0.018/kg. According to the marketplace, the price for *petai belalang* is RM12.70/kg. This scenario focuses on increasing the price of *petai belalang* if the feed mix is produced in regions other than Kedah and Perlis.

Table 4. 5

Result of scenario 2

Ingredients	Dry matter (%)	Protein (%)	Calcium (%)	Phosphorus (%)	$c_i x_i$ (kg)	Cost (RM/kg)
Napier Grass, x_1	18.4	12.2	0.3	0.24	87.5	0.2
Soy dregs, x_{10}	15.5	30.4	0.41	0.32	12.5	0.25
Optimal Value	18.0375	14.475	0.3138	0.25	100	20.625

Based on this scenario, by using the Excel Solver, there were two ingredients that have been chosen, which was 87.5kg of Napier grass (x_1) and 12.5kg of soy dregs (x_{10}) with the contains of nutrients 18.04% of dry matter, 14.48% of protein, 0.32% of calcium and 0.25% of phosphorus. The cost for this scenario was RM20.63. The cost for the feed mix was increased by RM5.66 from the optimal cost due to the consideration of the price for *petai belalang*.

4.4.3 Comparing of Proposed LP Model and What-If Analysis Result

Table 4. 6

Comparison of model and model evaluation

	Proposed LP model	**Result Scenario 1**	**Result Scenario 2**
The ingredients	Napier grass and *Petai belalang*	*Petai belalang*, Paddy bran and Palm fronds	Napier grass and soy dregs
Value of Dry Matter (%)	18.59	30	18.04
Value of Protein (%)	20	20	14.48
Value of Calcium (%)	0.32	0.34	0.32
Value of Phosphorus (%)	0.31	0.29	0.25
Total cost (RM)	14.97	26.27	20.63

In terms of total cost, the LP model shows a lower total cost compared to the result from what-if analysis, which is RM14.97 for 100kg of pellet, while the what-if analysis results shows RM26.27 and RM20.63 based on different scenarios. The differences between the proposed LP model and the two scenarios are RM 11.75 and RM5.66, respectively.

The ingredients selected differ between the proposed LP model and what-if analysis result. Based on the table above, the result obtained is two ingredients had been chosen for proposed LP model which is Napier grass and *petai belalang* meanwhile for the first scenario the feed mix contains of *petai belalang*, paddy brans and palm fronds. The second scenarios obtained two ingredients in feed mix: Napier grass and soy dregs.

4.6 Summary of Chapter Four

In developing the LP model, eleven ingredients and four nutrients were considered. Among all the ingredients, only two- comprising of 72.34% Napier grass and 27.66% *petai belalang* were selected to produce the optimal feed formulation for ruminants. This combination results in the optimal solution with a cost of RM14.97 and fulfils all the four nutrient requirements considered in this study. This demonstrates that the solution obtained from the LP model is viable for producing a feed mix at a minimum cost, while meeting all nutritional requirements and utilizing local ingredients. Finally, the model was evaluated by comparing the solution with other available feeds. The evaluation revealed that the LP model had successfully generated the optimal solution that was more cost-effective than other feeds, effectively addressing real-world challenges.

CHAPTER FIVE

CONCLUSION

5.1 Achievement of Research Objectives

The main research objective along with all three specific objectives was successfully achieved in determining the best combination of ingredients for ruminant feed through the optimization model. The main objective was considered accomplished upon the successful attainment of all three specific objectives.

The first specific objective, which was to identify appropriate local ingredients and nutrients for the ruminant's feed, was achieved through extensive literature reviews of all relevant materials and interviews with breeders and experts with extensive years of practical knowledge and experience as described in Section 3.5. The collected information was then used as constraints related to ingredients and nutrients, as discussed in Section 4.1.

The second specific objective, which was to develop an optimal feed formulation for ruminants that fulfils the requirement for nutrients and ingredients using linear programming approach, was achieved through the description in Section 3.5 and further described in Section 4.3. Overall, the proposed linear programming model provided an optimal solution at a significantly lower cost than RM50 per 100 kg of feed while satisfying all nutritional constraints and utilizing local ingredients.

In concluding this research, the third specific objective, which was to evaluate the developed model through what-if analysis, was achieved by assessing the proposed linear programming model through two scenarios, as implemented in Section 4.4.

5.2 Implication of The Study

The linear programming model applied to the ruminant feed formulation problem, incorporating specific constraints, has demonstrated that the problem can be effectively solved. This model serves as a valuable guide for practitioners in the ruminant industry. Consequently, the contributions of this research can be highlighted from two key perspectives: the body of knowledge and the end users, namely the breeders.

5.2.1 Implication to The Body of Knowledge

This study demonstrates the practical application of linear programming in solving real-life problems, particularly in feed formulation. By optimizing ingredient selection and cost while meeting nutritional requirements, it shows how mathematical modelling can be effectively applied to agricultural challenges. This contribution not only benefits livestock breeders but also enriches the body of knowledge in the field of optimization and animal nutrition.

5.2.2 Implication to The Breeders

The proposed feed formulation for goats can serve as a valuable decision-making tool to assist breeders in determining the most cost-effective feed composition for pellet production. By utilizing this optimized formulation, breeders can minimize feed costs while ensuring the nutritional requirements of the goats are met. This approach enhances efficiency in feed management, ultimately leading to improve profitability and sustainability in goat farming

5.3 Limitation of Study

Although this study was carefully conducted, certain unavoidable limitations were encountered. One such limitation was data collection for feed ingredients, as some ingredients were not readily available in the Northern region. Additionally, the cost of ingredients fluctuates over time, which affected the consistency and applicability of the proposed feed formulation.

5.4 Future Work

Future research can focus on addressing the limitations identified in this study to enhance the applicability and robustness of the proposed feed formulation model. One potential area of study is the exploration of alternative locally available ingredients to substitute those that are scarce in the Northern region. This could involve assessing the nutritional value, cost-effectiveness and sustainability of alternative feed sources.

Additionally, future research can incorporate dynamic pricing models to account for fluctuations in ingredient costs over time. By integrating real-time market data and sensitivity analysis, the model can be made more adaptive and practical for long-term use. Developing a more flexible and region-specific feed formulation model would further support breeders in making cost-effective decisions while maintaining optimal nutritional balance. Additionally, Stochastic Programming (SP) can be incorporated to account for uncertainties in ingredient availability and price fluctuations over time. By integrating real-time market data, this method can improve the model's practicality and adaptability.

REFERENCES

Abdulla, I., Arshad, F. M., Tasrif, M., Bach, N. L., & Mohammadi, S. (2015). A systems approach to study the malaysian pepper industry. *American Journal of Applied Sciences*, *12*(7), 487–494.

Abdulla, I., Mohamed Arshad, F., Bala, B. K., Bach, N. L., & Mohammadi, S. (2016). Management of beef cattle production in Malaysia: A step forward to sustainability. *American Journal of Applied Sciences*, *13*(9), 976–983.

Al-Deseit, B. (2009). Least-Cost Broiler Ration Formulation Using Linear Programming Technique. *Journal of Animal and Veterinary Advances*, *8*, 1274–1278.

Alqaisi, O., Ndambi, A., & Hemme, T. (2011). Global view on feed cost and feed efficiency on dairy farms. *AllAboutFeed*, *2(4)* (November), 1–5.

Ariff, O.M., Sharifah, N.Y., & Hafidz, A.W. (2015). Status of beef industry of Malaysia. *Malaysian Journal of Animal Science*, *18*(December), 1–21.

Bakshi, M. P. S., Wadhwa, M., & Makkar, H. P. (2016). Waste to worth: vegetable wastes as animal feed. CABI Reviews, (2016), 1-26.

Ban, Y., & Guan, L. L. (2021). Implication and challenges of direct-fed microbial supplementation to improve ruminant production and health. *Journal of Animal Science and Biotechnology*, *12*(1), 1–22.

Bekhet, A. H. (2017). Highlighting Innovation Policies and Sustainable Growth in Malaysia. *International Journal of Innovation, Management and Technology*, *8*(3), 228–239.

Bellingeri, A., Gallo, A., Liang, D., Masoero, F., & Cabrera, V. E. (2020). Development of a linear programming model for the optimal allocation of nutritional resources in a dairy herd. *Journal of Dairy Science*, *103*(11), 10898–10916.

Bocquier, F., & González-García, E. (2010). Sustainability of ruminant agriculture in the new context: feeding strategies and features of animal adaptability into the necessary holistic approach. *Animal*, *4*(7), 1258–1273.

Caballero, R., Núñez, T., & Ruiz, F. (2009). Goal Programming: realistic targets for the near future. *Journal of Multi-Criteria Decision Analysis*, *16*, 79–110.

Chagwiza, G., Chivuraise, C., & Gadzirayi, C. T. (2016). *Optimisation Problem Using the Bat Algorithm*. *2016*.

Danalatos, N., Archontoulis, S. V, & Tsiboukas, K. (2009). *Comparative analysis of sorghum vs corn growing under optimum and under water/nitrogen limited conditions in central Greece*.

Dijkstra, J., France, J., Ellis, J., Strathe, A. B., Kebreab, E., & Bannink, A. (2013). Production efficiency of ruminants: Feed, nitrogen and methane. In *Sustainable Animal Agriculture* (pp. 10–25.

Faraz, A., Waheed, A., Tauqir, N. A., Ishaq, H. M., Iqbal, F., & Zil-E-huma. (2021). Feedlot performance and serum profile of buffalo (Bubalus bubalis) calves under high input feeding systems. *Buffalo Bulletin*, *40*(2), 325–333.

Forbes, M.J. (2007). A personal view of how ruminant animals control their intake and choice of food: Minimal total discomfort. *Nutrition Research Reviews*, *20*(2), 132–146.

Ghosh, D., Sathianandan, T. V, & Vijayagopal, P. (2011). Feed Formulation Using Linear Programming for Fry of Catfish, Milkfish, Tilapia, Asian Sea Bass, and Grouper in India. *Journal of Applied Aquaculture*, *23*(1), 85–101.

Ghosh, S., Ghosh, J., Pal, D., & Gupta, R. (2014). Current Concepts of Feed Formulation for Livestock using Mathematical Modeling. *Animal Nutrition and Feed Technology*, *14*.

Guevara, V. R. (2004). Use of nonlinear programming to optimize performance response to energy density in broiler feed formulation. *Poultry Science*, *83*(2), 147–151.

Hart, S. P., & Schauer, C. (2015). Meat goat nutrition. *Proceedings of the 32nd Annual Goat Field Day*, 57–82.

Kaur, B. (2010). Consumer Preference for Goat Meat in Malaysia: Market Oppurtunities and Potential. *Journal of Agribusiness Marketing*, *3*(July), 40–55.

Kuntal, D., & Gupta, R. (2018). A Goal programming Approach to Ration Formulation Problem for Indian Dairy Cows. *International Journal of Advanced Computer Research*, *7*.

Kunwar, R., & Sapkota, H. P. (2022). Introduction to Linear Programming Problems with Some Real-Life Applications. *European Journal of Mathematics and Statistics*, *3*(2), 21–27.

Love, S. C. J., & Hutchinson, G. W. (2003). Pathology and diagnosis of internal parasites in ruminants. *Gross Pathology of Ruminants*, *350*(16), 309–338.

McDowell, L. R., & Arthington, J. D. (2005). *Minerals for grazing ruminants in tropical regions*. Gainesville: Institute of Food and Agricultural Sciences, University of Florida.

Meel, P., Bais, B., Choudhary, S., & Choudhary, S. (2018). Comparative evaluation of conventional and complete feed feeding system on body weight gain in marwari goats. *Veterinary Practitioner*, *19*(2), 295–296

Mohamed, W. Z., & Alimon, A. (2003). Use of Palm Kernel Cake and Oil Palm By-Products in Compound Feed Use of Palm Kernel Cake and Oil Palm By-Products in Compound Feed. *Palm Oil Developments*, *40*.

Nath, T., & Talukdar, A. (2014). *Linear Programming Technique in Fish Feed Formulation*. *17*(3), 132–135.

Nikkhah, A. (2012). Barley grain for ruminants: A global treasure or tragedy. *Journal of Animal Science and Biotechnology*, *3*(1), 1–9.

Olatunde, M.A., Afolayan, M., Author, C., & Olatunde, M. (2008). Nigeria Oriented Poultry Feed Formulation Software Requirements. *Journal of Applied Sciences Research*, *4*(11), 1596–1602. Retrieved from

Olugbenga, S. & Abayomi, O. (2015). Optimized Nutrients Diet Formulation of Broiler Poultry Rations in Nigeria Using Linear Programming. *Journal of Nutrition & Food Sciences*, *s14*, 2–7.

Phillips, C. (2016). *Nutrition and the Welfare of Farm Animals* (Vol. 16).

Reddy, P. R. K., & Hyder, I. (2023). Ruminant Digestion. In P. K. Das, V. Sejian, J. Mukherjee, & D. Banerjee (Eds.), *Textbook of Veterinary Physiology* (pp. 353–366).

Ritskes-Hoitinga, M., & Chwalibog, A. (2002). Nutrient requirements, experimental design, and feeding schedules in animal experimentation. In *Handbook of Laboratory Animal Science, Second Edition: Essential Principles and Practices* (pp. 281–310).

Sadiq, M. B., Syed-Hussain, S. S., Ramanoon, S. Z., Saharee, A. A., Ahmad, N. I., Mohd Zin, N., … Mansor, R. (2018). Knowledge, attitude and perception regarding antimicrobial resistance and usage among ruminant farmers in Selangor, Malaysia. *Preventive Veterinary Medicine*, *156*, 76–83.

Saxena, P., & Khanna, N. (2017). Modeling for development of simulation tool: Cattle diet formulation. *International Journal of ADVANCED AND APPLIED SCIENCES*, *4*(4), 58–66.

Sharma. (2014). *The Need for Feed: China's Demand for Industrialized Meat and Its Impacts*. (February), 2–5.

Sterman, J. D., & Sweeney, L. B. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249–286.

Swecker, W. S., & Van Saun, R. J. (2023). *Vitamins and Trace Minerals in Ruminants, An Issue of Veterinary Clinics of North America: Food Animal Practice, E-Book: Vitamins and Trace Minerals in Ruminants, An Issue of Veterinary Clinics of North America: Food Animal Practice, E-Book*.

Thapelo, B. S. (2018). *Effect of roughage quality and period of day on rumen fill after meal termination, digestion, passage rates, and diurnal feeding behaviour in cattle fed on tropical roughage* (Doctoral dissertation, University of KwaZulu-Natal).

Tozer, P. R. (2000). Least-cost ration formulations for holstein dairy heifers by using linear and stochastic programming. *Journal of Dairy Science*, *83*(3), 443–451.

Wadhwa, M., & Bakshi, S. P. M. (2013). Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products. In *RAP Publication 2013-04 (FAO)*.

Wijayaningrum, V. N., Mahmudy, W. F., & Natsir, M. H. (2017). *Optimization of Poultry Feed Composition Using Hybrid Adaptive Genetic Algorithm and Simulated Annealing*. (January).

Yang, X., & Gandomi, H.A. (2012). Bat algorithm: a novel approach for global engineering optimization. *Engineering Computations*, *29*(5), 464–483.

Zahari, M. W., & Alimon, A. R. (2005). Use of palm kernel cake and oil palm by-products in compound feed. *Palmas*, *26*(1), 57.

Žgajnar, J., Erjavec, E., & Kavčič, S. (2010). Multi-step beef ration optimisation: Application of linear and weighted goal programming with a penalty function. *Agricultural and Food Science*, *19*(3), 193–206.