AN ANALYSIS ON NATIVE CHICKEN MEAT PRODUCTION IN MALAYSIA: THE DEVELOPMENT OF CHICKEN GROWTH PERFORMANCE, FEED EFFICIENCY AND PROFITABILITY FRAMEWORK BASED ON DIFFERENT DIET SYSTEMS

By

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ABSTRACT

In Malaysia, the poultry industry is a fundamental pillar of livestock production, contributing significantly to the nation's agricultural economy. This study focuses on the native chicken production, a sector gaining increasing attention due to its lower fat content, enriched Omega-3 composition and highly regarded flavour profile. However, native chicken rearing is characterized by longer production cycles compared to conventional broilers. Additionally, the poultry industry in Malaysia faced significant challenges following the pandemic, with escalating chicken feed costs impacting production profitability. To address these issues, optimizing feed strategies becomes essential to reduce production costs and mitigate risks associated with currency fluctuations for imported feeds, ultimately bolstering the prospects of local poultry farmers.

The general objective of this study is to develop a framework of chicken growth performance, feed efficiency and profitability for native chicken meat production based on different diet feed systems in Malaysia with four Specific Objectives: (1) to describe the different diet feed systems for native chicken meat production; (2) to determine the feed efficiency of the six (6) different diet feed systems based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (AVG) and feed conversion efficiency ratio (FCE) for the native chicken meat production; (3) to analyse the relationship among the six (6) different diet feed systems, chicken age and body weight for native chicken meat production; and (4) to examine the profit level using the benefit-cost ratio (BCR) of the six (6) different diet feed systems for the native chicken meat production. To carry out this research, the study was conducted at *Bintang Maju Agri* Chicken Farm in Semenyih, Malaysia, involving the utilization of six (6) different diet feed systems. These encompass (1) Premium Starter Feed in 50kg pack (as control feed) (2) 5% *Pokok Ketum Ayam* (*Trichanthera Gigantean*) mixed into Premium Starter Feed (3) 5% *Protein Larva Askar Hitam* (BSFL) mixed into Premium Starter Feed (4) 200g Crude Palm Kernel Oil (CPKO) mixed into 50kg Premium Starter Feed (5) 100g Organic Acid mixed into 50kg Premium Starter Feed and (6) 100g Yellow Pigment (Brand: SK Gold) mixed into 50kg Premium Starter Feed. A total of 300 chickens, distributed across these six diet systems, underwent two production cycles, each spanning 84 days or 12 weeks.

The study comprised four fundamental phases. Initially, the selection of diet feed systems was grounded in a comprehensive literature review and consultation with poultry farmer and feed providers. Subsequently, feed efficiency was meticulously assessed using various parameters, including cumulative voluntary feed intake (CVFI), cumulative weight gain (CWG), average daily gain (AVG) and feed conversion efficiency ratio (FCE). Following this, quantitative analyses, employing regression and panel data techniques via Eviews 12.0 software, were carried out to elucidate the relationships between the diet feed systems, chicken age and body weight. Finally, profitability was gauged through the benefit-cost ratio (BCR), involving a comparison of revenue and production costs.

The study's findings revealed that diet feed system 6 (Yellow Pigment), consistently emerged as the top performer, yielding the highest growth performance across the study's parameters. Simultaneously, diet feed system 5 (Organic Acid) and diet feed system 6 exhibited the highest feed efficiency, with FCE ratio of 2.469 to 2.533. The panel data analyses revealed noteworthy insights: diet feed systems 5 and 6 exhibited significant positive relationships with chicken body weight, suggesting a favourable impact on growth ($p<0.05$). Conversely, diet feed systems 3 (*Protein Larva Askar Hitam*) displayed a significant negative relationship with chicken body weight, compared among all diet feed systems ($p<0.05$). For profitability, all diet feed systems demonstrated better profitability compared to diet feed system 1 (control feed), that is with benefit-cost ratio exceeding that of the control feed. Diet feed system 6 stood out as the most cost-effective choice over two production cycles spanning 12 weeks with benefit-cost ratio of 1.38 to 1.40. The study highlights the importance of strategic feed formulation in boosting poultry growth, improving feed efficiency and maximizing profitability — critical elements for scaling up sustainable and competitive native chicken meat production. The findings of this study offer clear, actionable insights for poultry farmers, feed manufacturers and agri-entrepreneurs seeking to improve production efficiency and profitability using diet feed system 6 (Yellow Pigment) and diet feed system 5 (Organic Acid).

Keywords: Native chicken meat production, chicken growth performance, feed efficiency, profitability, diet feed systems

Subject Area: SF94.5-99 Feeds and Feeding

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ABBREVIATION

ADG	Average Daily Gain
ADFI	Average daily feed intake
AGP	Antibiotic growth promoters
BCR	Benefit-cost ratio
BMI	Ratio of weight to length square
BMTKM	*Program Pembasmian Kemiskinan Tegar Keluarga Malaysia*
BSF	Black Soldier Fly
BSFL	Black Soldier Fly Larva
CPKO	Crude Palm Kernel Oil
CVFI	Cumulative Voluntary Feed Intake
CWG	Average Cumulative Weight Gain
DOC	Day-old chick
EO	Essential Oils
FA	Fatty Acid
FAO	The Food and Agriculture Organization
FCE	Feed conversion efficiency ratio
Felda	Federal Land Development Authority
F/G	Feed to gain ratio
FSBM	Fermented Soybean Meal
GDP	Gross Domestic Product
IBD	Infectious Bursal Disease
LDL	Low-Density Lipoprotein

MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MCO	Movement Control Order
ME	Metabolizable Energy
OA	Organic Acids
PBIT	Profit before interest and tax
PEF	Production Efficiency Factor
PP	Polyphenol Product
PPP	*Projek Pembangunan Peneroka*
RMSE	The Root Mean Square Error
TGLM	*Trichanthera Gigantea* Leaf Meal
UOP-PF	Unit Output Price of Profit Function
US	United States

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chapter 1 provides a comprehensive overview of the global and Malaysian chicken meat production scene, laying the foundation for this study. It commences by introducing the research's historical context and providing an up-to-date snapshot of chicken meat production on a global scale, with special attention paid to the Malaysian market. Then, the problem statements, study scope, research questions, research aims and study significance are presented. The chapter ends with a conclusion and lays out the framework for the remaining chapters.

1.2 Research Background

Global meat consumption, which includes poultry, beef, pork and sheep, has quadrupled since 1961, primarily due to factors such as increasing prosperity, disease outbreaks, natural disasters and shifts in consumer preferences. The rise in global meat consumption can also be attributed to the expanding human population, which has encouraged the growth of livestock. As a result, around 80 billion animals are slaughtered each year to produce 340 million tonnes of meat for human consumption (Poultry World, 2019).

Poultry, as defined by the Oxford Advanced Learner's Dictionary, encompasses chickens, ducks, and geese, raised for both meat and egg production (Hornby, 2021). Between 2000 and 2020, poultry production worldwide experienced a significant increase, with total poultry production rising from 68.7 million tonnes to 134.9 million tonnes (a 96% increase) and chicken production specifically growing from 58.7 million tonnes to 118.7 million tonnes (a 102% increase). For detailed figures, please refer to Table 1.1 below.

Table 1.1: Global Poultry Meat and Chicken Meat Production by Region (million tonnes) from 2000 to 2020

Global poultry meat production					
Region	**2000**	**2005**	**2010**	**2015**	**2020**
Africa	3.0	3.6	4.8	5.8	7.3
Americas	30.1	36.2	42.2	48.0	50.2
Asia	22.9	27.3	34.8	42.5	53.4
Europe	11.9	13.4	16.2	19.8	22.4
Oceania	0.8	1.0	1.1	1.4	1.5
World	**68.7**	**81.4**	**99.2**	**117.4**	**134.9**
Global chicken meat production (million tonnes)					
Africa	2.8	3.4	4.5	5.4	7.0
Americas	27.2	33.0	38.9	44.7	47.1
Asia	18.6	22.5	29.0	36.0	43.4
Europe	9.3	10.9	13.8	17.2	19.7
Oceania	0.7	0.9	1.1	1.3	1.5
World	**58.7**	**70.7**	**87.3**	**104.7**	**118.7**

Source: FAO (2023)

In Malaysia, poultry production also witnessed an increase from 2008 to 2017, specifically from 205.91 million heads to 318.61 million heads, representing a growth of 54.7%, that was aligned with the increased poultry production in the world, to meet the increased demand of the poultry consumption (refer to Figure 1.1 below).

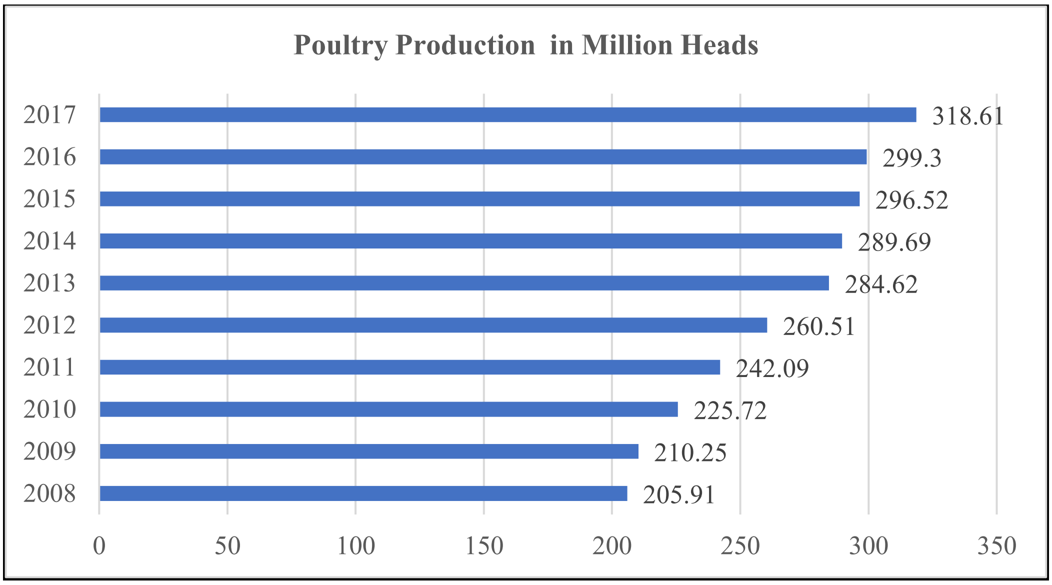


Figure 1.1: Poultry Production in Million Heads in Malaysia (2008-2017)

Source: FAO (2023)

The background study reveals a significant increase in poultry meat production globally and in Malaysia in the past. The current situation of the industry is further illustrated in the following section.

1.3 Current Situation of Study: Consumption and Production of Chicken Meat Around the World and Malaysia

Poultry meat and eggs are some of the most consumed animal-based foods worldwide, crossing geographic, cultural and religious boundaries. Data, as depicted in Figure 1.2 below, indicate that total global meat consumption grew from 1990 to 2023, increasing from 153.9 million tonnes to 350.3 million tonnes. Notably, poultry meat consumption displayed unwavering growth during this period, surging from 34.6 million tonnes in 1990 to 139.7 million tonnes in 2023. The world's consumption of poultry meat quadrupled over the past 30 plus years.

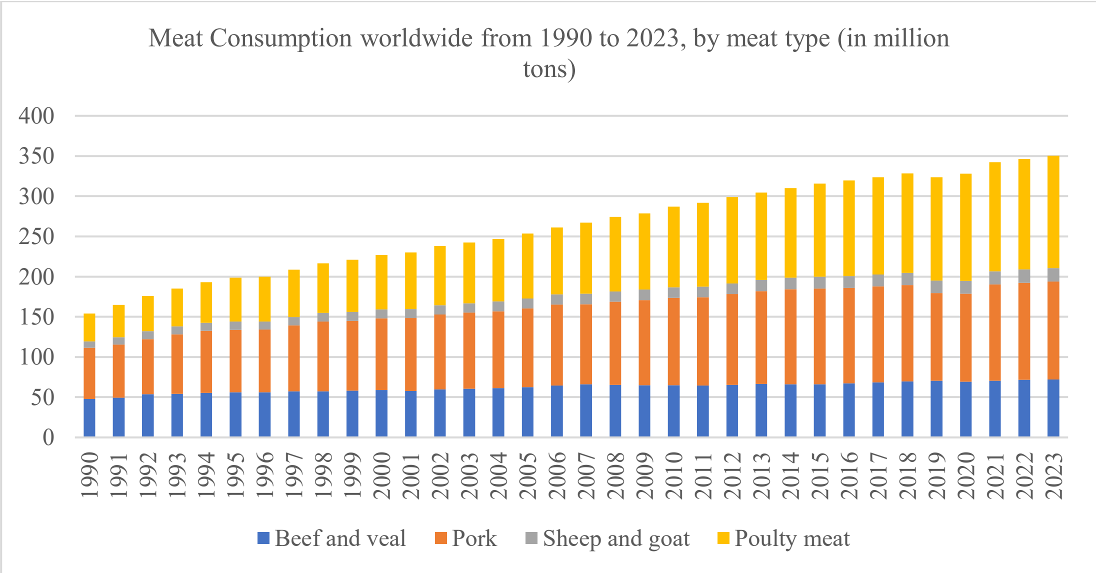


Figure 1.2: Meat Consumption Worldwide from 1990 to 2023

Source: FAO (2023)

Table 1.2: World Meat Consumption 2023

Type of meat	Total meat consumption (in million tons)	Share
Poultry	139.7	40%
Pork	122.0	35%
Beef and veil	71.9	21%
Sheep and goat	16.7	5%
Total	**350.3**	**100%**

Source: FAO (2023)

The high meat consumption is due to the population expansion, urbanization and increased earnings in developing countries (FAO, 2022). The breakdown of the world's total meat consumption in 2023 is shown in Table 1.2 above. It shows that poultry meat is the most favourable meat, constituted 40% of the total meat consumption, in the world in 2023.

On the other hand, a similar increasing trend in poultry meat consumption is observed in Malaysia (refer to Figure 1.3 below). The poultry meat consumption in Malaysia has increased steadily over the years, from 2014 to 2023, from 46.3 kg per capita per year to 50.5 kg per capita per year.

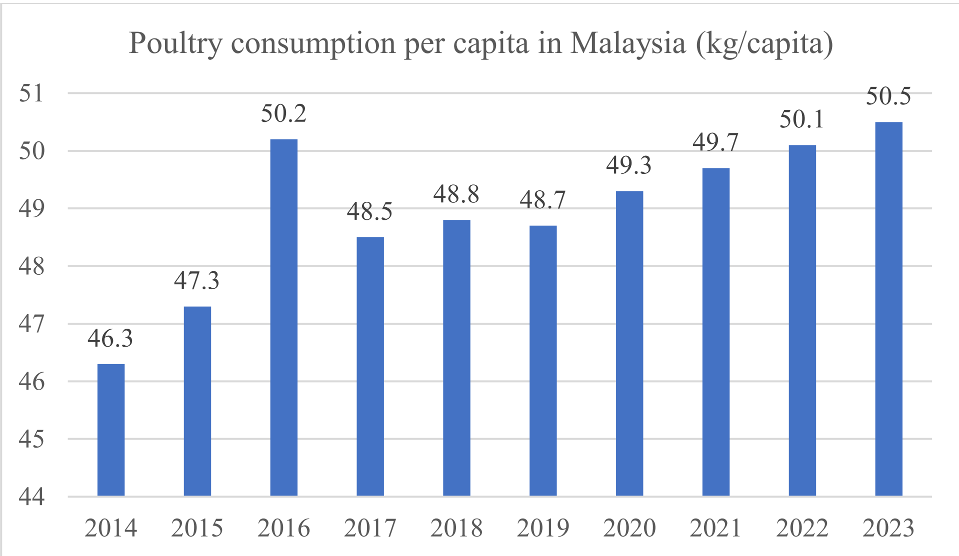


Figure 1.3: Poultry Consumption per Capita from 2014-2023 in Malaysia

Source: OCED (2024)

As per Figure 1.4 below, it is clear that, similar to the global consumption trend, poultry meat consumption (50.49 kg per capita per year) is the most favourable type in Malaysia, nearly 10 times higher than beef and veal meat

(5.73 kg per capita per year) and pork (5.16 kg per capita per year) consumption in 2023.

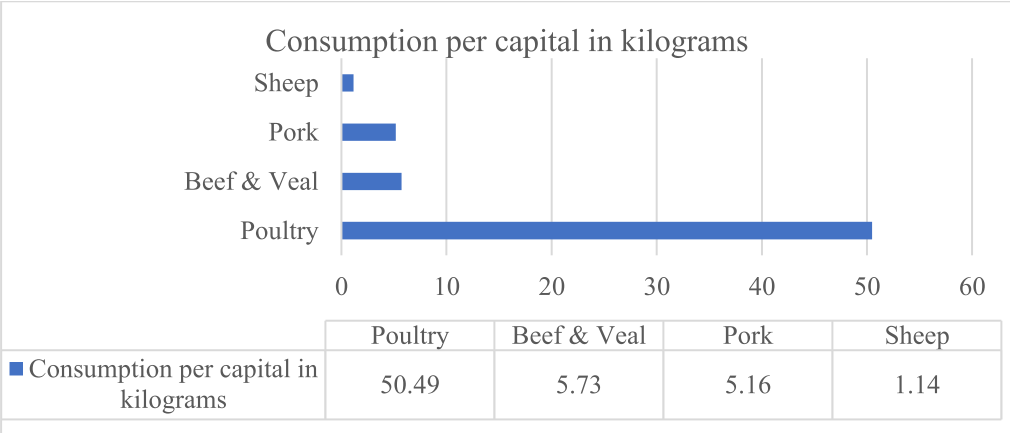


Figure 1.4: Meat Consumption per Capita in Malaysia in 2023, by Type

Source: OCED (2024)

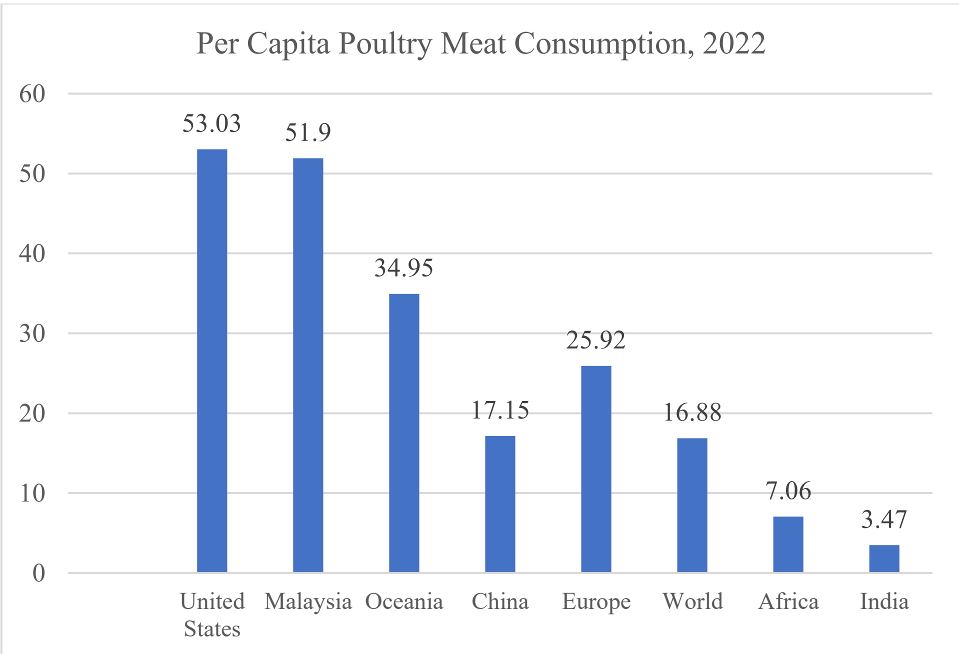


Figure 1.5: Global Poultry Meat Consumption Per Capita in 2022

Source: FAO (2023)

In 2022, FAO data (see Figure 1.5 above) showed that Malaysia's poultry meat consumption was 51.9 kg per capita per year which was one of the highest consumption after US, higher than the world consumption of 16.88 kg per capita per year, in the poultry meat consumption in the world (FAO, 2023). This showed how favourable poultry meat is among Malaysians compared to the rest of the world's population.

In Malaysia, poultry is the most important livestock sector (Bahri, Ariffin, & Mohtar, 2019). In 2021, the ex-farm value of livestock products in Malaysia exceeded RM 23.2 billion. Poultry meat contributes RM 12.4 billion, thus accounts for about 53% of livestock ex-farm value (Federation of Livestock Farmers Associations of Malaysia, 2022).

Chicken, a type of poultry, is the most widely consumed poultry meat due to its affordability, low fat content and minimal religious or cultural restrictions (FAO, 2022). According to Lawal et al. (2020), chicken, scientifically referred to as *Gallus domesticus*, is a domesticated descendant of the jungle fowl, retaining many characteristics of its wild species. Chickens are among the most prevalent and widely distributed domesticated animals (FAO, 2023). There are about 23 billions chicken in the world at any given point of time, at least 10 times more than any other birds (Gorman, 2018). According to Farrell (2013), chicken products play an important role in human nutrition, particularly in developing nations, due to a number of variables, including their low cost, lack of religious restrictions and high nutritional content.

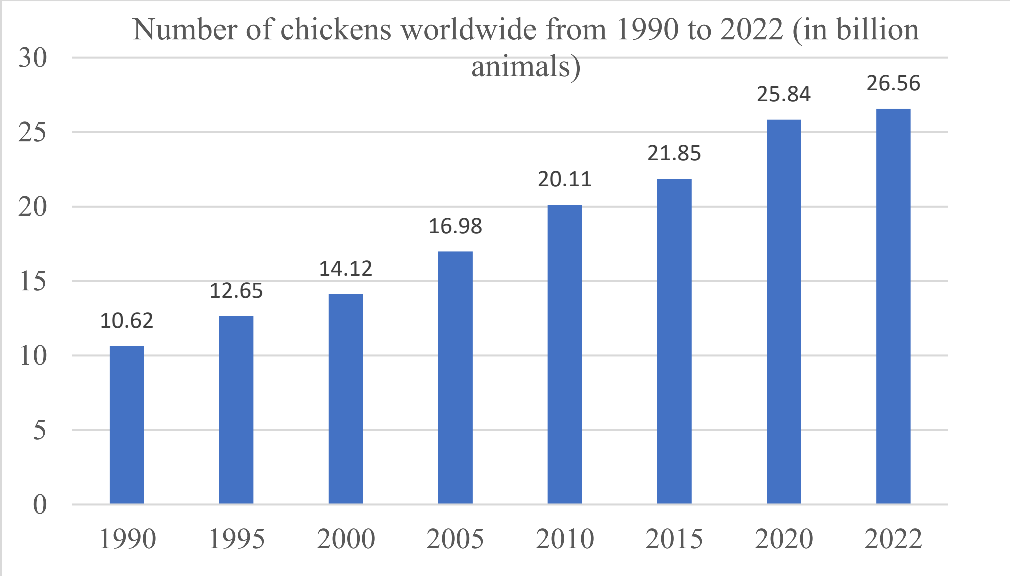


Figure 1.6: Number of Chickens Worldwide from 1990 to 2022

Source: FAO (2023)

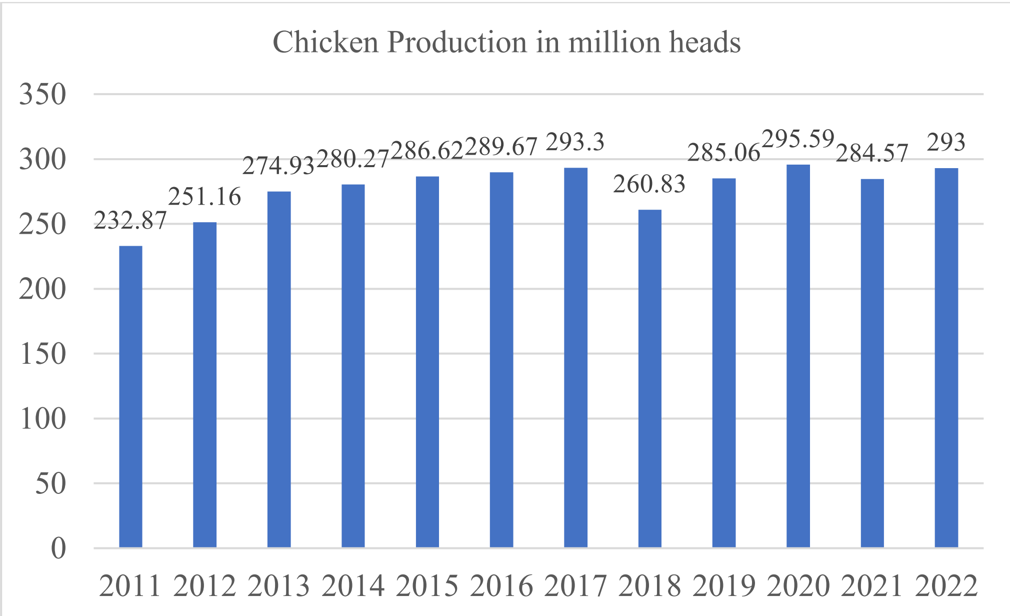


Figure 1.7: Chicken Production in Malaysia from 2011 to 2022

Source: FAO (2023)

Over the years, chicken has gained growing popularity among the global population, as shown in Figure 1.6 above, resulting in high production.

Similarly in Malaysia, refer to Figure 1.7 above, chicken production also increased from 232.87 million heads in 2011 to 293 million heads in 2022.

The above information highlights the significance of chicken meat production in both the Malaysian and global poultry industry. This importance extends to various aspects, including its impact on the economy (GDP) and its role in fulfilling human nutrition and consumption needs. Consequently, there arises a compelling need for further research and investigation into the realm of chicken meat production.

The study chosen on the poultry industry is the native chicken. Native chicken is the chicken breed reported from Indonesia and Malaysia and is also known as "*Kampung Chicken*". The chicken meat is appreciated for its good flavour and the breed is reported to be resistant against Coccidiosis, Infectious Bursal Disease (IBD) and Marek's disease. These chickens are highly adapted to hot and humid climate, and it is reported as highly prolific (FAO, 2022).

Based on the research in 2020 by Santoso, Suryani, Kadhung, & Prasetyo (2020), native chicken is becoming more and more popular with people, and it has promising future as a livestock commodity. The study by Islam et al. (2021) highlighted the vital role of indigenous (native) chickens in providing nutrition and supporting the livelihoods of rural smallholders. Native chicken had become a commodity with a wide market. The reasons for this are the community's healthy living culture (Santoso et al., 2020). Because native chicken has 30% less fat than regular chicken and is high in Omega 3, it is thought to be more nutrient-dense than broiler chicken (Meera Murugesan, 2018). In addition, native chickens are said to be efficient in converting low-protein inputs into high-quality meat product as reported by Setiadi, Santoso, Sumarsono, Mahfudz, & Susanto (2016). Additionally, it was said that there would be a market for native chicken meat that would meet the demands of the community, creating a possible opportunity (Rasyaf, 2010; Anas, Rohmadi, & Fadwiwati, 2020).

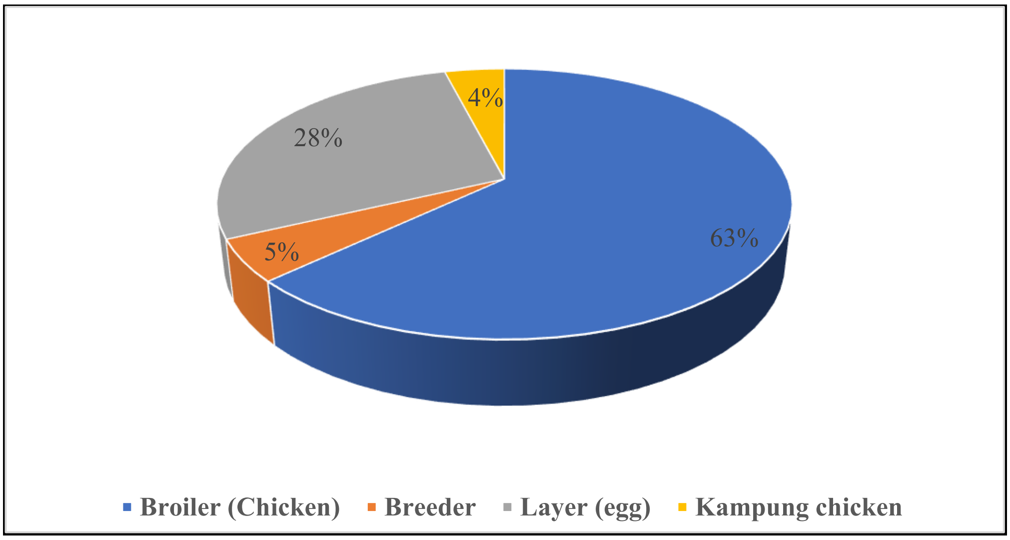


Figure 1.8: Chicken Production in Malaysia in 2019

Source: Bernama (2022)

As per Figure 1.8 above, based on the survey conducted and statistics published in The Edge Market, 2022, native chickens only constituted 4% of the total chicken population in Malaysia in 2019. This percentage remains relatively small when compared to the population of conventional broiler chickens.

Presently, Malaysia produces eight million native chicken heads each year, of which about 10% are sold to Singapore and the remainder primarily to Kuala Lumpur, Ipoh and Penang. Native chickens are in high demand and fetch high prices. Their demand is growing. Thus, one method to address the issue of poverty has been to involve Malaysians from lower income groups in the production of native chickens. In order to improve the settlers' income, the government gave the Federal Land Development Authority (Felda) RM 234 million for agricultural projects as part of the *Projek Pembangunan Peneroka* (PPP) and the *Program Pembasmian Kemiskinan Tegar Keluarga Malaysia* (BMTKM). According to the August 2022 news, 1,036 native chicken projects under Felda have already been approved nationwide by the government (Bernama, 2022). In 2023, it was reported that RM23 millions chicken farm to be built in Felda Tun Ghafar Bukit Senggeh, Jasin to create job for youths in the area (Malay Mail, 2023).

The current situation of study highlights the potential of the native chicken industry, driven by the rising demand and its relatively small market share within Malaysia's broader poultry industry. As the native chicken sector continues to expand, it is expected to contribute to increased chicken meat production, aligning with the growing demand among health-conscious consumers. Furthermore, this growth has the potential to address the issue of poverty in Malaysia.

1.4 Problem Statements

As the background study noted, one of the most accessible and popular forms of protein in Malaysia and around the world is chicken. The total meat consumption worldwide had grown from 153.9 millions tonnes in 1990 to 350.3 millions tonnes in 2023 as per Figure 1.2 above. To meet the demand, chicken production had grown also from 10.62 billions heads in 1990 to 26.56 billions heads in 2022, as shown in Figure 1.6 above.

Due to increased public awareness of healthy living, more consumers are choosing food with good nutritional value. Because native chicken is devoid of growth hormones and other chemicals frequently used in traditional poultry farming, it is highly sought after by people who are health-conscious (Meera Murugesan, 2018). In addition, native chicken is known to its resistance to several diseases which makes chicken farmers have great opportunity to produce good and healthy food (Wardiny, Sumiatis., & Setiyono, 2020). Native chicken production is also essential in Malaysia and India to support lower-income groups in rural areas (Bernama, 2022; Kaur, Ratwan, Kumar, & Singh, 2024). Nevertheless, these advantages do not translate into high productivity. It takes up to twice as long for native chickens to achieve the same body weight as conventional broiler chickens. This is due to factors such as the absence of growth hormones, less optimized feed, genetics and husbandry practices (Meera Murugesan, 2018; Wardiny et al., 2020).

In addition, the demand for animal protein production systems that integrate social, economic and environmental sustainability has been increasing. With the reduction in antibiotic growth promoters in animal feed, maintaining gut health and bird performance has become more challenging. Advances in feed technology, including ingredient modification and the formulation of high-quality animal feeds, are essential for promoting sustainable production while ensuring a consistent supply of high-protein feed (Nasarudin et al., 2024).

A new breed of native chicken, known as *Superior Kompong*, has emerged in the market. This breed reaches a body weight of over 1kg at 10 to 12 weeks of age, thanks to a balanced diet of protein and energy that focuses on the chicken's growth phase (Wardiny et al., 2020). Hence, the feed ingredients given to chickens, i.e. the chicken diet feed systems, play a crucial role in influencing their body weight for meat production. In India, the productive potential of poultry remains underutilised due to inadequate feed resources and the lack of adoption of advanced feeding strategies needed to achieve high productivity at an economical rate (Choudhury, Mahanta, Sapcota, Saikia, & Islam, 2018).

Notwithstanding the foregoing, the uncertain and expensive cost of feed ingredients remain the primary obstacle to the production of chicken meat (Libatique, 2021; Mohtar, 2022). During the COVID-19 pandemic and subsequent global disruptions, the cost of key poultry feed ingredients in Malaysia rose sharply (Malaysia Gazette, 2021). According to the Federation of Livestock Farmers' Associations of Malaysia (FLFAM), the price of corn increased by approximately 41%, from RM 950 per tonne in January 2020 to RM 1,300 in March 2021, while soybean meal surged by around 58%, from RM 1,650 to RM 2,600 per tonne over the same period (Live Stock Malaysia, 2021). Additionally, a separate report confirms that feed raw material costs increased by at least 40% in one year, with grain corn and soybean meal prices rising 13% and 11% respectively in 2022 alone (The Star, 2022).

The feed cost had been a major cost component in chicken production constituting approximately 65% to 70% of the total farming cost according to The Vibes (2022); Nasarudin et al. (2024), Moss, Chrystal, Crowley, & Pesti (2021), Libatique (2021) and Sugiharto (2019). As a result, any rise in the cost of feed ingredients or fluctuations in currency values would lead to higher chicken production costs, ultimately lowering the profit margins for chicken farmers (Sugiharto, 2019; Poultry World, 2019). According to Channel News Asia (CNA) (2022), the chicken farmers cannot afford to produce more chickens due to higher production cost.

If Malaysia produced its own chicken feed, it could significantly reduce poultry farming costs, especially considering the high price of wheat and the vulnerability of imports to currency fluctuations (Mohtar, 2022). Hence, there is a need to study the chicken diet feed system, especially the locally sourced feed ingredients – Research Specific Objective (1).

Chicken diets consist of various ingredients, including protein- and energy-rich components. Numerous studies indicate that adding agroindustry byproducts can lower the price of feed ingredients that provide protein and energy (Sugiharto & Ranjitkar, 2019). Similarly, Poultry World (2019) reported that increased feed efficiency would lower the cost of the chicken meat production which would then increase the profitability. It suggested to have alternative feed ingredients, ideally those made locally to be scrutinized as priority to resolve the industry challenge – Research Specific Objective (1).

Numerous studies have demonstrated that the feed efficiency and growth performance of chickens are significantly impacted by the type of diet feed systems used – Research Specific Objective (2) and (3). According to Poultry World (2019), alternative feed ingredients can help reduce high feed costs and enhance farmers' profitability – Research Specific Objective (4).

For example, according to recent research conducted in the Philippines, adding *Trichanthera gigantea* leaf meal boosted feed conversion efficiency and enhanced the growth performance of chickens (Libatique, 2021). In another research, it was proven that the inclusion of Azolla leaf meal improves chicken growth performance (Abdelatty, et al., 2021). As per the research carried out by Tajede & Kim (2021), the inclusion of dietary fibre in the chicken feed would have changes on the chicken growth performance.

This study bridged the research gap as it was found that most of the researches on chicken diet was done on conventional broiler chickens and conducted overseas. According to Poultry World (2019), some ingredients are also more suitable for broilers than broiler breeders and vice versa. Alternative feed ingredients, also vary from region to region. An ingredient may be considered alternative in one region but commonly used in another. In addition, many previous studies have been carried out on particular chicken diet feed systems, e.g. different inclusion of *Pokok Ketum*, palm oil, etc (Morbos, Espina and

Bestil, 2016; Saminathan, Mohamed, Ibrahim, Fuat & Ramiah, 2022). There are quite limited studies carried out to compare the effect of different diet feed systems on the chicken growth performance especially the native chicken and in Malaysia. Hence, a study for the effect of different diet feed system in Malaysia shall be carried out under Research Specific Objective (2) and (3).

Therefore, a comprehensive study on native chickens is urgently needed. These chickens have been identified as having significant potential (Rasyaf, 2010; Anas et al., 2020; Wardiny et al., 2020) and offer superior nutritional benefits when compared to conventional broiler chickens.

Six (6) diet feed systems with locally sourced feed ingredients, i.e. *Pokok Ketum Ayam* (*Trichanthera Gigantean*), *Protein Larva Askar Hitam* (Black Soldier Fly), Organic Acid, Crude Palm Kernel Oil (CPKO) and Yellow Pigment together with Premium Starter Feed (Control Feed) were selected for this study based on expert consultation with native chicken meat producers and local feed providers. The leaf meal (*Pokok Ketum Ayam*) and insect meal (*Protein Larva Askar Hitam*) were found to have high protein composition (Ahmad et al., 2024; Morbos et al., 2016). Organic acid can act as antibiotic that promotes chicken growth performance (Khan & Iqbal, 2016). Crude Palm Kernel Oil (CPKO) and Yellow Pigment are found to be low-cost but high calorie option for the chicken to promote growth performance (Abdulla, et al., 2017). Examining the impact of these selected diet feed systems on the growth performance, feed efficiency and benefit-cost ratio of chicken meat production based on various diet feed systems will help farmers assure long-term profitability – Research Specific Objective (2), (3) and (4).

1.5 Research Questions

The research questions for this study are:

(1) What are the details for the 6 diet feed systems available for the native chicken production?

(2) How effective is each of the diet feed system under study compared to the control feed based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (AVG) and feed conversion efficiency ratio (FCE) for the native chicken meat production?

(3) What are the relationships among the six (6) different diet feed systems, chicken age and chicken body weight for the native chicken meat production?

(4) What is the profit level using the benefit-cost ratio (BCR) for each of the diet feed system selected for the native chicken meat production?

1.6 Research Objectives

1.6.1 General Objective

The general objective of this study is to develop a framework of chicken growth performance, feed efficiency and profitability for native chicken meat production based on different diet feed systems in Malaysia.

1.6.2 Specific Objective

The Specific Objectives of this study are:

(1) to describe the different diet feed systems for native chicken meat production;

(2) to determine the feed efficiency of the six (6) different diet feed systems based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (AVG) and feed conversion efficiency ratio (FCE) for the native chicken meat production;

(3) to analyse the relationship among the six (6) different diet feed systems, chicken age and body weight for native chicken meat production; and

(4) to examine the profit level using the benefit-cost ratio (BCR) of the six (6) different diet feed systems for the native chicken meat production.

1.7 Significance of Study

Overall, this study makes both theoretical and practical contributions by combining rigorous statistical modelling with real-world feed innovations. It fills a methodological and contextual gap in native chicken production research and offers a scalable model for optimizing poultry performance through strategic feed design.

1.7.1 Significance of Study – Theoretical

While numerous international studies have examined the effects of diet feed systems on chicken growth performance, there is limited empirical work in the Malaysian context that incorporates both local feed innovations and data analysis based on regression models. This study addresses that gap by analysing six (6) diet feed systems selected based on expert consultation with native chicken meat producers and local feed providers.

The study contributes to the theoretical understanding of poultry nutrition and growth by applying panel data analysis, method that integrates cross-sectional and time-series elements (Gujarati & Porter, 2009). Unlike conventional methods that focus on static comparisons, panel data allows for dynamic tracking of chicken weight across different ages and feed systems. This methodology is underutilized in Malaysian poultry research and represents a novel approach to modelling chicken growth patterns.

Further, the use of a feed efficiency formula (based on Morbos et al., 2016) and weight gain modelling (Michalczuk, Stępińska, & Łukasiewicz, 2011) provides a quantifiable framework to compare performance outcomes across feed systems. These tools enhance predictive modelling in poultry science and can inform future theoretical models of feed efficiency and meat yield forecasting.

By integrating econometric methods in animal science research, this study bridges the gap between agricultural practice and data-driven decision-making, offering a replicable framework for chicken growth performance benchmarking in meat production.

1.7.2 Significance of Study – Empirical

Native chicken meat production involves converting feed into body mass, where feed cost accounts for 65%–70% of total production expenses (Nasarudin et al., 2024; Moss et al., 2021; Libatique, 2021; Sugiharto, 2019). With rising feed costs, optimizing feed efficiency is crucial for improving farm profitability and sustainability.

This study empirically identifies the most effective diet feed system in terms of both chicken growth performance and economic viability, using real feed compositions that include locally sourced alternatives such as leaf meal, insect meal, organic acid, and crude oil. These locally formulated feeds could reduce reliance on imported protein sources, thus mitigating risks related to currency fluctuations and global supply chain disruptions.

Moreover, this study's findings provide practical recommendations for small- and medium-scale poultry farmers on how to maximize weight gain and lower cost per kilogram of meat, ultimately enhancing profitability. By offering a localized, data-backed feed strategy, the study directly contributes to Malaysia's food security and import substitution goals, while promoting more cost-effective and sustainable native chicken farming practices.

1.8 Chapter Layout

This study consists of five (5) chapters.

Chapter 1 – Introduction: This chapter covers the research background, current situation of study, problem statements, research questions, research objectives and significance of study.

Chapter 2 – Literature review: This chapter covers relevant theoretical models review and empirical reviews.

Chapter 3 – Research methodology: This chapter explains about the research framework, hypothesis development, data collection and research methods for this study.

Chapter 4 – Data analysis and results: This chapter covers the data analysis done over 2 cycles, its interpretation and conclusion.

Chapter 5 – Discussion, conclusion and implications: This is the final chapter to conclude the study with findings, limitation of study and recommendation for future research.

1.9 Conclusion

As discussed in the problem statements, the rising cost of feed has reduced chicken farmers' profits, which in turn may negatively impact chicken meat production. For the local native chicken farmers, there is an urgent need to investigate and make use of inexpensive and readily available feed resources, particularly generated locally, to reduce farming production costs and mitigate the risk of currency volatility and enhance profitability. This study can help to provide information and insight to the native chicken farmers on the optimum and cost-effective diet feed systems to be used to increase profitability for the native chicken meat production.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This study was conducted to develop a framework of chicken growth performance, feed efficiency and profitability for native chicken farmers based on different diet feed systems in Malaysia. Chapter 2 begins with an exploration of four pertinent theoretical models, followed by empirical reviews of chicken meat production concerning various diet feed systems.

To support the goals of the study and the research, a summary table of the empirical reviews of earlier studies relevant to the study has been included at the end of the chapter.

2.2 Review of Theoretical Models

This section presents key theoretical models related to chicken production, chicken growth performance, feed efficiency, profitability and benefit-cost analysis. These models provide the foundation for evaluating native chicken production across six different diet feed systems.

2.2.1 Chicken Production

The chicken meat production can be analysed using the producer's supply curve model. The supply curve indicates the quantities of goods that a producer wishes to supply at various prices. The market supply curve illustrated in Figure 2.1: can be derived by summing the supply curves for all producers in the market (Boardman, Greenberg, Vining, & Weimer, 2017). When the market price rises (movement up the supply curve), it will make producers better off. The producers will tend to supply more to the market. This supply curve shows the producer's marginal costs, since the producer will maximize profits where price = marginal cost (Hanley, Barbier, & Barbier, 2009).

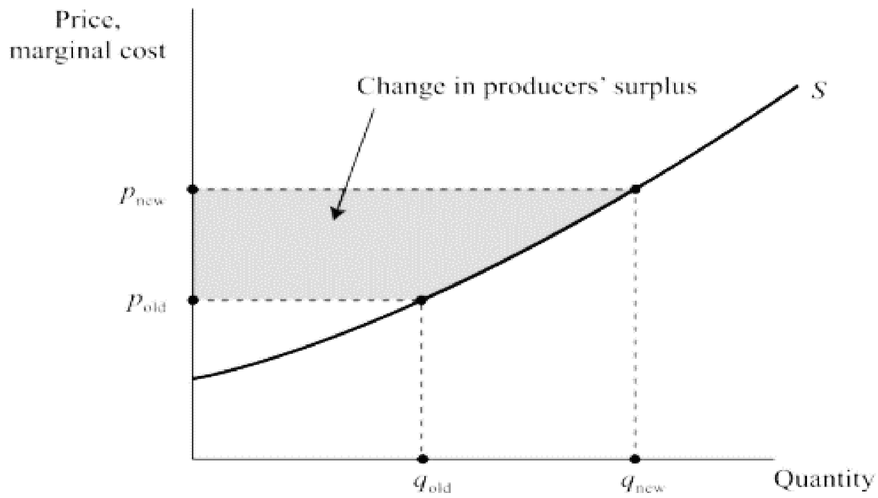


Figure 2.1: Market Supply Curve & Measurement of Producer's Surplus

Source: Hanley et al. (2009)

Hicks (1943) proposed four types of consumer surplus, all of which presuppose constant utility. In practice, only market demand functions can be empirically assessed and observed.

As production increases, the total cost of producing a good or service typically rises more quickly. The marginal cost of production typically increases with output. To cover their costs and make a profit, producers must charge a price that matches their marginal cost. As more units are produced, the supply curve shifts to the right, indicating the total cost of producing those units. When the market price is higher than the price producers are willing to accept, the extra money they earn above their costs is called producer surplus (Mankiw, Goh, Yen, Muszfarshah, & Ong, 2022).

According to Mankiw et al. (2022), the production, i.e. how much the sellers choose to sell any good depends on price of the good, input prices, technology, expectations and number of sellers. It is also noted that the market price is also sensitive to the production level. Hence, in this study, the input prices, i.e., the chicken production cost, including the feed cost which is the major cost of the production input cost and the revenue, calculated using the market rate of chicken, are being studied.

In summary, the concept of the producer's supply curve is central to understanding chicken meat production economics. As explained by Hanley et al. (2009) and Boardman et al. (2017), the supply curve reflects a producer's marginal cost and shows the quantity of goods a producer is willing to supply at different market prices. When market prices rise, producers are incentivized to supply more, as the price exceeds the marginal cost, leading to an increase in producer surplus. This surplus represents the economic benefit producers gain when market prices are above their minimum acceptable price. In the context of this study, feed cost, being the largest component of chicken production cost, directly influences the supply curve and profitability. According to Mankiw et al. (2022), input prices, technology and expectations all affect supply decisions. By evaluating different feed systems and their effects on cost, growth performance and efficiency, this study explores how alternative feed strategies can potentially lower marginal costs and increase producer surplus, making chicken production more profitable and sustainable.

2.2.2 Chicken Growth Performance and Feed Efficiency

This section discusses the chicken growth performance and feed efficiency concepts useful for Specific Objective (2) to determine the feed efficiency of the six (6) different diet feed systems based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (AVG) and feed conversion efficiency ratio (FCE) for the native chicken meat production; and Specific Objective (3) to analyse the relationship among the six (6) different diet feed systems, chicken age and body weight for native chicken meat production.

The chicken meat production is often tied with either the numbers of chicken produced, size of the chicken or the chicken body weight. For improved accuracy, the body weight of the chickens was used as the unit of measurement for their growth performance. According to the Table 2.1 below based on the preliminary investigation, the body weight of chickens would increase with age.

Table 2.1: Chicken Body Weight vs Chicken Age (Days)

Age (Days)	Weight (Grams)		
	Low Initial Weight	**Medium Initial Weight**	**High Initial Weight**
1	41.24±0.23	44.32±0.20	47.76±0.37
8	148.67±1.83	158.41±2.43	159.29±3.40
15	359.92±5.30	375.88±6.85	379.77±7.48
22	680.27±11.67	700.73±12.10	712.00±16.38
29	1011.31±20.80	1030.12±20.17	1043.81±25.70
36	1370.92±34.28	1374.27±31.86	1414.73±36.87
43	1691.65±47.78	1712.31±39.44	1758.69±49.52

Source: Patbandha, Garg, Vaghamashi & Patil, 2017

When the chicken weight increases, chicken production also increases. The growing process of the aspects is defined as growth performance. The chicken's performance was improved based on several factors such as weight or size. Chicken body weight is being selected as the measurement unit and it is an important economic element since it symbolises the farm's economic benefits and production level.

Regardless of the breed's final mature body weight, the chicken's body is made up of many cells that are all roughly the same size. Cell multiplication is responsible for most of the initial growth spurts in embryos: one cell splits into two, two into four, four into eight, eight into sixteen and so on. However, this steady rise does not last forever. Cell specialization, which is required to generate distinct body components, will occur soon (Weaver, 2002).

According to Weaver (2002), age and function impact on the different specialized cells' rates of growth and division. The chick's daily increases in body weight are less as it gets older. Following hatching, muscle and nerve cell growth results from cell enlargement rather than cell division, as the number of muscle fibres (single cells) stops increasing. The maximal size of muscle fibres is primarily determined by the genetic composition of the chick; however, activity levels can cause the size of the fibres to change. There is involvement with both protein production and breakdown. The simultaneous processes of synthesis and breakdown result in the muscles to either enlarge or contract. Since chickens use their breast muscles to move their wings during flight, these muscles are incredibly well-developed.

The quantity of fat-containing cells in chickens determines their fatness, with selective breeding for larger, plumper carcasses leading to certain breeds having more fat cells. During early growth, the number of fat cells reaches its maximum, and a broiler's ability to gain weight quickly is due to fat deposits in these cells rather than increased muscle or skeletal growth.

Morbos et al. (2016) have discovered four (4) methods for calculating the growth performance of local chickens from the Philippines: (1) cumulative voluntary feed intake (CVFI), (2) cumulative weight gain, (CWG), (3) average daily gain (ADG) and (4) feed conversion efficiency ratio (FCE).

According to Morbos et al., (2016), body size and genotype impact voluntary feed intake. A larger body will require more nourishment to maintain that size. Additionally, according to a study by Magala, Kugonza, Kwizera, & Kyarisiima (2012) larger chickens throughout the growth phase exhibited significantly higher voluntary feed intake than smaller-sized chickens. In general, larger chickens have higher dietary needs than smaller chickens.

Over time, the net difference in an animal's body weight is known as cumulative weight gain (CWG). The gram unit is used for calculation. According to study results, chickens often grow more quickly when their CVFI is higher.

The average weight gain an animal experiences each day is called average daily gain (ADG). The gram unit is used for calculation. Males exhibit higher ADG than females for similar reasons as CWG: sexual dimorphism and higher levels of voluntary feed intake. Ndegwa, Mead, Shephered, Kimani, & Wachira (2012) corroborate this conclusion by stating that cockerels typically grow faster than pullets and respond better to diets high in protein.

Voluntary feed intake per gram of weight gain over time is measured by the feed conversion efficiency ratio or FCE. The gram unit is used for calculation. According to Hardy & Kaushik (2021) and Bestil (2001), an efficient system has a lower FCE value. It should be noted that as chickens get older, they are better able to eat protein-rich feed (Morbos et al., 2016).

In summary, understanding growth performance indicators such as CVFI, CWG, ADG and FCE is crucial for evaluating the efficiency of different diet feed systems in native chicken meat production. These metrics not only reflect the biological growth patterns influenced by age, sex, and genotype but also provide insights into the nutritional adequacy and economic viability of feed strategies. By analysing the relationship between chicken age, body weight, and feed intake across different diets, this study aims to identify feeding systems that optimize growth while minimizing feed cost, thereby contributing to more sustainable and profitable poultry production.

2.2.3 Profitability

This section discusses concept that is related to Specific Objective (4) to identify the profit level using the benefit-cost ratio (BCR) of the six (6) different diet feed systems for the native chicken meat production.

Cinnamon & Helweg-Larse (2010) stated that while the term "profit" may seem simple, it can refer to various types, ranging from gross to net and operating to post-tax. Cash and profit are not the same. Profits stated in the company statement are based on accrual basis. The revenue is recorded even though the payment has not been collected (Keown, Martin, & Petty, 2017).

Hence, Cinnamon & Helweg-Larse (2010) mentioned that profit is a sum; only cash is real. According to Horton (2021), profitability is closely linked to profit, but they differ in an important way. While profit is an absolute figure, profitability is a relative measure.

Business owners must manage both short-term cash flow and long-term profit to maintain the viability of their company. Earnings alone do not accurately reflect the value a company is generating for its owners. Ultimately, shareholders are more focused on cash flow than profit, as depreciation is considered a cost in profit calculations. Cash is what allows a business to grow, develop, and distribute dividends. Cinnamon & Helweg-Larse (2010) further explained that the gross profit margin and profit can be used to measure company financial performance.

Ross (2019) mentioned that profit margin is one of the most widely recognized and commonly used financial ratios to assess profitability. Companies place significant focus on their profit margin. Profit margin is expressed in Equation 2.1 below:

$$\text{Profit Margin} = \text{Net Income} \div \text{Sales} \qquad (2.1)$$

In a business, having the highest sales is meaningless if they are not profitable. Profits can be measured as profit before interest and tax (PBIT) or operating profit, as this is the amount from which the company must cover its obligations, including interest, taxes, and dividends.

Profitability is an indicator of efficiency, acting as a key measure of a business's success or failure. It can be further defined as the ability of a company to generate returns on investment relative to its resources, compared to other investment opportunities. In other words, production involves using inputs to create valuable output, such as goods or products, that customers or end-users are willing to pay for, ultimately generating profit (Cinnamon & Helweg-Larsen, 2010).

Constructing a break-even chart can help to examine the profitability. It consists of 2 axis, units of sales on the x-axis and value on the y-axis. There are 2 types of costs, i.e. fixed cost and variable cost. Variable costs increase in proportion to units sold (Cinnamon & Helweg-Larsen, 2010).

Employee expenses and various types of supplies are usually considered variable costs (Kingma, 2001). Fixed cost is anything that is not a variable cost (Cinnamon & Helweg-Larsen, 2010). Fixed costs remain constant regardless of production levels. They cannot be altered within a given time, no matter how much is produced (Kingma, 2001).

Figure 2.2 and Figure 2.3 illustrate that profit is calculated by subtracting total costs (fixed cost plus variable costs) from total sales (Mankiw et al., 2022).

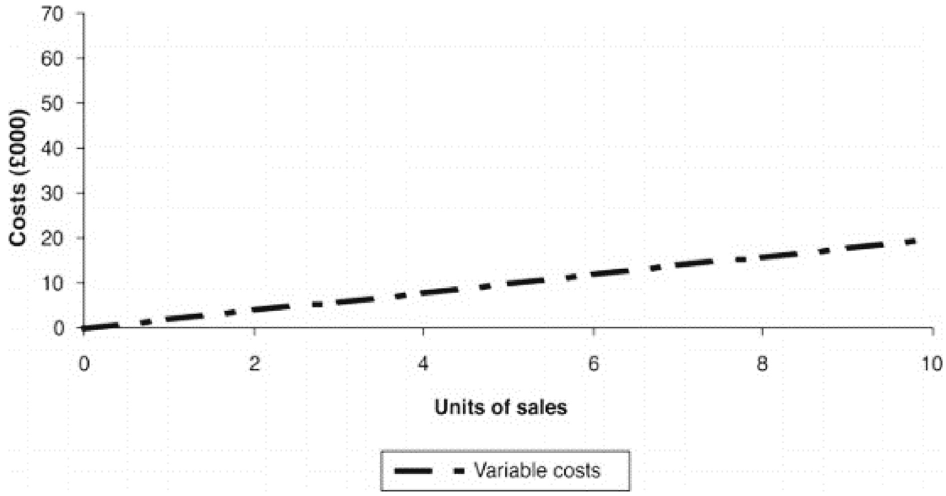


Figure 2.2: Variable cost

Source: Cinnamon & Helweg-Larsen (2010)

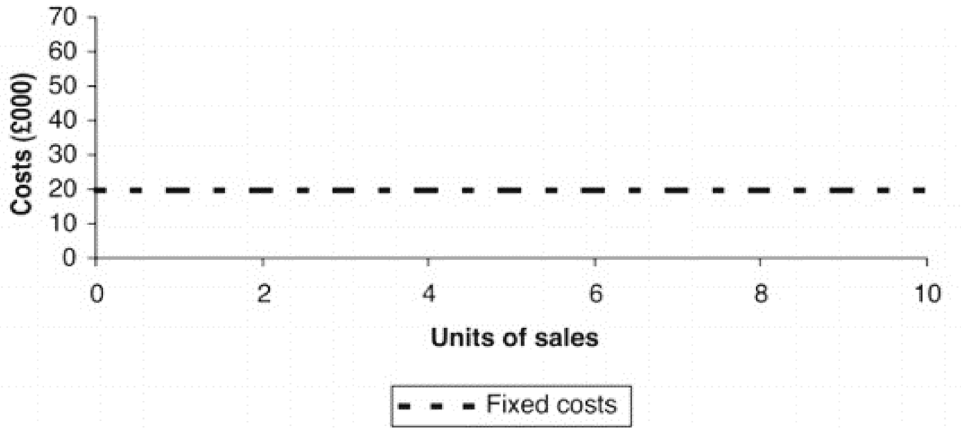


Figure 2.3: Fixed cost

Source: Cinnamon & Helweg-Larsen (2010)

To enhance business profitability, the break-even chart suggests four strategies:

(1) Lower fixed costs

(2) Decrease variable costs

(3) Raise selling prices

(4) Boost sales volume

Weaver (2002) identified that, when manufacturing poultry meat, feed and labour are two of the most significant cost components. Even though the ideal situation is to have both low feed and low labour, feed is found to be by far the most important. The cost of labour is the next greatest expense after feed. The author highlighted that in the U.S., producing whole eviscerated broilers costs approximately 45% per pound, making labour cost reductions ineffective when grain prices are high. In a hypothetical country with lower labour costs (50% less) but higher feed costs (50% more), production would rise to 49% per pound. Since feed represents a major portion of production costs, lower feed costs can more than compensate for higher labour expenses.

As a result, nations that export grains yet have relatively high labour costs can still compete (refer to Table 2.2). In many cases, high labour cost nations can increase competitiveness by replacing labour with capital and technology.

Table 2.2: Whole Eviscerated Broiler Meat Cost – US vs Other Countries

	United States	**Higher grain / lower labour country**
	Cents per pound	
Feed	18	27
Labour	10	5
All other	17	17
Total	45	49

Source: Weaver (2002)

In conclusion, understanding profitability in native chicken meat production requires more than just assessing profit as a simple figure; it involves examining the relationship between costs, revenues and the efficient use of resources. Feed remains the most critical cost factor, followed by labour, indicating that strategies aimed at reducing feed expenses can significantly enhance profitability. The use of tools like profit margins allows producers to evaluate the financial performance of different production systems and identify ways to improve efficiency, such as lowering costs or increasing chicken weight. These insights are essential for making informed decisions that support sustainable and profitable poultry farming.

2.2.4 Benefit-Cost Analysis

This section discusses theory that is related to Specific Objective (4) to identify the profit level using the benefit-cost ratio (BCR) of the six (6) different diet feed systems for the native chicken meat production. Boardman, Greenberg & Vining (2018) explained that the cost-benefit analysis offers thorough, authoritative, approachable and useful explanations of the procedures for evaluating the investment project. Students from a range of backgrounds can create strong conceptual foundations with its detailed presentation of crucial subjects with no mathematical preparation and its review of key microeconomics principles.

Figure 2.4 below illustrates that a benefit-cost analysis provides decision-makers with crucial information to assess a project's viability. The analysis measures the impact of an investment by comparing two hypothetical scenarios: one where the project is implemented and one where it is not. A project should only proceed if its benefits outweigh the opportunity costs of not undertaking it (Campbell & Brown, 2003).

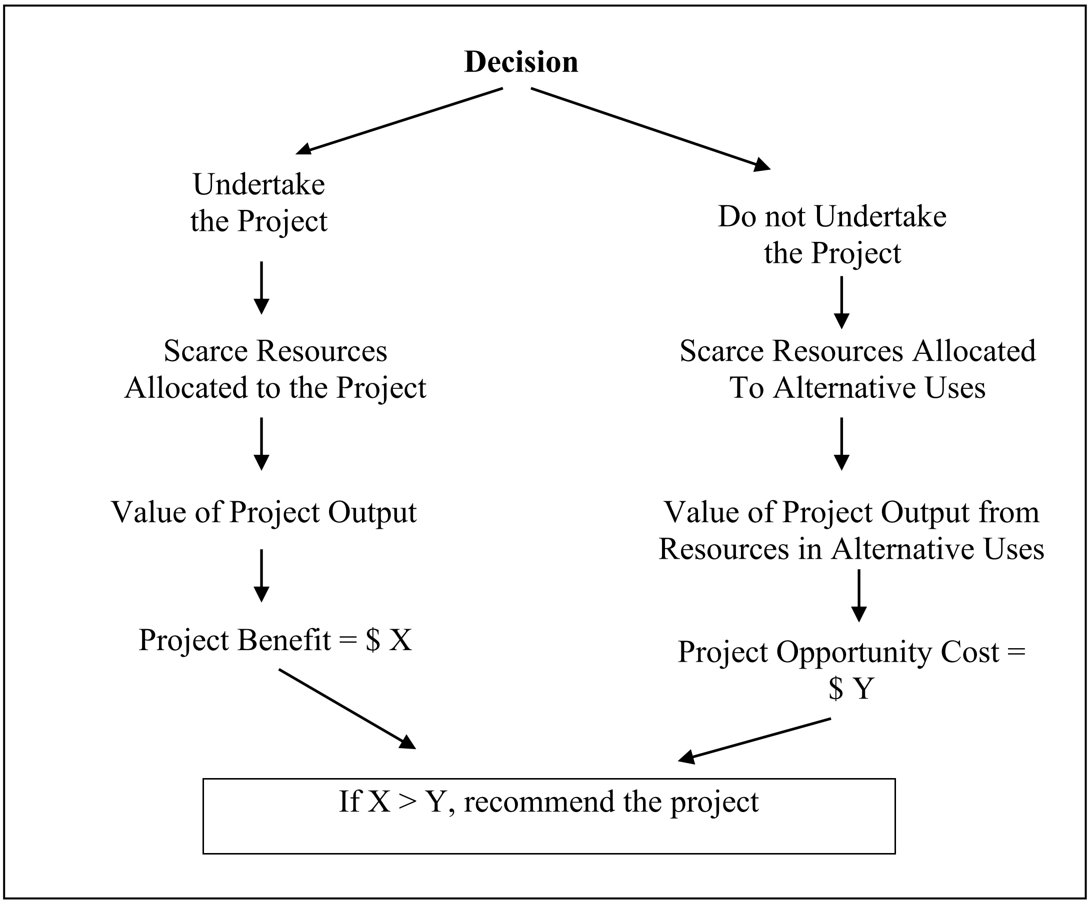


Figure 2.4: The "With and Without" Approach to Benefit-Cost Analysis

Source: Campbell & Brown (2003)

To produce output an organization must purchase and combine inputs (resources). The cost of producing a unit of output is the combined costs of the inputs necessary to make it. The inputs or the resources include labour, land, rent, construction, computers, supplies, telecommunications, legal services, administration and other inputs to produce the goods and services. All these resource costs are summed up to calculate the cost per unit. In each case, it is important to quantify the costs, the amount and types of outputs and the amount and types of inputs (Kingma, 2001).

The above theory is relevant with the chicken meat industry. If the benefit (profit) for farmers is not sufficiently high, they may decide against continuing chicken production.

Mankiw et al. (2022) explained that to maximise profit, a firm must consider both its total revenue and total cost. While total revenue can be increased by simply raising output, controlling production costs is more complex. According to Cinnamon and Helweg-Larsen (2010), total cost consists of fixed and variable costs.

In this study, labour costs are classified as fixed costs, remaining constant up to a certain production level and only increasing significantly with a major expansion. Variable costs, on the other hand, include feed expenses and the cost of the chickens themselves, both of which fluctuate based on production scale and market conditions. Efficient cost management is crucial for maximising profitability and ensuring sustainable operations.

Benefit-Cost Ratio (BCR) serves as a crucial relative measure for assessing the profitability of different diet feed systems in native chicken meat production. Unlike absolute profit, BCR compares the benefits gained per unit of cost, offering a clearer picture of economic efficiency. A BCR greater than 1 indicates that the benefits outweigh the costs, guiding farmers toward more viable and cost-effective feeding strategies.

2.3 Empirical Review: Framework of Chicken Growth Performance, Feed Efficiency and Profitability for Native Chicken Meat Production based on Different Diet Feed Systems in Malaysia

Based on the theoretical review, Weaver (2002) identified that feed and labour are two of the important cost items when producing poultry meat. He found out that feed is found to be by far the most important aspect in the chicken meat production. This was confirmed by a study carried out by Moss et al. (2021) and Nasarudin et al. (2024) which revealed that feed contributes for more than 60-75% of the cost of chicken production. Both studies confirmed that precise feed formulation is crucial to ensuring chickens receive a balanced diet with neither nutrient deficiencies nor excesses.

Research has shown that diet feed systems for chicken diets significantly impact growth performance, feed efficiency, and, ultimately, the profitability of chicken farmers. If chicken farmers earn sufficient profit, they will continue producing chicken meat. Otherwise, production will slow down. Therefore, ensuring consistent profitability for chicken farmers is crucial. The profitability of chicken meat production depends on the following aspects, which will be further explored through empirical review:

(1) Effect on different selected diet feed systems on the feed efficiency. Six (6) diet feed systems were selected for this study. Four (4) formulas were adopted to measure the chicken feed efficiency, i.e. cumulative voluntary feed intake (CVFI), cumulative weight gain (CWG); average daily gain (AVG) feed conversion efficiency ratio (FCE) (Morbos et al., 2016)

(2) The growth performance of chickens was analysed using multiple regression and panel data analysis based on six (6) distinct diet feed systems, considering the relationships among diet, age, and body weight.

(3) The production cost of native chicken meat was compared across various diet feed systems relative to revenue. Revenue was calculated based on the market rate and final body weight, while costs included feed ingredients, chicken cost, labour, and other related expenses.

2.3.1 Feed Efficiency and Chicken Growth Performance for the Six (6) Diet Feed Systems for Native Chicken

This section discusses journal article review pertaining to the chicken growth performance and feed efficiency concepts that are useful for Specific Objective (2) to determine the feed efficiency of the six (6) different diet feed systems based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (AVG) and feed conversion efficiency ratio (FCE) for the native chicken meat production.

Six (6) diet feed systems for native chicken were selected based on the preliminary study with the chicken meat producer's (*Bintang Maju Agri Sdn Bhd*). Discussions were held with the chicken meat producer and 2 diet feed system providers (*Palma Tech Sdn Bhd and Bio Loop Sdn Bhd*) Six (6) diet feed systems were selected based on previous research, the experience of the producer and diet feed system providers, feed availability, locality, cost and the benefits of each feed.

The benefits of the selected diet feed systems, along with their impact on growth performance and feed efficiency, are further demonstrated in the empirical review. The selected diet feed systems are as follow:

(1) Premium Starter Feed in 50kg pack.
(2) 5% *Pokok Ketum Ayam* (*Trichanthera Gigantean*) mixed into Premium Starter Feed
(3) 5% *Protein Larva Askar Hitam* (Black Soldier Fly) mixed into Premium Starter Feed
(4) 200g Crude Palm Kernel Oil (CPKO) mixed into 50kg Premium Starter Feed
(5) 100g Organic Acid mixed into 50kg Premium Starter Feed and
(6) 100g Yellow Pigment (Brand: SK Gold) mixed into 50kg Premium Starter.

2.3.1.1 Diet Feed System 1: Premium Starter Feed

Since diet feed system 1 is one of the most used treatments among chicken farmers, it serves as the foundational feed. Moran (1989) and Dozier III, Behnke, Gehring & Branton, (2010) have mentioned that the physical structure of the feed significantly impacts the growth performance and feed intake of chickens.

The size of the grain and feed particles impacts the growth performance of chickens, particularly during the early growth phases. It is also influenced by the diet's processing techniques, such as pelleting and crumbling (Sogunle, et al., 2013). The premium starter pack being studied is in crumbled form.

A study by Idan, Nortey, Paulk, Beyer & Stark (2020) found that broiler feed consumption and growth rate were influenced by the physical form of the feed. The effects of the starting feed type on broiler growth performance were studied in a 42-day trial. 900 male Cobb 500 broiler chicks, weighing an average of 38g at birth, were divided into 36 floor pens, each holding 25 chickens, at random. Pens were randomly assigned to one of the four diet feed systems, with nine pens per diet feed system. The diet feed systems were supplied to the chickens from day 1 to day 21 and from day 22 to day 42, they were fed a traditional mash meal. The diet feed systems used were as follows:

(1) T1: 21 D mash
(2) T2: 7 D crumbles followed by 14 D mash

(3) T3: 14 D crumbles followed by 7 D mash

(4) T4: 21 D crumbles were the diet feed system

Overall, chickens fed crumbles had higher body weight, average daily gain (ADG) and average daily feed intake (ADFI) than those on the mash diet. The feed conversion efficiency ratio (FCE) of the chicken fed crumbles was improved compared to those chickens fed with mash diet. When compared to the other diets, chickens fed T4 were heavier at both 21 and 42 days and exhibited a higher FCE. The findings suggest that feeding broiler chicks crumbled instead of mash diet for at least 7 days improved BW, ADG, ADFI and FCE.

In addition to the above, Omede & Iji (2018) conducted a study examining the impact of different levels (0, 50, and 100 g/kg) of processed soy protein (PSP) in mash or crumbled form on chick growth up to 10 days after hatching. Using 324 Ross 308 male broiler chicks, with 9 per replication and 6 repetitions per group, researchers found that chicks fed crumbled diets had higher body weight gain and feed intake than those on mash diets, except for the control mash group. To support optimal future growth, it is essential to promote early chick development with more palatable and digestible feed types.

The findings of the studies above are supported by research conducted by Chewning, Stark & Brake (2012) and Amerah & Ravindran (2008). Both studies have shown that feeding broilers pellets or crumbles stimulates feed intake, resulting in higher body weight and improved feed conversion efficiency compared to a mash diet.

A study by Behnke & Beyer (2002) also indicated that crumbles are ideal for starter chicks. Starter chicks are unable to consume pellets due to their small beak size. To make the feed suitable, pellets are crushed using two steel rolls into crumbles, which have a coarser texture than mash.

Based on the studies above, crumbled feed significantly improves broiler growth performance, feed intake and feed conversion efficiency compared to mash. Studies show that feeding chicks crumbles in the early stages enhances body weight, average daily gain, and overall feed efficiency. This suggests that using crumbled feed for starter chicks can optimise poultry growth and production.

2.3.1.2 Diet Feed System 2: Premium Starter Feed + *Pokok Ketum Ayam*

Trichantera gigantea (*Pokok Ketum Ayam*), rich in protein, provides several ecological benefits such as improving soil quality, preventing erosion, and fixing nitrogen, all of which boost crop productivity. Additionally, it serves as an alternative plant protein source, reducing the nation's dependence on imported proteins, ensuring food security, and promoting the health and well-being of poultry (Nasarudin et al., 2024). Studies have shown that increasing *Pokok Ketum Ayam* in the poultry diet improves chicken performance. The leaves contain soluble carbohydrates, real protein, and minimal levels of anti-nutritional elements, making them highly appealing to animals (Morbos et al., 2016).

A review by Nasarudin et al. (2024) found that including 10% and 15% *Trichantera gigantea* in broiler feed was economically viable. The same authors also investigated the viability of palm kernel cake (PKC) as animal feed and found it rich in nutrients. Enhancing PKC-based feed with *Trichantera gigantea* improved chicken growth and helped manage agro-industrial waste. In their study, chickens were fed either conventional corn-based feed (D1), PKC-formulated feed (D2), or PKC with *Trichantera gigantea* (D3). By day 20, chickens on D3 had the highest weight (780.0g), comparable to premium-grade PKC feed (785-800g). While growth performance was similar across all diets until day 25, commercial feed showed a slight advantage afterward. These findings highlight *Trichantera gigantea*'s potential to enhance PKC-based feed, improving nutrient intake and promoting sustainable animal feed solutions.

Kathiraser, Mohd Abdul Nasir, Mat Saad, & Wan Md Zain (2024) conducted a study on the low utilization (less than 5%) of *Trichantera gigantea* as a feed additive to enhance the growth of *Ayam Saga*. In this study, 120 four-week-old male *Ayam Saga* were randomly assigned to four treatment groups: control, 1%, 3%, and 5% *Trichantera gigantea*. Each group had six (6) replicates with five birds per replicate and the birds underwent an eight-week feeding trial until they reached 12 weeks of age. Body weight, feed intake, body weight gain and feed conversion efficiency ratio were recorded. The results showed that birds fed with 1% *Trichantera gigantea* and the control group had significantly higher ($p<0.05$) final body weight and weight gain compared to those given 3% and 5% *Trichantera gigantea*. The 1% supplementation and control group also demonstrated better feed conversion efficiency.

Libatique (2021) conducted a study on the higher utilization (greater than 5%) of the leaves in chicken feed. His study showed the effect of *Trichanthera gigantea* leaf meal (TGLM) on weight, feed conversion efficiency ratio, and cumulative feed intake. Four diet systems with varying percentages of inclusion of the leaf were selected:

(1) Feed 1 – Control Home-mixed Feeds (HF) + 0% of TGLM
(2) Feed 2 – HF + 5% of TGLM
(3) Feed 3 – HF + 10% of TGLM
(4) Feed 4 – HF + 15% of TGLM

The chickens were split into these four feeds, each of which had ten chickens and was repeated three times. There was no significant result from the first to the third week. However, from the fourth to the sixth week of the trial, the broilers' feed conversion efficiency ratio, cumulative feed intake and body weight were significantly affected by 10% and 15% of TGLM. Notably, 15% of TGLM showed a significantly better feed conversion efficiency ratio.

This outcome aligns with a previous study in the Philippines conducted by Morbos et al. (2016), which also examined different doses of TGLM supplementation on chicken growth. Thirty-six three-month-old native chickens of both sexes were randomly assigned to four feed regimens using a 2 x 4 factorial design with three replicates and four chickens per replicate. For 13 weeks, diet feed systems included 0%, 5%, 10%, and 15% doses of TGLM supplementation in a semi-confinement setting. The findings demonstrated that cumulative voluntary feed intake (VFI) increased with higher TGLM supplementation, especially in weeks 10, 11, and 12, where the increase for 15% TGLM was considerable. Cumulative weight gain (CWG) trended downward as TGLM levels increased, with no discernible differences between the groups other than in weeks 4 and 7. The feed conversion efficiency ratio (FCE) dropped as TGLM levels climbed, reaching a significant low at 15% in week 7, but the effects of different TGLM supplementation doses on average daily gain (ADG) were not statistically significant.

In conclusion, *Trichantera gigantea* (*Pokok Ketum Ayam*) is a valuable alternative protein source for sustainable poultry feed, offering both nutritional and ecological benefits. Studies suggest that incorporating up to 15% can enhance feed efficiency, though lower levels (1-5%) are more effective for weight gain. Its potential to complement palm kernel cake further supports its role in improving poultry nutrition while reducing reliance on imported proteins.

2.3.1.3 Diet Feed System 3: Premium Starter Feed + *Protein Larva Askar Hitam*

The Black Soldier Fly (BSF), scientifically known as *Hermetia illucens*, is a versatile polysaprophagous insect native to the Neotropics, now found in warmer regions globally. Adults of this species are identifiable by distinct features in their head, thorax, legs, wings and genitalia (Zaid, et al., 2023). BSF larvae (BSFL) are capable of thriving on a variety of substrates (Nguyen, Tomberlin & Vanlaerhoven, 2015; Diener, Studt Solano, Roa Gutiérrez, Zurbrügg & Tockner, 2011) and exhibit impressive dry matter (DM) conversion efficiency, with rates reaching up to 40% (Diener, Zurbrügg, & Tockner, 2009). The crude protein (CP) content in BSFL varies widely, ranging from 35% DM (Diener et al., 2009) to 57% DM (Dierenfeld & King, 2008), and their fat content is typically around 30% DM (Gao, et al., 2019). Insects are recognized as excellent sources of protein, essential amino acids, minerals and vitamins (Spranghers, et al., 2017).

Due to its nutritional profile, BSFL has gained attention as an alternative ingredient in animal feed. Experts and a growing body of research suggest that incorporating insect meals into feed formulations could offer a sustainable and effective approach to enhance feed efficiency (Kouřimská & Adámková, 2016; Van Huis, 2013).

Over the past decade, numerous studies have emphasized the potential of insect-based feeds, particularly BSFL, in promoting sustainability within poultry production. There are two primary methods for incorporating BSF into poultry diets: (1) processing larvae into protein-rich meals and fat to be included in poultry feed, and (2) using live larvae as environmental enrichment (Schiavone & Castillo, 2024).

In a recent study by Cattaneo et al. (2025) the effects of laying hen age and the inclusion of live BSFL in diets on egg quality were assessed using nuclear magnetic resonance (NMR) spectroscopy. The study involved 108 Lohman Brown hens, housed in 27 cages, and supplemented with either 15% or 30% live BSFL based on expected daily feed intake (DFI). The results showed that up to 30% BSFL inclusion did not negatively impact egg and eggshell quality, although it did alter the fatty acid profile in the yolk.

Brah et al. (2024) conducted a study to determine the optimal inclusion rate of full-fat BSFL meal (BSFLM) in broiler diets for improved zoo-economic performance. Broiler chicks were divided into groups receiving 0%, 4%, 8%, 12%, and 16% BSFLM over a 49-day period. The findings revealed that a 12% inclusion rate of BSFLM offered the most significant improvement in feed efficiency and overall performance. However, feed intake decreased with higher BSFLM inclusion, and the 16% inclusion resulted in poorer performance.

Ahmad et al. (2024) found that incorporating 15% BSFL in village chicken diets led to the highest weight gain (1231.45 g) and improved feed conversion efficiency ratio (2.03). This suggests that a 15% BSFL inclusion could enhance growth performance in village chickens without negative effects. This study evaluated the nutritional composition of black soldier fly larvae and its impact on the growth performance of village chickens. Proximate analysis revealed that the larvae contained 773.0 g/kg dry matter, 408.8 g/kg crude protein, 283.0 g/kg ether extract, 40.9 g/kg crude fibre, and 2.041 MJ/kg metabolisable energy, along with essential vitamins and minerals. A feeding trial was conducted on 280 one-day-old village chicks, divided into four groups and fed diets where corn and soybean were partially replaced with black soldier fly larvae at 0% (Control), 5% (T1), 10% (T2), and 15% (T3) for 70 days. Each group had seven replicates of 10 birds. Growth performance indicators, including body weight, weight gain, and feed conversion efficiency ratio, were assessed. The results showed that chickens on Diet T3 (15% larvae inclusion) had the highest weight gain (1231.45 g) and the most efficient feed conversion efficiency ratio (2.03).

Kierończyk et al. (2023) investigated the impact of BSF larvae fat on broiler growth performance. Four groups of Ross 308 broilers were fed diets containing 0%, 30 g/kg, 60 g/kg, or 90 g/kg of BSF larvae fat. The results indicated that the 60 g/kg inclusion level (HI06) resulted in the best growth performance, suggesting that this may be the optimal level of BSF fat supplementation for broilers. While higher BSF fat levels altered the fatty acid profile in the meat, they did not affect meat quality.

In a separate study by Facey et al. (2023) , lower levels of BSFL inclusion (4%) were found to promote broiler growth similarly to antibiotics. This study supported previous findings that BSFL can effectively substitute fish meal (FM) and soybean meal (SBM) in broiler diets, providing a cost-effective protein source without negatively affecting performance (Mat, et al., 2022). Waithaka et al. (2022) further confirmed that insect-based feeds could replace up to 20% of fish meal, offering a more economical solution without compromising broiler growth.

Not all studies show consistently positive outcomes from BSFL inclusion. For instance, the study by Pietras, Orczewska-Dudek, Szczurek, & Pieszka (2021) demonstrated no change in body weight or daily growth rate when BSF larvae were included in the diet, compared to the control group that only received soybean meal. Interestingly, feed conversion efficiency ratio (FCE) improved with the inclusion of insect meals, suggesting that while growth rates did not increase significantly, the efficiency of feed utilization was enhanced.

In the study, a total of 160 broiler chicks were used in the experiment. Broiler chicks, with four replication pens and eight chicks per pen, were randomly assigned to five distinct food regimens at three weeks of age. Using corn soybean meal (CON) as the control diet, low-alkaloid yellow lupine seeds (Lup; Lup - SBM group) replaced 60% of SBM and full-fat insect meals made from mealworms (Tenebrio molitor; Lup - TMM), silkworm pupae (Bombyx mori), or superworm larvae (Zophobasmorio; Lup - ZMM) replaced 100% of SBM. When compared to those fed the soybean meal diet, it was discovered that broiler chicken fed diets including lupine along with soybean meal, silkworm, or mealworm did not exhibit any differences in final body weight (42 days) or daily body weight gain (21 to 42 days). Contrarily, compared to the other groups, the broiler chicks in the Lup - ZMM group actually showed lower body weight and weight growth. Broiler chicks fed the Lup - TMM diet system exhibited the highest feed conversion efficiency ratio (FCE).

Murawska et al. (2021) found that replacing more than 50% of soybean meal (SBM) protein with full-fat BSFL meal led to decreased growth performance, with lower final body weights, reduced meat yield and higher abdominal fat. Chickens in the HI75 and HI100 groups had notably lower juiciness and taste intensity in their meat, with no significant difference in feed conversion efficiency ratio compared to the control group. These findings suggest that excessive BSFL inclusion could negatively affect growth and meat quality. Similarly to a study carried out by Schiavone et al. (2018), it was found that substituting soybean oil with 50% or 100% BSF in broiler diets showed no adverse effects on growth performance. However, they noted that the extent of substitution did not significantly improve growth either.

Hwangbo et al. (2009) concluded that 10% to 15% BSFL inclusion enhanced growth and carcass quality, improving weight gain and muscle yield. Yet, they observed no significant change in feed conversion efficiency ratio, indicating that while BSFL supplementation can promote growth, it may not always lead to more efficient feed utilization.

In summary, the impact of BSFL inclusion in poultry diets varies, with some studies indicating improvements in growth, feed conversion efficiency and egg quality, while others report decreased effects or no significant changes. The optimal inclusion rate appears to be context-dependent, influenced by factors such as species, age, and diet composition. Moderate inclusion levels, such as 4% to 15%, generally show positive results, while higher levels (above 16%)

may lead to diminished performance or no significant changes in certain aspects of poultry growth and carcass quality.

2.3.1.4 Diet Feed System 4: Premium Starter Feed + Crude Palm Kernel Oil (CPKO)

Oil was added to the chicken feed in the form of Crude Palm Kernel Oil (CPKO). It was demonstrated that dietary oils provide a high caloric value, delivering more energy at a lower cost (Abdulla et al., 2017; Baião & Lara, 2005). In broiler chickens, palm oil increases feed palatability and contributes substantially to the high metabolizable energy (ME) of the feed formulation (Saminathan et al., 2022). Additionally, it facilitates more effective nutrient absorption, particularly enhancing the absorption of oil-soluble vitamins (Baião & Lara, 2005; Chwen, Foo, Thanh, & Choe, 2013; Saminathan et al., 2022). The findings from these studies suggest that dietary palm oil enhances growth performance in broiler chicks (Saminathan et al., 2022).

In the study by Yendou-Gname, Romziath, Ahmed, & Jacques kossi-messan (2024), it evaluated the impact of palm oil supplementation on the growth performance and feed efficiency of slow-growing Dutch blue broilers over a 14-week period in a tropical environment. A total of 240 broilers were divided into four groups, each fed diets containing 0%, 1%, 2%, and 3% palm oil. Results showed that feed intake increased with higher palm oil inclusion, while average daily weight gain was highest in the 2% and 3% palm oil groups. Feed conversion efficiency ratio (FCE) improved with 1% and 2% palm oil supplementation. The study concluded that incorporating 1%-2% palm oil in broiler diets enhances both growth performance and feed efficiency.

A similar study conducted by Long et al. (2019) confirmed that the inclusion of dietary palm oil can influence broiler chicken growth performance. The study aimed to determine how different levels of dietary palm oil affected the growth of *Sanhuang* broiler chickens. In a 42-day trial, 208 one-day-old female *Sanhuang* chickens were randomly divided into four groups, each receiving one of the following treatments: a control diet (no palm oil), and diets supplemented with 2%, 4%, or 6% palm oil. Chickens fed diets containing 4% and 6% palm oil exhibited lower average daily feed intake (ADFI) and feed-to-gain ratio (F/G) from days 22 to 42 and throughout the trial. However, from days 1 to 42, chickens on palm oil-enriched diets showed higher average daily growth (ADG) than those on the control diet. These results suggest that including 4% to 6% palm oil may enhance growth performance despite reduced feed intake.

Similarly, the study by Rahman, Akbar, Islam, Iqbal & Assaduzzaman, (2010), showed that adding palm oil to the diet of Hubbard Classic broiler chickens affected feed intake, growth performance and profitability. In the study, 300-day-old Hubbard Classic broiler chickens were used to examine the effects of different palm oil inclusion levels (2%, 3%, 4%, and 5%) on growth. From the second to the fourth week of the trial, adding 4% palm oil had an additive effect on the chicken's growth. Broilers fed diets with 2% and 3% palm oil had live weights of 1791g and 1777.67g, respectively—4% and 3% greater than the control group. These results indicated that adding palm oil significantly increased feed consumption.

Additionally, Adrizal et al. (2011) highlighted the potential nutritional value of palm kernel meal (PKM), a by-product of palm kernel oil extraction, for poultry. In countries where palm oil is produced in large quantities, increasing the use of PKM in poultry diets is of critical importance. The study involved 180 48-week-old native laying hens, which were divided into 15 groups with different PKM inclusion levels (0%, 15%, and 30%). The study found that the inclusion of palm kernel meal did not affect egg production, feed conversion efficiency, or egg weight. Egg quality remained similar in hens fed diets with 15% or 30% palm kernel meal, suggesting that palm kernel meal could be a viable supplement for poultry diets without adversely affecting egg production or quality.

In conclusion, the supplementation of palm oil or its derivatives, such as Crude Palm Kernel Oil (CPKO) has been shown to enhance the growth performance and feed efficiency of broiler chickens. Various studies indicate that palm oil can improve feed intake, average daily growth and feed conversion efficiency ratios, making it an effective and economical ingredient for poultry diets. Optimal inclusion levels of palm oil range from 1% to 6%, depending on the specific circumstances and the type of broiler. Additionally, palm kernel meal (PKM) has been identified as a valuable feed ingredient in poultry diets, with no adverse effects on egg production or quality, suggesting its potential for broader use in poultry nutrition. These findings underscore the importance of palm oil products in enhancing the nutritional profile and overall performance of broiler chickens, benefiting both poultry producers and the industry at large.

2.3.1.5 Diet Feed System 5: Premium Starter Feed + Organic Acid

Diet feed system 5 highlights the incorporation of organic acids (OAs) into poultry diets as an effective alternative to antibiotic growth promoters (AGPs) (Du, et al., 2024), particularly in the post-antibiotic era (Khan & Iqbal, 2016). Research shows that OAs can replace AGPs without compromising broiler growth. For example, a study by Roy et al (2024) involving Cobb 500 chicks revealed that organic acids such as citric, formic, and acetic acids significantly improved feed conversion efficiency ratio (FCE) and body weight gain (BWG) compared to controls and AGP groups. Among the acids, citric and acetic acids showed the best FCE outcomes, reinforcing their potential as effective substitutes for AGPs.

Similarly, studies by Elnaggar, & El-kelawy (2024) and Islam et al. (2024) found that organic acid supplementation not only enhanced final body weight, weight gain, and FCE, but also improved overall production efficiency, including dressing percentage and abdominal fat reduction. This underscores the promising role of organic acids in optimizing poultry performance.

Further research by Ebeid & Al-Homidan (2022) and Sobotik et al. (2021) highlighted the additional physiological benefits of organic acids, such as boosting immunity and supporting growth in challenged conditions, including *Salmonella* exposure. These studies emphasize that the supplementation of organic acids can enhance both growth performance and immune responses, even when poultry are exposed to pathogens.

Incorporating organic acids into broiler diets also improves nutrient digestibility, metabolism, and overall health, as demonstrated by Adhikari et al. (2020), who found that organic acid mixtures effectively managed infections while maintaining optimal growth. Furthermore, Aljumaah et al. (2020) showed that organic acids can improve feed conversion efficiency and production efficiency, even under pathogen challenge, suggesting their versatile role in promoting poultry health and performance.

The study by Sabour, Tabeidian, & Sadeghi (2019) further supports the positive impact of organic acids (OAs) on broiler performance, demonstrating that dietary supplementation with OAs enhances immune responses and gut health. Their investigation, which included a mix of fibre sources (rice hulls and sugar beet pulp) alongside OAs, revealed that broilers fed diets with organic acids had better antibody responses against influenza. Additionally, these chickens exhibited a higher population of beneficial *Lactobacillus* bacteria in their gut compared to other groups. This suggests that incorporating OAs into broiler diets not only improves growth performance but also enhances the immune system and gut microbiota, which are critical for overall poultry health.

In conclusion, the body of evidence supports organic acids as an effective and sustainable alternative to AGPs in broiler diets, contributing to enhanced growth performance, improved feed conversion efficiency, and overall production efficiency. These benefits make organic acids an important component in modern poultry feeding strategies, particularly in the context of reducing reliance on antibiotics and improving overall poultry health and productivity.

2.3.1.6 Diet Feed System 6: Premium Starter Feed + Yellow Pigment (Brand: SK Gold)

SK Gold, a revolutionary technology derived from the unique first-cut cold process, helps preserve the natural nutrients in palm oil, particularly β-carotene and vitamin E. The incorporation of stearin from this process contributes to maintaining the integrity of these valuable nutrients.

According to the product catalog from Palma Tech (2021), the manufacturer of SK Gold, the yellow pigment derived from this process can enhance feed efficiency, growth performance, and energy availability, while also improving palatability. This suggests that SK Gold could be a valuable addition to poultry diets.

In a study by Wang, et al. (2023), the effects of dietary β-carotene supplementation on laying breeder hens were explored to assess its impact on the growth performance of their offspring. Hens were fed diets containing either 120 mg/kg (βc-L) or 240 mg/kg (βc-H) of β-carotene, and the chicks hatched from these hens were subsequently fed the same diets. The results indicated that β-carotene supplementation significantly improved body weight at 21 days (βc-L, $p<0.01$) and tibia length at 42 days (βc-H, $p<0.05$). Additionally, β-carotene enhanced serum levels of growth-regulating factors such as HGF and leptin, and increased the expression of growth-related genes (GHR, IGF-1R, LEPR), which contributed to improved overall growth performance in chickens.

Mazur-Kuśnirek et al. (2019) conducted a study on 120 Ross 308 broilers, divided into six (6) different diet feed systems, each with 10 replications and two chickens per replication. The purpose of the study was to examine how vitamin E and a polyphenol product (PP) called Proviox affected the growth performance of the chickens. The diet feed systems included various combinations of supplementation with vitamin E and PP, with some groups subjected to higher temperatures (10 hours per day). The study found that chickens fed diets containing antioxidants, primarily PP, exhibited improved growth performance metrics, including body weight, weight gain, and feed consumption, up to the age of 28 days.

In conclusion, SK Gold, derived from a unique first-cut cold process, preserves the natural nutrients in palm oil, particularly β-carotene and vitamin E. This technology enhances feed efficiency, growth performance and energy availability in poultry diets. Studies have shown that β-carotene supplementation improves body weight, tibia length and serum growth-regulating factors in offspring, while the addition of antioxidants, such as those found in SK Gold, can further improve growth performance. These benefits make SK Gold a valuable addition to poultry nutrition, promoting healthier and more efficient poultry production.

2.3.2 Chicken Age and Chicken Body Weight

This section reviews journal articles relevant to Specific Objective (3), which aims to analyse the relationship between six (6) different diet feed systems, chicken age, and body weight in native chicken meat production.

Chick weight and morphometric features, such as chick length and shank length, play a significant role in chicken growth, as these factors positively impact slaughter yield at market age (Michalczuk et al., 2011; Wolanski, Renema, Robinson, Carney, & Fancher, 2006 and Willemsen et al., 2008). Since body weight is an easily measurable trait, breeders prioritise it when evaluating a chick's growth performance (Michalczuk et al., 2011). Therefore, in this study, chicken body weight is used as the primary measure of growth performance.

The relationship between chicken age and body weight has been extensively examined in poultry production research, particularly among commercial broiler breeds. Empirical studies consistently demonstrate that body weight increases as chickens age, with the most rapid growth typically occurring in the early weeks of life. For example, Tamzil, Ichsan, & Taqiuddin (2015), age significantly influenced body weight gain, carcass weight, feed efficiency and carcass part percentages, showing that growth performance improves with age. A significant interaction between chicken line and age was found for body weight gain, indicating that growth response to age varies by chicken type.

Similarly, Chu et al. (2020) show that body weight (BW) in broiler chickens increases significantly with age, particularly from week 1 to 6, due to both genetic and environmental influences. As chickens grow older, the genetic, maternal environmental, and residual variances in BW also increase substantially, mainly due to scaling effects. However, the impact of maternal environment diminishes over time, indicating that age has a direct and dominant role in determining BW in later stages. While weekly BW traits show high genetic correlations across consecutive weeks (0.85–0.99), the correlations between early and late-stage weights are weaker (0.32–0.57), suggesting early growth does not fully predict later BW outcomes. These findings support the idea that chicken age is a key factor in understanding and predicting body weight trends, and that age-specific feed and genetic strategies may be needed to optimize growth.

Several studies have examined the relationship between chicken age and body weight. A study by Saragih, Salsabila, Deliaputri, Firdaus, & Kurnianto (2024) found that *kampong* chickens reached their optimal body weight growth rate between 42 and 45 days of age, while overall body morphometry continued increasing until 63 days. Rapid growth occurred between 35 and 49 days post-hatch, underscoring the need for proper nutritional management from hatch to

49 days to maximise growth potential.

Gultom, Gushairiyanto, & Depison (2021) investigated the correlation between body weight and weight gain in Sentul chickens aged from day-old chick (DOC) to three months. The study involved 41 male and female *Sentul* and *Merawang* chickens in an experimental setting. Data on body weight and weight gain were collected for DOC-3 months, with a t-test used to analyse differences and a correlation test to examine relationships between body weights. The study found no significant difference (P>0.05) in body weight between male and female Sentul chickens up to two months, but a significant difference (P<0.05) emerged at three months. The most substantial weight gain occurred within the first two months. The strongest correlation between body weights was observed between one and two months of age, suggesting that the one-month body weight is a reliable predictor for body weight selection.

The findings were further supported by Patbandha et al., (2017), who conducted a study at Junagadh Agricultural University, Gujarat, between June and August 2017. The study examined the effects of factors such as weight, length, weight-to-length square ratio (BMI), weight-to-length ratio, and shank length on the growth performance of 76 coloured broiler chickens. Chicks were divided into three groups (low, medium, and high) based on their initial values. Results showed that chickens with a higher initial body weight gained significantly more weight (19.65g) by day 15 compared to those with a lower initial weight. However, by the end of the trial, body weights were similar across all groups. Chicks with a longer initial body length gained more weight (126.31–139.42g) by market age than those with shorter lengths. On day eight, medium-weight and medium-length day-old chicks had a greater live weight (9.74g and 8.39g, respectively) than their low-weight and low-length counterparts. The study also found that shank length and body mass index had no significant impact on chicken growth. Additionally, on day eight, chicks with a higher weight-to-length ratio had a significantly greater live weight (7.7–8.0g) compared to those in the low group. The findings suggest that during the early growth phase (up to two weeks), the live body weight of coloured broilers is significantly influenced by chick weight at day one.

The importance of initial body weight as a key determinant of weight performance at market age is further confirmed by other studies. Michalczuk et al. (2011) found that after 42 days, the growth rate and body weight of Ross 308 chicks were influenced by their initial birth weight. The study involved 728 Ross 308 chicks housed in litter compartments divided into eight cubicles. One-day-old chicks were individually weighed on days 1, 8, 15, 22, 29, 36, and 42. The data were categorised into three groups: group 1 (≤39g), group 2 (40–42g), and group 3 (>42g). The study concluded that Ross 308 broilers weighing more than 40g at hatch should be selected for raising, as smaller chicks exhibited lower body weights at day 42 despite having the highest growth rate.

Additionally, research by Behnke & Beyer (2002) demonstrated that early chick growth significantly impacts final body weight. Later studies by

Wolanski et al. (2006) and Willemsen et al. (2010) also confirmed that chicks with a larger initial body weight tend to grow faster until they reach market age.

These findings collectively highlight the critical role of early body weight in determining growth performance and market weight in native chicken meat production.

Most of these empirical studies focus on commercial broiler chickens, which are genetically selected for fast growth and high feed conversion efficiency. Native chickens, on the other hand, grow more slowly and have different nutritional requirements and adaptive responses. Existing studies on native chickens are limited and tend to focus on single diet systems without evaluating growth patterns across multiple feed treatments or age intervals. Moreover, there is a lack of data combining age-based growth trajectories with different diet feed interventions. This gap presents an opportunity for more nuanced research that considers how various feed systems affect weight gain at different stages of the chicken's development.

The current study addresses this empirical gap by analyzing weekly body weight across 12 weeks of growth under six different diet feed systems in native chickens. This approach provides a more dynamic and comprehensive understanding of how age and feed interact to influence growth. The findings are expected to contribute new evidence for optimizing native chicken production through age-sensitive feed strategies, particularly valuable for small-scale and rural poultry farmers in Malaysia seeking to improve profitability under rising feed costs.

2.3.3 Profitability Framework for Native Chicken Meat Production

This section reviews journal articles related to Specific Objective (4), which aims to identify the profit level using the benefit-cost ratio (BCR) of six (6) different diet feed systems for native chicken meat production.

To maximise profit, any poultry company must feed chickens a healthy diet at the lowest possible cost while also producing products that attract premium prices. For decades, farmers and feed manufacturers have faced challenges in efficiently reducing the cost of chicken production while maintaining high-quality output. Various factors influence production costs and product quality, including genotype, diet formulation, feed type, processing methods, environmental conditions, and disease, all of which impact feed consumption, weight gain, and feed conversion efficiency (FCE) (Ahiwe, Omede, Abdallh, & Iji, 2018).

In a study by Wantasen, Umboh & Leke (2024), the factors influencing the profitability of native chicken farming in Kakas District, Minahasa Regency, North Sulawesi Province were examined. Data was collected through surveys and interviews with 60 farmers between April and May 2023. Using the Unit Output Price of Profit Function (UOP-PF) technique and regression analysis, the study found that farmers earned an average annual profit of IDR

2,742,127.60 from selling 68 chickens per farmer. The regression model indicated that 58.3% of profit variation was explained by costs related to chicken purchasing, corn feed, bran, medicine and vitamins, labour, and electricity, while 41.7% was influenced by other unaccounted factors. Among these, the costs of chicken purchasing, electricity, and corn feed had a significant impact ($p<0.05$) on profitability, whereas bran, medicine or vitamins, and labour costs did not show a significant effect. This highlights that feed costs, particularly corn feed, along with input expenses like chicken purchasing and electricity, play a crucial role in determining profitability in native chicken farming.

A review conducted by Nasarudin et al. (2024) discovered that the inclusion of 15% *Trichantera gigantea* in broiler feed yielded the highest return on cost. Also, according to Libatique (2021), broilers fed with 15% *Trichantera gigantea* achieved the highest return on investment at 110.23₱ (RM8.85), compared to those fed with 0% *Trichantera gigantea*, which had a return of 70.25₱ (RM5.65).

A study by Supriya et al. (2024) confirmed that the inclusion of organic acids in the chicken diet led to higher profit margins. In the study, 160 day-old Vencobb 430Y broiler chicks were randomly selected, divided into five diet feed systems, and reared for 42 days. The diet feed systems were:

(1) T1: Basal diet with a corn-soybean meal (control)

(2) T2: Control diet with 100% replacement of soybean meal by

Fermented Soybean Meal (FSBM)

(3) T3: Control diet supplemented with 0.05% probiotics

(4) T4: Control diet supplemented with 0.1% organic acids

(5) T5: Control diet supplemented with both probiotics and organic acids

The study found that organic acid supplementation had no significant impact on serum cholesterol or LDL levels. However, the FSBM (T2) group achieved the lowest production cost and highest net profit due to reduced feed costs, followed by the organic acid (T4), probiotic (T3), control (T1), and combination (T5) groups.

In another study, Waithaka et al. (2022) examined the growth performance of improved indigenous chickens (IIC) when fed diets incorporating various levels of Black Soldier Fly Larvae (BSFL) meals. The study found notable differences in gross profit margin, cost-benefit ratio, and return on investment. Birds fed with Diet 4 had the highest cost-benefit ratio of 2.12. The study suggests that substituting up to 20% of fish meal with insect-based meal, can be a cost-effective and sustainable alternative that does not compromise poultry productivity. This substitution could reduce feed costs while maintaining optimal production levels for meat and egg products.

In Delta State, Nigeria, Gbigbi & Isiorhovoja (2022) investigated the resource allocation efficiency and profitability of exotic chicken farms. A structured questionnaire was used to collect data from 120 farmers selected through a multistage sampling procedure. The study applied descriptive and inferential statistics, using budgetary techniques to analyse profitability. Profitability indicators such as net income, profit margin percentage and return per naira invested were calculated using the Equation 2.2 below:

Net farm income = TR −TC

Profit margin % = net income/total income*100

Returns per naira invested = Total income/total cost

TC = TFC + TVC;

TR= Total revenue; TC= Total cost; TFC= Total fixed cost;

TVC= Total variable cost (2.2)

The study revealed that feed costs (34.28%) constituted the largest expense, followed by labour (23.29%) and the cost of one-day-old chicks (14.11%). Rent for generators was the least expensive component (0.93%). The profit margin for exotic chicken production was 63.42%, with a return on investment of N1.73 per naira invested, indicating that for every N1.00 invested, farmers realised a profit of N73,000. The study concluded that exotic chicken production is a profitable business.

Rifky (2016) studied factors affecting the profitability of contract broiler chicken growers in Sri Lanka. The research involved 100 randomly selected broiler producers from *Kurunegala, Puttalam, and Kalutara* districts. Using the profit function approach, the study analysed factors such as feed conversion efficiency ratio (FCE), mortality rate, input quantity, average body weight, and hours spent on farming. The study found that FCE, input quantity, body weight, and flock mortality were the most significant factors influencing profitability. The contracting company provided day-old chicks, transportation, and incentives to enhance productivity and product quality. Environmental conditions and feed quality also affected body weight and FCE. The study concluded that reducing operating costs such as feed, transportation, electricity, and labour, while optimising input levels could enhance profitability.

Based on the findings of these studies, FCE will be incorporated into the cost computation of variable costs to determine the profitability of chicken meat production using the benefit-cost ratio.

2.4 Conclusion

This chapter summarises the theoretical and empirical frameworks essential for conducting the study. It covers four key theoretical frameworks: production theory, chicken growth performance and feed efficiency, profitability, and the benefit-cost ratio — each aligning with the four Specific Objectives of the study.

Empirical evaluations indicate that different diet systems have varying effects on chicken growth performance and feed efficiency. The primary objective of this research is to identify the most efficient and cost-effective diet feed system to enhance the profitability of local chicken farmers.

Based on theoretical and empirical reviews, chicken growth performance and feed efficiency are primarily measured using cumulative feed intake and body weight gain, as widely referenced in books and journals. Profitability is assessed using the benefit-cost ratio, which is derived from production cost computations, incorporating both fixed and variable costs alongside revenue calculations.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter explains the research philosophy and methodology of the study while outlining the methodology used to address the research questions and objectives.

It details the research framework, the development of hypotheses, the data collection methods and the analytical techniques employed. The study follows a structured and sequential approach to assess the growth performance, feed efficiency and profitability of chickens within the context of Malaysia's native chicken meat production.

To achieve this, the research adopts the hypothetico-deductive method, as advocated by the Austrian philosopher Karl Popper. This approach provides a systematic framework for generating knowledge to address the identified research problem. Ultimately, the chapter concludes by drawing insights from the collected and analysed data, contributing to the study's overall finding (Sekaran & Bougie, 2016).

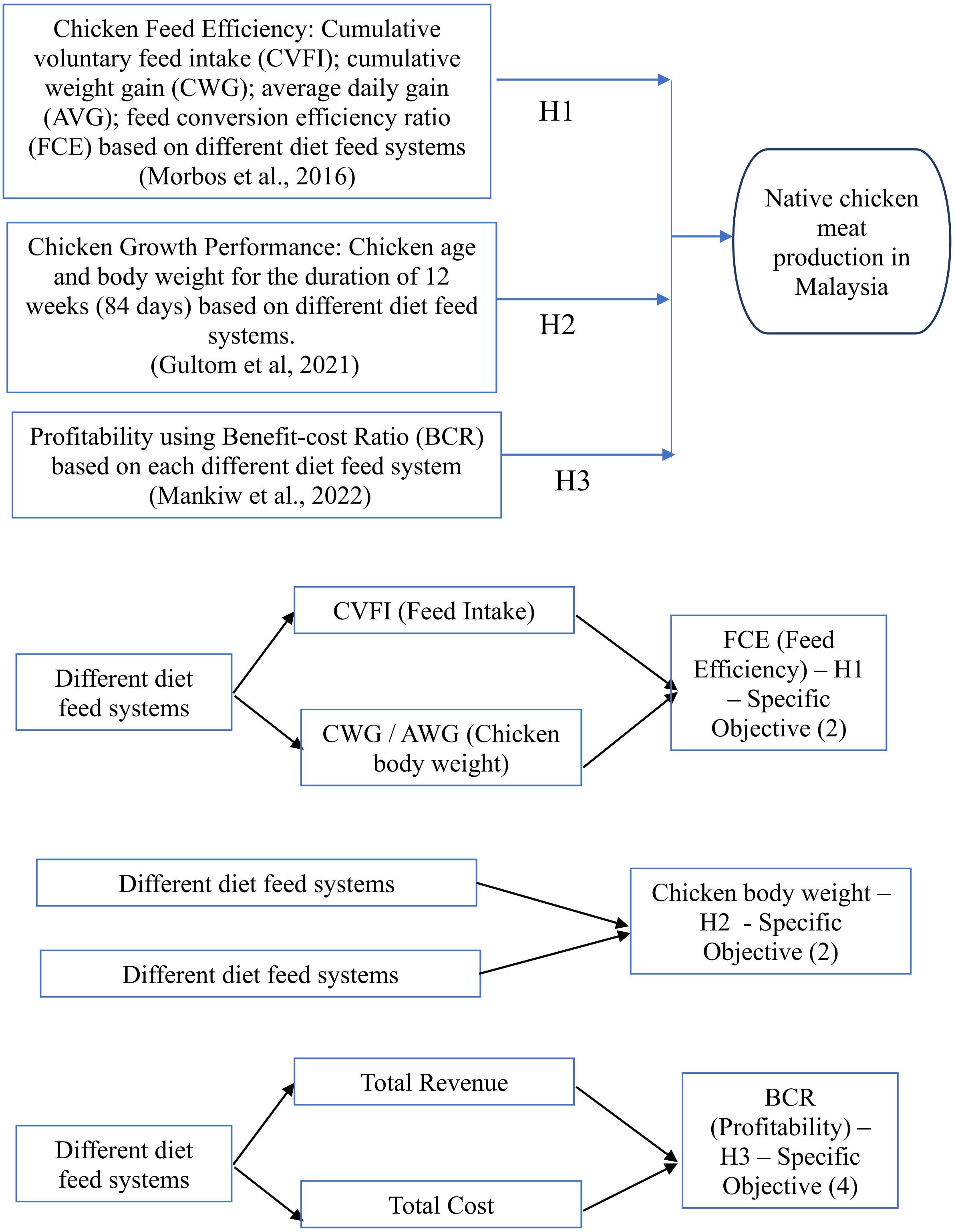
3.2 Research Framework

The research framework provides a structured outline of how the study was conducted. Within this context, the theoretical framework establishes relationships among variables relevant to the research problem. These variables are identified through observation and a comprehensive literature review, forming a rational and well-documented foundation. Additionally, experiential insights and intuition contribute to the development of the theoretical framework. This structured approach ensures that the research remains systematic, logical and aligned with the study's objectives, facilitating a clearer understanding of the relationships between key variables.

A strong synergy exists between the theoretical framework and the literature review. The literature review identifies key variables based on prior research findings and conceptual relationships, forming the cornerstone of the theoretical framework. In turn, the theoretical framework elaborates on these relationships, explains underlying theories, and clarifies the nature and direction of the interactions among variables.

Ultimately, the literature review supports the construction of a robust theoretical framework, which then serves as the basis for formulating testable hypotheses. This iterative process ensures that the study remains grounded in established knowledge and theory (Sekaran & Bougie, 2016). Figure 3.1 shows the research framework for this research study.

Figure 3.1: Research Framework for Native chicken Meat Production in Malaysia Based on Different Diet Feed Systems



Source: Own Development

A variable represents any factor that can take on different values over time or across individuals and objects. This study incorporates four types of variables: dependent, independent, mediating and control variables.

(1) Dependent Variable: The primary focus of the study, this variable is analysed to understand, explain or predict changes in response to other factors.

(2) Independent Variables: Factors that influence the dependent variable, either positively, negatively or neutrally. For an independent variable to be considered a causal factor, the following conditions must be met:

    (a) A change in the dependent variable must be accompanied by a change in the independent variable.

    (b) The independent variable must precede the dependent variable.

    (c) No external factors should significantly affect the dependent variable.

    (d) A hypothesis should explain how the independent variable influences the dependent variable.

(3) Mediating Variable: This variable explains how or why an independent variable affects the dependent variable, acting as a bridge in the relationship.

(4) Control Variable: A factor kept constant to prevent it from influencing the study's outcomes (Sekaran & Bougie, 2016).

The six (6) types of diet feed systems were determined before the experimental research was carried out at the chicken farm. According to the study's problem statements, the use of inexpensive, readily available feed resources, produced locally, is important to help local native chicken farmers lower their production costs and risk of currency volatility to boost profitability. Hence, the diet feed systems were selected based on 3 elements, i.e. the cost of the feed, the availability of the feed and the locality of the diet feed systems. To include some local made diet feed system, the chicken meat producer suggested to include some new products in the market to test the efficiency of the diet feed systems. The selection of the diet feed systems is based on the followings:

1) Study on previous research papers on the effective diet feed systems: the research papers can be found on agriculture science journals from different countries including Malaysia. An increasing number of studies have focused on using leaf meal and insect meal as alternatives to traditional protein sources. Leaf meal has a higher crude protein content compared to agro-industrial by-products (Tesfaye, Animut, Urge, & Dessie, 2013; Sugiharto, Yudiarti, Isroli & Widiastuti, 2018; Morbos et al., 2016). Insect diets, on the other hand, can have up more protein and antimicrobial peptides (Liu, et al., 2024). Hence, the *Trichanthera Gigantea* Leaf Meal (TGLM), also known as *Pokok Ketum Ayam* and the insect meal (*Protein Larva Askar Hitam*) were selected as part of the six (6) diet feed systems for this study.

2) Presentations from the diet feed system providers: As the previous studies cover mostly the established products, new product information

was limited in the market. Hence, two chicken feed suppliers, namely *Palma Tech Sdn Bhd* and *Bio Loop Sdn Bhd* were invited to give presentation on their products which are still new to the market. It was suggested by both feed suppliers that the diet feed systems be investigated with the inclusion of insect meal, Crude Palm Kernel Oil (CPKO), Organic Acid and Yellow Pigment. Benefits, advantages and cost of the diet feed systems were presented.

Insect meal is becoming a popular alternative to other protein sources in feed, such as soybean meal. It is healthy, inexpensive and easily produced locally. Black soldier fly insect meal, as suggested by the feed provider, contains significantly more lipids and calcium than soybean meal (Marono, et al., 2017; Cullere, et al., 2022)

Crude Palm Kernel Oil (CPKO) and Yellow Pigment are crude palm oil products produced locally which is lower in cost and with lesser currency fluctuation risk. Among other additives, organic acid was recommended since it has been shown to be a successful replacement for antibiotic growth promoters and to improve growth performance in the post-antibiotic era (Khan & Iqbal, 2016).

3) Experience of *Bintang Maju Agri Sdn Bhd*: the chicken meat producer was asked to provide some suggestions for the diet feed systems used before and currently based on the cost and availability. Based on the chicken meat producer experience, the Premier Starter Feed was

selected as the control diet feed system.

After the presentations from the diet feed system providers and discussions with the chicken meat producer, six (6) diet feed systems were selected: (1) Diet feed system 1 - F1: Premium Starter Feed in 50kg pack (as control feed) (2) Diet feed system 2 – F2: 5% *Pokok Ketum Ayam* (*Trichanthera Gigantean*) mixed into Premium Starter Feed (3) Diet feed system 3 – F3: 5% *Protein Larva Askar Hitam* (Black Soldier Fly) mixed into Premium Starter Feed (4) Diet feed system 4 – F4: 200g Crude Palm Kernel Oil (CPKO) mixed into 50kg Premium Starter Feed (5) Diet feed system 5 – F5: 100g Organic Acid mixed into 50kg Premium Starter Feed and (6) Diet feed system 6 – F6: 100g Yellow Pigment (Brand: SK Gold) mixed into 50kg Premium Starter.

In this study, for Specific Objective (2): to determine the feed efficiency of the six (6) different diet feed systems based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (AVG) and feed conversion efficiency ratio (FCE) for the native chicken meat production, the various types of variables are as follow:

Independent variables	**Mediator variables**	**Control variables**	**Dependent variable**
Six (6) different diet feed system	Cumulative voluntary feed intake (CVFI)	Temperature	Chicken feed efficiency measured in feed conversion efficiency ratio (FCE)
	Cumulative weight gain (CWG)	Chicken activities	
	Average daily gain (AVG)		

For Specific Objective (3): to analyse the relationship among the six (6) different diet feed systems, chicken age and body weight for native chicken meat production, the various types of variables are as follow:

Independent variables	**Control variables**	**Dependent variable**
Six (6) different diet feed system	Temperature	Chicken growth performance measured in chicken body weight
Age	Chicken activities	

While the study design aimed to ensure consistency across diet systems, several potential biases and confounding factors were considered. Firstly, the use of data from farm may introduce limitations, particularly in environmental conditions such as temperature and the chicken activities, which could influence chicken growth but were not directly measured. Hence, temperature and chicken activity levels marked are controlled variables, as they can affect cumulative voluntary feed intake (CVFI) and cumulative weight gain (CWG).

To standardize conditions, chickens are housed in fenced open areas, with 50 chickens allocated per defined space for each diet feed system. The environmental temperature is maintained at 30 ± 3°C, and chicken activities are restricted due to confined spaces, ensuring uniform conditions across all study groups (refer to the images below for setup details.)

Source: Pictures from the chicken farm

Additionally, farm management practices, although consistent within each cycle, may have subtle differences that remain unobserved. To control for these unmeasured, time-invariant factors, a fixed time-effect panel data model was employed in the panel data analysis allowing the analysis to focus on changes over time within each group. Dummy variables were also used to represent the six (6) different diet feed systems in regression to isolate the effect of diet systems, helping to reduce omitted variable bias:

(1) F1 = diet feed system 1

(2) F2 = diet feed system 2

(3) F3 = diet feed system 3

(4) F4 = diet feed system 4

(5) F5 = diet feed system 5

(6) F6 = diet feed system 6

In multiple regression and panel data analysis, a diet feed system is assigned a value of “1” when applicable, while other systems receive a value of “0”. For example, if body weight is linked to F1, then F1 = 1, while F2 to F6 = 0.

For Specific Objective (4): to identify the profit level using the Benefit-cost ratio (BCR) of the six (6) different diet feed systems for the native chicken meat production, the various types of variables are as follow:

Independent variables	**Mediator variables**	**Dependent variable**
Six (6) different diet feed system	Total cost (linked to feed efficiency)	Benefit-cost ratio (BCR)
	Total revenue (linked to cumulative chicken body weight)	

3.3 Hypothesis Development

According to Sekaran & Bougie (2016), a study aims to test whether the proposed relationships between variables exist after identifying key factors and their connections in the theoretical framework. By applying appropriate statistical analyses or qualitative research methods, researchers can verify these relationships. The results provide insights into potential solutions to the problem. This process is called hypothesis development, where a hypothesis is a testable statement about the relationship between two or more variables. Testing the hypothesis helps in finding solutions to the problem.

The hypotheses were formulated based on insights from previous research and industry best practices, ensuring a comprehensive approach to evaluating the impact of different diet feed systems on native chicken meat production.

Based on the research framework presented in Figure 3.1 above, three hypotheses have been developed for this research:

The first hypothesis is relating to the chicken feed efficiency based on six (6) different diet feed systems for native chicken meat production. Feed efficiency is a critical factor influencing the productivity and cost-effectiveness of poultry farming. Previous studies have shown that diet composition, nutrient balance and feed conversion significantly affect key growth indicators such as cumulative feed intake (CVFI), cumulative weight gain (CWG), body weight gain (BWG) and feed conversion efficiency (FCE). It is therefore reasonable to hypothesise that alternative diet feed systems, formulated based on improved nutritional profiles or cost efficiencies, will perform better than a standard control feed.

- $H_0$1: The selected diet feed system will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- H_A1: The selected diet feed system will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

Five (5) sub-hypotheses for each diet feed system are generated based on the general hypothesis above.

- $H_0 1_1$: Diet feed system 2 will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_A 1_1$: Diet feed system 2 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_0 1_2$: Diet feed system 3 will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_A 1_2$: Diet feed system 3 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_0 1_3$: Diet feed system 4 will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_A 1_3$: Diet feed system 4 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_0 1_4$: Diet feed system 5 will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_A 1_4$: Diet feed system 5 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI,

CWG, BWG and FCE ratio.

- $H_0 1_5$: Diet feed system 6 will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.
- $H_A 1_5$: Diet feed system 6 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

Second hypothesis is relating to the relationship among the different diet feed system, chicken age and chicken body weight for native chicken meat production. Growth in native chickens is a biological process influenced by both age and diet. Previous studies suggest a significant interaction between feed type and age in determining final body weight. As chickens age, their nutrient needs change and different feed systems may support or limit weight gain depending on their composition. Thus, it is expected that there is a statistically significant relationship among feed system, age, and weight.

- $H_0 2$: There is no relationship among the different diet feed systems, chicken age and body weight for native chicken.
- $H_A 2$: There is relationship among the different diet feed systems, chicken age and body weight for native chicken.

Third hypothesis is relating to the profitability of the native chicken meat production based on the benefit-cost ratio (BCR). Profitability in poultry farming can be effectively measured using the benefit-cost ratio (BCR), which compares the total returns against total production costs. A BCR of 1 or higher indicates that a project is financially viable. Given that different feed systems incur different input costs and result in different weight gains (which affect revenue), it is expected that some systems will yield a BCR greater than 1, indicating profitability.

- $H_0 3$: There is no profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using different diet feed system.
- $H_A 3$: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using different diet feed system.

Six (6) sub-hypotheses for each diet feed system are generated based on the general hypothesis above.

- $H_0 3_1$: There is no profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 1.
- $H_A 3_1$: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using diet feed system 1.
- $H_0 3_2$: There is no profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 2.

- H_A3_2: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using diet feed system 2.
- H_03_3: There is no profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 3.
- H_A3_3: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using diet feed system 3.
- H_03_4: There is no profit for farmers, calculated using the benefit-cost ratio (BCR) (ratio less than 1) for native chicken meat production using diet feed system 4.
- H_A3_4: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using diet feed system 4.
- H_03_5: There is no profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 5.
- H_A3_5: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using diet feed system 5.
- H_03_6: There is no profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 6.

- H_A3_6: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio equal or more than 1) using diet feed system 6.

3.4 Diet Feed Systems

After the preliminary study and discussions with the chicken meat producers together with the presentations from the feed system providers, six (6) diet feed systems were selected. They are:

(1) Diet feed system 1 - F1: Premium Starter Feed in 50kg pack (as control feed)

(2) Diet feed system 2 - F2: 5% *Pokok Ketum Ayam* (*Trichanthera gigantean*) mixed into 50kg Premium Starter Feed

(3) Diet feed system 3 - F3: 5% *Protein Larva Askar Hitam* (Black Solder Fly) mixed into 50kg Premium Starter Feed

(4) Diet feed system 4 - F4: 200g Crude Palm Kernel Oil (CPKO) mixed into 50kg Premium Starter Feed

(5) Diet feed system 5 - F5: 100g Organic Acid mixed into 50kg Premium Starter Feed and

(6) Diet feed system 6 - F6: 100g Yellow Pigment (Brand: SK Gold) mixed into 50kg Premium Starter.

Diet feed system 1

Premium Starter Feed

This pack is supplied by *Supreme Feedmill Sdn Bhd* which is a nutritionally balanced feed formulated to support the early growth and development of chicks. The composition of the feed is as follow:

- Crude Protein: ≥ 19.50%
- Crude Fat: ≥ 5.00%
- Crude Fiber: ≤ 4.50%
- Moisture: ≤ 12.00%
- Calcium: 0.80% – 1.10%
- Phosphorus: ≥ 0.70%

Diet feed system 2

Pokok Ketum Ayam, i.e. *Trichanthera gigantea*, is a promising protein source containing 13% to 22% crude protein in its dry matter form (Abuan, et al., 2022). These proteins are of high quality and rich in essential amino acids, which are easily absorbed by the animal's body (Nasarudin, et al., 2024).

Pokok Ketum Ayam

Leaf meals were prepared using *Pokok Ketum Ayam* grown at the chicken farm, where the trees were periodically fertilized. After harvesting, the leaves were manually separated from the branches, sun-dried and ground using a hammer mill to produce the leaf meal. This meal was then incorporated at a 5% inclusion rate into the feed formulation.

Based on existing literature, the rough chemical composition of *Trichanthera gigantea leaf meal* (dry matter basis) may be estimated as follows (Morbos, Espina, & Bestil, 2016; Libatique, 2021; Nasarudin, et al., 2024):

- Crude Protein: 13–22%
- Crude Fiber: 15–20%
- Ether Extract (Fat): 3–5%
- Ash: 10–14%
- Nitrogen-Free Extract (NFE): 30–55%

These values may vary slightly depending on the soil fertility, harvesting stage and drying conditions.

Diet feed system 3

The Black Soldier Fly Larvae (BSFL) was supplied by *Bio Loop Sdn Bhd* based in *Teluk Intan, Perak*, Malaysia. The company specializes in sustainable biotechnology to convert organic waste into high-quality protein sources for animal feed. This meal was then incorporated at a 5% inclusion rate into the feed formulation. The nutritional profile of BSFL selected based on the manufacturer's details are as follow:

- Crude protein: approximately 40%,
- Crude fat: 25%,
- Total carbohydrate: 16% and has a gross energy value of 4400 kcal/kg.

Diet feed system 4

At tropical ambient temperatures, Liquid Crude Palm Kernel Oil (CPKO) remains in liquid form, making it easy to mix into feed formulations for poultry. 200g of the liquid was mixed into the feed formulation. Based on manufacturer's detail, the composition of Liquid Feed-Grade Crude Palm Kernel Oil is as follow:

- Lauric Acid (C12:0): 45–52%
- Myristic Acid (C14:0): 14–18%
- Palmitic Acid (C16:0): 7–9%
- Caprylic Acid (C8:0): 3-5%
- Capric Acid (C10:0): 2-4%
- Oleic Acid (C18:1): 10-15%
- Linoleic Acid (C18:2): 1-3%

- Moisture & Impurities: <0.5%
- Free Fatty Acid (FFA): <5%

<u>Diet feed system 5</u>

PERFAT PFI-7 is an organic acid-based feed additive developed by *Palma Tech Sdn Bhd*, designed to enhance poultry gut health and overall performance. 100g of this powder was mixed with the premium starter feed in 50kg pack.

The exact formulation of PERFAT PFI-7 is proprietary. Based on similar products in the industry, its composition include:

- Organic Acids such as formic acid, lactic acid and citric acid
- Medium-Chain Fatty Acids (MCFAs) including caprylic and capric acids.
- Emulsifiers
- Carrier materials such as silica to facilitate mixing and stability.

Diet feed system 6

SK Gold is a feed additive developed by *Palma Tech Sdn Bhd* using a revolutionary first-cut cold process. This technology effectively preserves the natural nutrients found in palm oil, particularly β-carotene and vitamin E.

While the exact formulation of SK Gold is proprietary, it typically includes:

- Natural Carotenoids (β-carotene)
- Vitamin E (Tocopherols and Tocotrienols), naturally retained from palm oil, offering added antioxidant properties.
- Palm stearin base serves as a natural carrier and stabilizer for nutrient preservation.
- Natural emulsifiers and carriers to aid in uniform distribution and shelf stability.

3.5 Data Collection and Sources of Data

The farming research was conducted at *Bintang Maju Agri Chicken Farm* in *Sungai Lalang, Semenyih* (see the picture below).

Source: Picture from the chicken farm

The six (6) types of diet feed ingredients are mixed using a mixer (as shown in the picture below) to ensure uniformity in the feeding samples, and the mixed feed is then used to feed the chickens in the study.

Source: Picture from the chicken farm

The research was carried out over two production cycles, each lasting 12 weeks (84 days), as recommended by the chicken meat producer. Data was collected from the chicken farm, including weekly body weight and feed quantity of the chickens. The first production cycle ran from 7 January 2022 to 8 April 2022, while the second production cycle took place from 14 August 2022 to 27 November 2022.

A total of 600 native chickens, plus spares, aged 7 days, were supplied by *Kami Farming Sdn Bhd*. The chickens were fed using six (6) selected diet feed systems across the two production cycles. Fifty chickens were housed in each space, with six (6) spaces allocated for the six (6) types of diet feed systems, as shown in the pictures below.

Source: Pictures from the chicken farm

Each production cycle utilized 300 chickens, with each diet feed system being fed to 50 chickens per cycle. The total number of chickens used in the study was 600, calculated as follows:

> 50 chickens per diet feed system × 6 diet feed systems × 2 production cycles.

Based on Hair, Black, Babin & Anderson (2010), a sample size of 300 per cycle is considered sufficient for multivariate statistical methods like regression and panel data analysis, especially when the model includes a moderate number of predictors.

In addition, for animal studies involving multiple treatment groups, sample size can be calculated using the Equation 3.1 below (Charan & Kantharia, 2013):

$$n= [2 \times SD^2 \times (Z_{\alpha/2}+Z_\beta)^2]\div d^2 \quad (3.1)$$

where

SD = Standard deviation, 1g

$Z_a/_2$ = Z value for Type I error (1.96 for 5% significance)

Z_β = Z value for desired power (0.842 for 80% power)

d = Minimum detectable difference (1g)

Sample size, n

$= 2 \times (1)^2 \times (1.96+0.842)^2 \div (1)^2$

$= 15.7 \approx 16$ chickens

The current sample size per group of 50 is more than sufficient (3 times higher). This provides high statistical power to detect meaningful differences in growth performance. Additionally, the use of weekly repeated measurements and panel data modelling further enhances precision and reliability, making the sample size both statistically and practically robust.

In this research, a mortality rate of 6% was assumed, reflecting the anticipated loss of chickens during the production cycles. This rate was treated as a constant factor throughout the study, influencing the allocation of additional chickens to compensate for potential losses. For each production cycle, an initial count of 300 chickens was utilized, and data was collected solely for these chickens. However, to account for the expected mortality, a surplus of chickens was allocated as replacements in case of losses. Given the assumed mortality rate, an additional 6% of chickens were allocated beyond the primary count, acting as spares. These surplus chickens were not included in data collection but served as reserves to replace any chickens that died during the production cycle.

In practical terms, for every 300 chickens used per production cycle, an extra 18 chickens (3 per diet feed system) were allocated as spares. Consequently, the total number of chickens utilized per cycle was 318, with data collection focused solely on the initial 300 chickens.

By incorporating the mortality rate into the research methodology and adjusting the allocation of spare chickens accordingly, this study aimed to ensure the continuity and integrity of data collection despite potential losses during production cycles.

For Specific Objectives (2) and (3), concerning growth performance and feed efficiency, data on chicken body weight and feed quantity were collected weekly. As a result, the data consisted of 50 chickens × 6 diet feed systems × 12 weeks = 3,600 replications per production cycle. Two production cycles were conducted for this research, resulting in a total of 7,200 replications for the entire study. This data was used for chicken body weight and feed efficiency analysis.

The data replications followed a completely randomized design (CRD), with one primary factor, defined by three variables:

- k = number of factors (6 diet feed systems)
- L = number of levels / weeks (12 weeks)
- n = number of replications (50 chickens)

Thus, the total sample size is $N = k \times L \times n$.

According to Hinkelmann & Kempthorne (2007), the CRD is the simplest design, and in this research, six (6) diet feed systems were compared.

For Specific Objective (4), the profitability level was determined using the cost of input and expected revenues. The input costs included the feed cost based on the feed quantity collected from the farm for feed efficiency calculations, as well as other production costs. The expected revenues were calculated based on the final chicken body weight and the market rate per unit weight.

3.6 Research Methods

There are three dimensions under study for each of the diet feed systems to determine the best diet feed system(s) for native chicken meat production. The three dimensions under investigation are:

(1) Specific Objective (2): Feed efficiency based on different diet feed systems
(2) Specific Objective (3): Relationship between chicken weight, chicken age and diet feed systems
(3) Specific Objective (4): Profitability level using the benefit-cost ratio for chicken production based on each diet feed system

Specific Objective (2): to determine the feed efficiency of the six (6) different diet feed systems based on the cumulative voluntary feed intake (CVFI); cumulative weight gain (CWG); average daily gain (ADG) and feed conversion efficiency ratio (FCE) for the native chicken meat production.

To achieve this objective, four (4) formulas are used to calculate the cumulative voluntary feed intake (CVFI), cumulative weight gain (CWG), average daily gain (AWG) and feed conversion efficiency ratio (FCE) (Morbos et al., 2016). The four (4) formulas used at i^{th} period of measurement as follows:

(1) Cumulative voluntary feed intake (CVFI) as shown in Equation 3.2

$$\text{CVFI, g} = (\text{Total Feed Given} - \text{Feed Refused}) \div \text{Number of Birds} \qquad (3.2)$$

(2) Cumulative weight gain (CWG) as shown in Equation 3.3

$$CWG, g = BW_i - BW_0 \quad (3.3)$$

where:

BW_i= body weight of chicken at i^{th} period of measurement

BW_0 = initial body weight

(3) Average daily gain (ADG), g as shown in Equation 3.4

$$ADG, g = (\text{Final live weight} - \text{Initial Weight}) \div \text{Feeding days} \quad (3.4)$$

(4) Feed conversion efficiency ratio (FCE) as shown in Equation 3.5

$$FCE = CVFI \div BW_i - BW_0 \quad (3.5)$$

where:

CVFI = the cumulative voluntary feed intake of chicken

BW_i= body weight of chicken at i^{th} period of measurement

BW_0 = initial body weight

Based on the four formulas mentioned above, the diet feed system with the smallest FCE was determined. This concluded the most optimal and efficient diet feed system.

A one-way analysis of variance (ANOVA) was then used to compare the mean chicken body weight across the six (6) different diet feed systems, to determine if there was a statistically significant difference between them (Ross, Willson, Ross, & Willson, 2017). One-way ANOVA is particularly useful in identifying variations in outcomes caused by different treatments or conditions. In this study, the total body weight (BW) of chickens was compared across the six (6) different feed systems. The test works by assessing the variance between groups relative to the variance within groups, providing insights into whether observed differences are due to random chance or the effect of the feed systems (Okoye & Hosseini, 2024).

Specific Objective (3): to analyse the relationship among the six (6) different diet feed systems, chicken age and body weight for native chicken meat production.

To achieve this objective, the study employs two key statistical techniques: multiple regression (for preliminary analysis) and panel data analysis (for final analysis).

Before the multiple regression and panel data analysis was carried out, the unit root test was conducted using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) methods to determine whether the time series data from Cycle 1 and Cycle 2 were stationary. Stationarity is essential for reliable analysis, as non-stationary data can produce misleading statistical results.

Multiple regression analysis is a powerful statistical tool used to examine the relationships between a dependent variable and multiple independent variables. In this study, the dependent variable is chicken body weight, which is the primary focus. The independent variables include various diet feed systems and age. The cross-sectional data, i.e., different diet feed systems and chicken body weight, was analysed together with the time-series data of the chicken's age. The analysis was performed using 3,600 observations (50 chicken data x 6 diet systems) per production cycle, with a total of 7,200 observations across two production cycles. The data analysis was carried out using Eviews version 12 software. Through multiple regression analysis, the study explores how changes in the independent variables (i.e., different feed systems and age) relate to changes in chicken body weight, considering all the diet feed systems (refer to Section 3.6.3 for details on the multiple regression analysis procedure).

Panel data analysis is a robust method used to examine data that combines aspects of both cross-sectional and time-series data (Hsiao, 2007). In this study, the dataset involves observations from multiple production cycles, making it suitable for panel data analysis. Panel data analysis is particularly useful because it allows researchers to account for individual variation (such as differences among chickens) and time-related changes simultaneously. This method was applied to develop cumulative weight gain profiles for each type of diet feed system over the course of the study. These cumulative weight gain profiles provide valuable insights into the long-term effects of each diet on chicken growth and performance (refer to Section 3.6.5 for details on the panel data analysis procedure).

Specific Objective (4): to identify the profit level using the Benefit-cost ratio (BCR) of the six (6) different diet feed systems for the native chicken meat production.

This objective concerns the profitability framework for native chicken meat production. It involves an accounting or financial benefit-cost analysis of the profitability for the farmer, based on the different diet feed systems for chicken.

The analysis was conducted using data obtained from the *Bintang Maju Agri* Chicken Farm. The predicted income of the company from the sale of its native chicken after the production cycle, along with the total cost of the inputs the firm employs in production (i.e., the various diet feed systems for chicken farming), were used to determine the accounting profit for the native chicken farm. The Benefit-Cost Ratio (BCR) was used for this purpose.

The BCR is a method used to assess the advantages and disadvantages of different options, helping to identify the best approach for achieving benefits while saving costs (David, Dube, & Ngulube, 2013).

The BCR is calculated for two production cycles and compared to assess the consistency of the results. This analysis helps determine if chicken farming is financially viable. It shows the relationship between the costs and benefits of a project, which can be expressed in monetary or qualitative terms. If the BCR is 1.0 or higher, the project is expected to generate a positive profit/return for the company and its investors (Adam, 2022). The formula for BCR is per Equation 3.6 (Mankiw et al., 2022):

$$\text{Benefit-cost ratio} = \text{Total revenue} \div \text{Total Cost} \quad (3.6)$$

where

Total revenue = unit price of chicken meat per kg x weight of chicken meat

Total cost = 7 days' chicken cost + feed cost + labour + vitamin

It is recommended that farmers diversify and optimize their feed plans to meet local demand sustainably and maximize profits (Morel, Léger, & Ferguson, 2019). The goal was to compare the total costs and benefits to determine if the benefits outweigh the costs. It is logical to proceed with the project if the BCR result is greater than or equal to 1. If not, the feed technique should be reconsidered or abandoned.

BCR helps determine whether a particular feed system delivers sufficient economic return (e.g., body weight gain, feed efficiency, profit) compared to the investment in that feed (cost of ingredients, processing, etc.). In addition, when comparing six different feed systems, BCR provides a standardized metric that accounts for both performance and cost. This supports transparent and data-driven selection.

The following sections show the data analysis methods and procedures used in this study.

3.6.1 Descriptive Analysis

Descriptive statistics are applied to Specific Objectives (2), (3), and (4) to summarise and describe the characteristics of the dataset (Chattamvelli & Shanmugam, 2023). Descriptive measures generally concentrate on two key aspects: central tendency and variability (Satake, 2014). Central tendency measures (mean, median, mode) and variability measures (range, variance, standard deviation) provide insights into the distribution and spread of the data (Raykov & Marcoulides, 2012).

(1) Median: The middle value of the dataset calculated as (ML) = (n +1)/2 for the median location.

(2) Mean: The average of all values, calculated by dividing the sum of the observations by their number. It is sensitive to outliers, meaning extreme values can distort the mean.

(3) Range: The difference between the highest and lowest values in the dataset.

(4) Variance (σ^2 or s^2): Indicates the extent of variation or dispersion of the data points from the mean.

(5) Standard Deviation (s): The square root of the variance, providing a measure of spread in the same units as the data.

3.6.2 Unit Root Test

A unit root test determines whether a time series is stationary (i.e., it does not exhibit trends over time). Non-stationary data may cause inaccurate regression results, and transformations (such as differencing) can help make the series stationary.

The most common unit root tests are the Dickey-Fuller test (ADF) and Phillips-Perron test (PP), which assess the stationarity of the series. These tests compare a test statistic to critical values to assess whether the series is stationary or non-stationary based on chosen significance levels. It is represented as I(d), where d is the integration order. I(0) indicates that the data are stationary at level data; I(1) (1) indicates that the data become stationary only after first differencing (Herranz, 2017).

Interpreting the results of a unit root test involves comparing the test statistic to the critical values. A smaller test statistic than the critical value leads to rejecting the null hypothesis and confirms stationarity. The hypothesis testing for the panel unit root test is as follows:

H_0: each time series contains a unit roots (non-stationary) ($\rho = 0$)

H_A: each time series contains no unit roots (stationary) ($\rho < 0$)

3.6.3 Multiple Regression Analysis

Multiple analysis is used as the preliminary analysis for Specific Objective (3) to analyse the relationship among the six (6) different diet feed systems, chicken age and body weight for native chicken meat production. Regression analysis is a statistical method that uses an equation to explain changes in a dependent variable based on changes in one or more independent (explanatory) variables.

A regression model is acquired to explain how the values on one of the variables (the result) change as the values on the other variables (the predictors) change if a link can be established, both practically and conceptually. The outcome variable is known as the dependent variable, often represented by Y, while the predictor variables are called independent variables, typically represented by X (Gujarati & Porter, 2009).

The regression equation is shown in Equation 3.6:

$$Y_t = \beta_0 + \beta_1 X_{1\ t-1} + \beta_2 X_{2\ t-1} + \varepsilon_t \qquad (3.6)$$

where,

Y is the dependent variable; X_1 and X_2 are the independent variables; ε is the error term and β_0, $\beta_1$and β_2 are the regression coefficients; The objective is to test if the variable Y depends on X_1 and X_2. In this study, Y was the diet feed systems, the X_1 is Age and X_2 was different diet feed systems.

R Square and Adjusted R Square

The amount of variance in the dependent variable that is explained by all of the independent variables is measured by the R-Square, which is sometimes referred to as the coefficient of determination.

The R-Square and Adjusted R-Square are used to evaluate how well the model explains the variance in the dependent variable, with a higher value indicating better explanatory power.

The range of the R-square is 0 to 1. A minimum R-square value of 0.15 is a necessary norm in the social sciences. The sample size and the number of independent variables are frequently taken into account when adjusting the R-Square value in simple linear regression. This prevents a model from being overfit. The adjusted R-square is the name of the corrected value. The interpretation is identical.

3.6.4 One-way ANOVA

The One-way ANOVA tests for significant differences in means across multiple groups (in this case, chicken body weight across different feed systems). It compares group variance to within-group variance and provides an F-statistic.

The null hypothesis (H_0): no significant difference in chicken body weight across the six (6) diet feed systems.

The alternative hypothesis (H_1): at least one diet feed system produces a significantly different chicken body weight.

The test calculates an F-statistic, which compares the variance between groups to the variance within groups. A higher F-statistic indicates greater differences between group means. The significance level (α) is set at 0.05; if the p-value derived from the F-statistic is less than α, the null hypothesis is rejected, indicating that at least one group differs significantly from others (Quirk & Quirk, 2012).

The test was conducted using SPSS software. To perform one-way ANOVA using SPSS, the total body weight data for each diet feed system is entered into the software, and treatment groups are appropriately labelled. The dependent variable, i.e. total body weight for Cycle 1 and 2 and the factor variables, i.e. different diet feed systems were defined. A post-hoc test, such as Tukey's Honestly Significant Difference (HSD), is applied to identify specific group differences when the ANOVA result is significant (Nordstokke & Stelnicki, 2024). The output includes an ANOVA table showing the F-statistic and p-value, along with post-hoc comparisons that provide pairwise differences and confidence intervals.

The one-way ANOVA method is justified due to its ability to compare multiple groups simultaneously, avoiding the inflated Type I error risk associated with performing multiple t-tests. It is a powerful tool for quantifying the effect of diet systems on total body weight outcomes and provides critical insights for decision-making in the poultry industry.

3.6.5 Panel Data Analysis

Panel data analysis is used subsequently after the multiple regression analysis for Specific Objective (3). Panel data analysis, commonly referred to as longitudinal data, is a method for tracking the development of a variable or group of people through time. It combines cross-sectional and time series data. By incorporating both cross-sectional and time series dimensions, panel data delivers more useful data with greater variability.

The outcome of Specific Objective (2) provided general conclusion of which diet feed system is the most efficient and optimum to produce heaviest chicken throughout the whole production cycle. However, by using panel data analysis, time series data is included which can help to give insight to producers which period is more sensitive compared to other periods.

Additionally, panel data analysis can increase degrees of freedom and decrease collinearity between the model's variables, leading to more accurate model parameter inference by increasing the effectiveness of econometric estimations (Hsiao, 2007). Furthermore, panel data analysis tolerates the model's heterogeneity because a panel data model generally relates to persons or organizations (Gujarati & Porter, 2009). Panel data can regulate the effect of missing variables in a model since it provides information on both intertemporal dynamics. Furthermore, the entities' individuality can regulate the influence of unseen variables.

Panel data model results would be expressed in the Equation 3.7 below:

$$\text{Body Weight}_{ti} = C + \beta_1 \text{Feed}_{ti} \qquad (3.7)$$

The following sections show the procedures for carrying out the panel data analysis.

Panel Model Selection

Panel models can be broadly classified into three categories: Fixed Effect Model (FEM), Random Effect Model (REM) and Pooled Ordinary Least Square (POLS).

Ordinary Least Square (OLS) was preferred if the individual impact was not there because it may produce dependable and accurate parameter estimations. The presence of individual impacts can determine whether they are random or fixed. A FEM model looks into whether intercepts differ between groups or time periods, whereas a REM looks into variations in error variance components between individuals or time periods.

In essence, POLS provides a straightforward generic regression by pooling all the observations. If OLS assumed that there was no individual effect, it would produce a reliable and efficient result. However, in the case of individual effects, FEM or REM may be present (Gujarati & Porter, 2009). Finally, the Hausman test result indicates that the null hypothesis is rejected if the p-value is less than the $\alpha = 0.05$ level, leading to the conclusion that a FEM is better in this situation (refer to

below).

Table 3.1: Panel Model Selection

Tests	**Hypothesis**	**P-value**	**Conclusion**
Redundant Fixed Effect Test	H_0 = POLS is preferable H_A = FEM is preferable	$0.000 < \alpha = 0.05$	Reject H_0 = FEM is preferable.
Breusch-Pagan LM Test	H_0 = POLS is preferable H_A = REM is preferable	$0.000 < \alpha = 0.05$	Reject H_0 = REM is preferable.
Hausman Test	H_0 = REM is preferable H_A = FEM is preferable	$0.000 < \alpha = 0.05$	Reject H_0 = FEM is preferable.

Source: Gujarati and Porter, 2009

Model Evaluation

When models are ready, it needs to be evaluated to make sure the presented model is the best model. The followings show the criteria for best model (Gujarati & Porter, 2009):

(1) The first requirement is theoretical consistency, meaning the signs of the estimators (positive or negative) should align with the theory.
(2) The second is that the independent variables should not be correlated with the error term.
(3) The third is that the estimated parameters should be stable and consistent.
(4) The fourth is that the residuals should be random and constant over time.
(5) The fifth is that the model should be complete and capable of explaining the results.
(6) Finally, the sixth is that the model must be logically feasible.

There are four (4) criteria to select the best model (Gujarati & Porter, 2009).

(1) The R^2 Criterion: A higher R-squared value indicates that the independent variables account for a greater proportion of the variation in the dependent variable.
(2) The Adjusted R^2 Criterion: The R^2 value may conflict with parsimony. In this case, the adjusted R-squared value is used.
(3) Akaike's Information Criterion (AIC): The model with the lower value of AIC is preferred. Value is to be taken from Eview software.

(4) Schwarz's Information Criterion (SIC): The model with the lower value of SIC is preferred. Value is to be taken from Eview software.

The Root Mean Square Error (RMSE)

Regression analysis, climatology and prediction all employ the Root Mean Square Error (RMSE) to verify experimental findings. The standard deviation of the residual, or RMSE, is a measurement of a regression line data point's distance. An effective way to gauge how well the model predicts the reaction is to look at the RMSE. The data's concentration in relation to the line of best fit is displayed (Gujarati & Porter, 2009). Lower values of RMSE indicate better fit. The lower the RMSE, the better a model is able to "fit" a dataset. Hence, this measure was used to select the best model. The formula of RMSE is shown in Equation 3.7:

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}i - yi)2}{n}} \tag{3.7}$$

where

$\hat{y}_i$ = predicted value

y_i = observed value

n = number of observations

Mean Absolute Error (MAE)

The statistical measure known as Mean Absolute Error (MAE) evaluates the accuracy of continuous variables without considering their direction. The mean absolute error (MAE) is calculated by averaging the absolute values of the deviations between the relevant observation and the forecast across the verification sample. Since the MAE is a linear score, each individual difference is given the same weight in the average (Gujarati & Porter, 2009).

The lower the MAE score the better as we want to minimize the value of the average error between the predictions and intended targets. Hence, a model with a lower MAE score is preferred and selected. The formula of MAE is shown in Equation 3.8:

$$\text{MAE} = \frac{|(\hat{y}i - yi)|}{n} \quad (3.8)$$

where

$\hat{y}_i$ = predicted value

y_i = observed value

n = number of observations

Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error (MAPE) is the average of all absolute percentage errors, which is the difference between the actual and predicted values. It adds the percentage errors together, ignoring the sign. Since the errors are expressed as percentages, MAPE is easy to understand and avoids the issue of positive and negative errors cancelling each other out. This makes it a popular forecasting metric in management, where a lower MAPE indicates a more accurate forecast. A model with lower MAPE was selected. The following is as per Equation 3.9:

$$\text{MAPE} = \frac{\sum_{\mathbf{i=0}}^{\mathbf{n}} (|\hat{y}i \quad - yi|) * \mathbf{100}}{n} \tag{3.9}$$

where

$\hat{y}_i$ = predicted value

y_i = observed value

n = number of observations

U-Theil Statistics

Theil's Inequality Coefficient, or U-Theil Statistics, is a metric for inequality. It displays the degree to which a time series of observed values and an estimated value time series agree. U-Theil Statistics is used to calculate the model's fitness, and its range is 0 to 1. A fitted model is better if the result is around zero. The model with the best and least values was selected. The formula of U-Theil Criteria is as per Equation 3.10:

$$\text{U-Theil Criteria} = \frac{\sqrt{\frac{\sum(\hat{y}i - yi)2}{n}}}{\sqrt{\frac{\sum(\hat{y}i)2}{n}} + \sqrt{\frac{\sum(yi)2}{n}}} \tag{3.10}$$

where

$\hat{y}_i$ = predicted value

y_i = observed value

n = number of observations

3.6.6 Residual Analysis

Residual analysis involves evaluating the residuals (the differences between observed and predicted values) through graphical methods to check the assumptions of the data model. This process helps determine if the model effectively captures the underlying patterns and if any issues, such as heteroscedasticity or outliers, are present. Below are the steps to conduct residual analysis for panel data using graphical techniques:

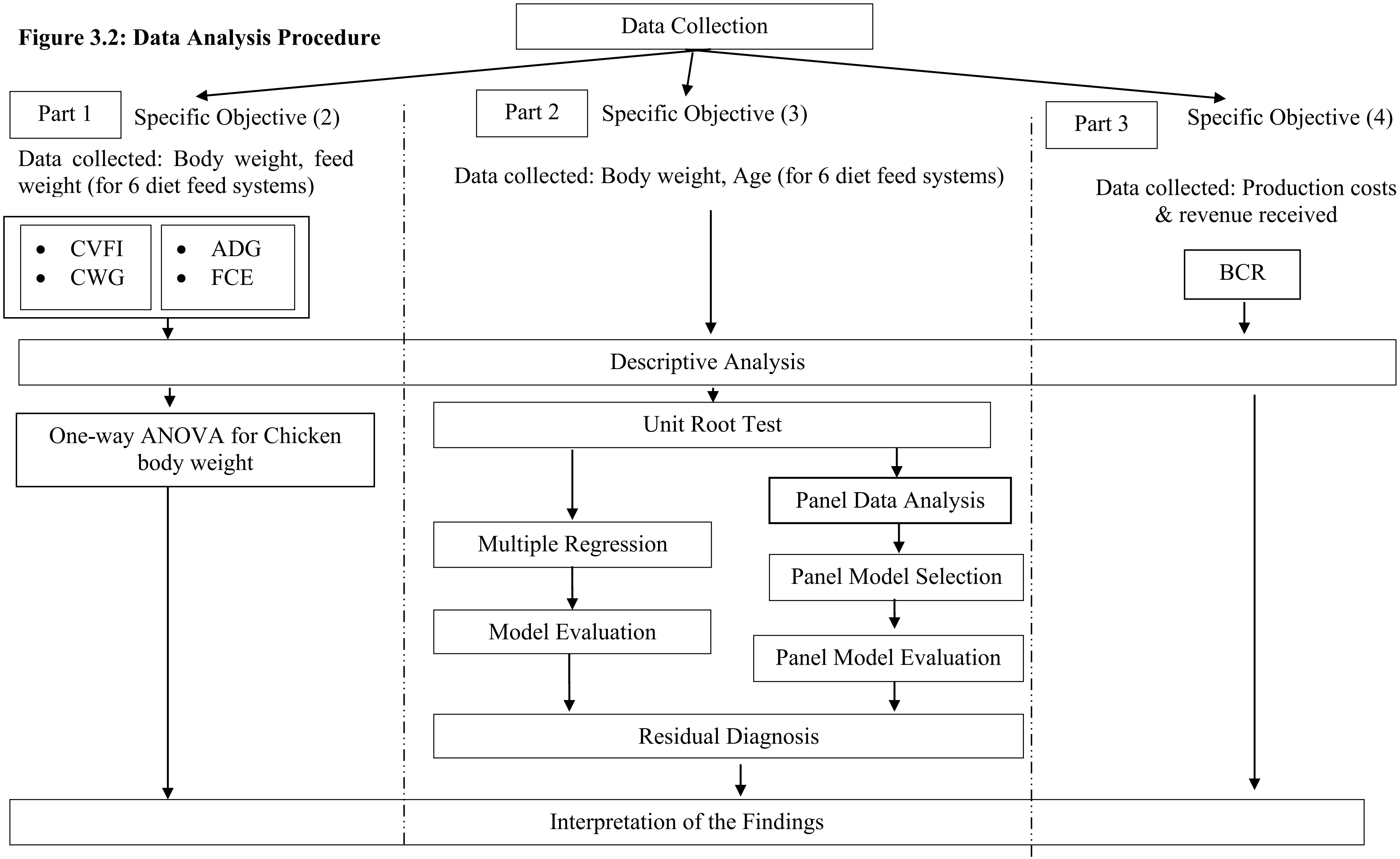
1) Obtain Residuals: Begin by collecting the residuals from the panel data regression model. These represent the differences between the observed data points and the predicted values from the model.
2) Plot Residuals vs. Fitted Values: Create a scatter plot of the residuals against the fitted values (predicted values) from the model. This plot is known as a "Residuals vs. Fitted" plot. It helps to check for heteroscedasticity, which occurs when the spread of residuals varies across different levels of the independent variables. In the plot, if there is any funnel-like or cone-shaped patterns, this would indicate heteroscedasticity. Step 1 and 2 can be done through E-view.

If any issues are detected during the residual analysis, the data model needs to be adjusted by adding or removing variables, transforming variables, or considering alternative model specifications.

3.7 Data Analysis

After data collection for 84 days per cycle, the data analysis was done in three (3) parts according to three (3) Specific Objectives, Specific Objective (2), (3) and (4). The data analysis procedures are shown in Figure 3.2:

Figure 3.2: Data Analysis Procedure



Source: Own Development

3.8 Conclusion

The six (6) diet system were described in Chapter 2 prior to the field data collection to determine the six (6) different diet systems. Subsequent three (3) parts are carried out based on three (3) Specific Objectives.

Descriptive analysis was used to find out the basic data results, i.e. mean, standard deviation, etc. for the three (3) Specific Objectives.

Next, Specific Objective (2) is fulfilled using the four (4) formulas, i.e. CVFI, CWG, ADG and FCE with one-way ANOVA test to provide insights into whether the observed differences in chicken body weight are due to random chance or the effect of the diet feed systems. Specific Objective (3) is achieved using correlation analysis to check (1) whether there is any relationship among the diet feed systems and the chicken body weight (2) type of relationship among the diet feed systems and the chicken body weight (3) strength of relationship among the diet feed systems and the chicken body weight. Panel data analysis was used to carry out in-depth analysis on the time series data (chicken age) and the cross-sectional data (chicken body weight) for more meaningful output to test the relationship among the diet feed system, chicken body weight and the chicken age. Specific Objective (4) is achieved using the benefit-cost ratio (BCR) analysis based on production cost and expected revenue.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction

This chapter presents the major findings regarding the feed efficiency of six different diet feed systems, denoted as F1, F2, F3, F4, F5, and F6.

The analyses included in this chapter encompass descriptive analysis, feed efficiency analysis using four formulas with one way ANOVA as mentioned in Chapter 3, multiple regression analysis, panel data model analysis and benefit-cost analysis. Subsequently, hypothesis testing is conducted, leading to the chapter's conclusion.

4.2 Descriptive Analysis

Descriptive analysis helps in understanding the key features of a dataset by providing a summary of its sample size and characteristics. It achieves this through measures of central tendency, such as the mean and median, and measures of variability, including standard deviation, variance, and the minimum and maximum values. The standard deviation shows how data points vary around the mean. Table 4.1 and Table 4.2 below present the descriptive statistics for chicken body weight, age and the various diet feed systems in Cycles 1 and 2. Cycle 1 ran from 7 January 2022 to 8 April 2022, while the Cycle 2 took place from 14 August 2022 to 27 November 2022.

Table 4.1: Descriptive Statistics of Chicken Body Weight, Age and Different Diet Feed Systems (Cycle 1 Data)

	Body Weight (kg)	**Age (days)**	**F1 to F6**
Mean	1.0844	46	0.1667
Median	0.9500	46	0.00
Maximum	2.4700	84	1.00
Minimum	0.0840	7	0.00
Standard Deviation	0.7619	24.1677	0.3727
Observation	3600	3600	3600

Source: Eviews Output

Note: F1, F2, F3, F4, F5 and F6 denote six (6) different diet feed systems and when 1 diet feed system, e.g., F1 is "1", other diet feed systems are "0".

Table 4.2: Descriptive Statistics of Chicken Body Weight, Age and Different Diet Feed Systems (Cycle 2 Data)

	Body Weight (kg)	**Age (days)**	**F1 to F6**
Mean	1.0585	46	0.1667
Median	0.9700	46	0.00
Maximum	2.4300	84	1.00
Minimum	0.0780	7	0.00
Standard Deviation	0.7498	24.1677	0.3727
Observation	3600	3600	3600

Source: Eviews Output

For Cycle 1 and 2, there were 3,600 observations in each cycle (6 different types of diet systems x 12 weeks x 50 chicken = 3,600 observations), comprises of time-series data.

For age, the study was carried for total of 12 weeks, i.e. 84 days. The mean and median values for age for both cycles are the same, i.e. 46 days. The maximum and minimum value of age is 84 days (12 weeks x 7 days) and 7 days (1 week x 7 days), respectively.

For different diet feed systems, the maximum value is 1 while the minimum value is 0. The mean value for all the diet feed systems, i.e. diet feed system 1 (F1), diet feed system 2 (F2), diet feed system 3 (F3) and diet feed system 4 (F4) is 0.1667 ± 0.3727 and for the median, the value is 0.

For the average chicken body weight, based on Table 4.1 above the Cycle 1 results indicate that the average chicken body weight is 1.0844 ± 0.7619kg. The median shows that the middle value of body weight is around 0.9500kg. The maximum and minimum value of body weight is 2.47kg and 0.084kg, respectively.

Based on Table 4.2 above, the Cycle 2 results indicate that the average chicken body weight is 1.0585± 0.7498kg. The median shows that the middle value of body weight is around 0.9700. The maximum and minimum value of body weight is 2.43kg and 0.078kg, respectively.

In conclusion, the descriptive statistics for both Cycle 1 and Cycle 2 provide key insights into the body weight, age, and diet feed systems of chickens.

(1) Body Weight: The average body weight for both cycles (1.0844 kg in Cycle 1 and 1.0585 kg in Cycle 2) indicates that the chickens' weight is relatively consistent between the two cycles, with a moderate standard deviation showing some variation in individual weights. The median body weights (around 0.95 kg and 0.97 kg) are lower than the mean, suggesting that a larger proportion of chickens had lower body weights.
(2) Age: The minimum and maximum values for age (7 days and 84 days) reflect the study's time frame and range of observations.
(3) Diet Feed Systems: The diet feed systems (F1 to F6) each had a mean of 0.1667, with a standard deviation of 0.3727, indicating that each of the feed systems was used for approximately 16.67% of the observations in both cycles.

4.3 Feed Efficiency of Six (6) Diet Feed Systems

Feed represents a significant portion of the production costs in the chicken meat industry. Feed efficiency hence is a critical metric in the chicken meat industry as it affects the profitability.

It refers to the ability of chickens raised for meat production; to convert the feed they consume into body weight or product output efficiently. In simple terms, it measures how effectively chickens turn their food into meat.

It is determined based on several factors, including cumulative voluntary feed intake (CVFI), cumulative weight gain (CWG), average daily gain (AVG) and the feed conversion efficiency ratio (FCE) for native chicken meat production. Chapter 3 discusses four different formulas related to these factors.

CVFI measures the total weight of feed consumed over a 12-week period. Table 4.3 and Table 4.4 below display the feed weight used by a single chick. To determine the average feed weight per chick, we measured the total weight of feed for 50 chickens on a weekly basis and then divided this total by the number of chickens, which is 50.

As depicted in Table 4.3 and Table 4.4 below, the CVFI steadily increased over the 12-week period, suggesting that feed consumption aligns with the chickens' growth and energy needs.

Table 4.3: Cumulative Voluntary Feed Intake, g (CVFI) for 1 Chick Fed with Six (6) Diet Feed Systems (Cycle 1)

Diet Feed System	Week												Total	Rank
	1	**2**	**1**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		
F1	175	245	345	450	525	575	620	660	700	715	730	735	6475	6
F2	175	240	340	450	525	570	615	655	695	710	720	730	6425	4
F3	180	240	340	445	525	575	615	660	695	710	725	730	6440	5
F4	170	240	340	445	520	570	615	655	700	710	725	730	6420	3
F5	155	220	320	415	485	535	585	615	645	665	675	685	6000	1
F6	160	225	325	415	490	555	605	645	675	700	715	720	6230	2
Average	**169.2**	**235.0**	**335.0**	**436.7**	**511.7**	**563.3**	**609.2**	**648.3**	**685.0**	**701.7**	**715.0**	**721.7**	**6331.7**	

Note: the feed intake shown above represents the average feed intake for each treatment for 50 chicken samples.

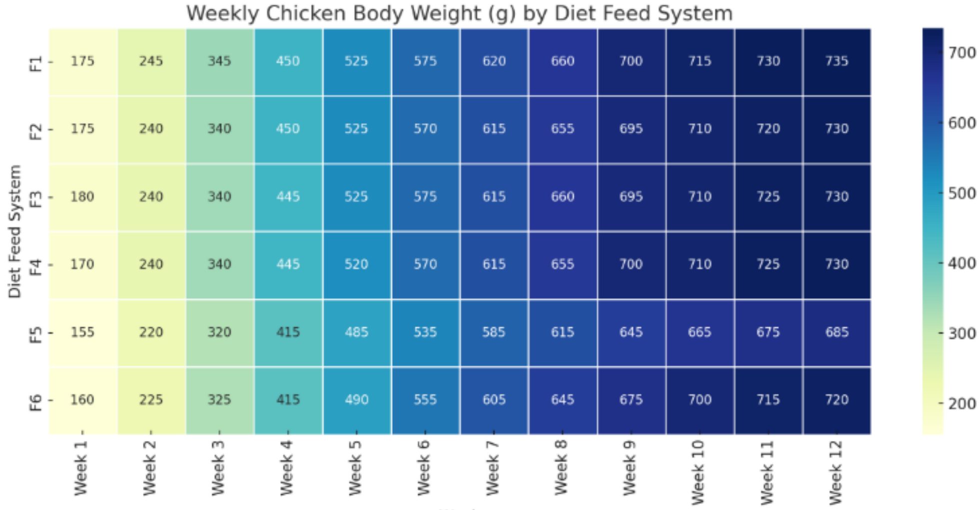
Source: Own Analysis

Table 4.4: Cumulative Voluntary Feed Intake, g (CVFI) for 1 Chick Fed with Six (6) Diet Feed Systems (Cycle 2)

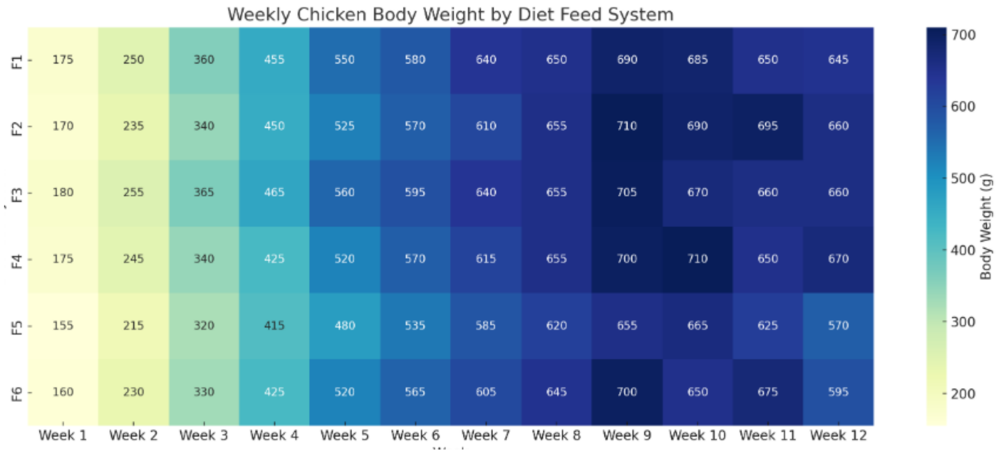
Diet Feed System	Week												Total	Rank
	1	2	3	4	5	6	7	8	9	10	11	12		
F1	175	250	360	455	550	580	640	650	690	685	650	645	6330	5
F2	170	235	340	450	525	570	610	655	710	690	695	660	6310	4
F3	180	255	365	465	560	595	640	655	705	670	660	660	6410	6
F4	175	245	340	425	520	570	615	655	700	710	650	670	6275	3
F5	155	215	320	415	480	535	585	620	655	665	625	570	5840	1
F6	160	230	330	425	520	565	605	645	700	650	675	595	6100	2
Average	**169.2**	**238.3**	**342.5**	**439.2**	**525.8**	**569.2**	**615.8**	**646.7**	**693.3**	**678.3**	**659.2**	**633.3**	**6210.8**	

Note: the feed intake shown above represents the average feed intake for each treatment for 50 chicken samples.

Source: Own Analysis



Heat Map for Table 4.3



Heat Map for Table 4.4

Based on Table 4.3 and Table 4.4 above, the average feed weight for a 12-week cycle in both Cycle 1 and Cycle 2 is 6.332 kg and 6.211 kg, respectively. Notably, the diet feed system 5 (Organic Acid) displayed the lowest feed consumption, requiring only 6 kg and 5.840 kg for Cycle 1 and 2, respectively. Diet feed system 6 (Yellow Pigment) displayed the second lowest feed consumption, requiring only 6.23 kg and 6.1 kg for Cycle 1 and 2, respectively.

In Cycle 1, diet feed system 1 (Control Feed) had the highest feed consumption for a 12-week period, totaling 6.475 kg. Conversely, in Cycle 2, diet feed system 3 (Black Soldier Fly) exhibited the highest feed consumption over 12 weeks, amounting to 6.410 kg.

Across both cycles, diet feed systems 5 and 6 required less feed weight than the average feed weight. On the other hand, diet feed systems 1, 2, 3 and 4 necessitated more feed than the average feed weight.

Figure 4.1 below depicts the cumulative voluntary feed intake (CVFI) over 12 weeks across the diet feed systems. It illustrates a steady increase in feed consumption as the weeks progress, with the CVFI mean rising rapidly from Week 1 to Week 7, where it starts to plateau. This trend suggests that the chickens' feed consumption aligns with their growth and energy requirements, which typically increase during earlier growth phases and stabilize as they approach maturity. The plateau observed after Week 8 indicates a stabilization in feed intake, possibly reflecting reduced growth rates or the chickens reaching their peak feed efficiency. This data is essential in evaluating the efficiency of diet feed systems, as higher CVFI values could indicate better feed palatability or energy content, directly influencing body weight and overall productivity.

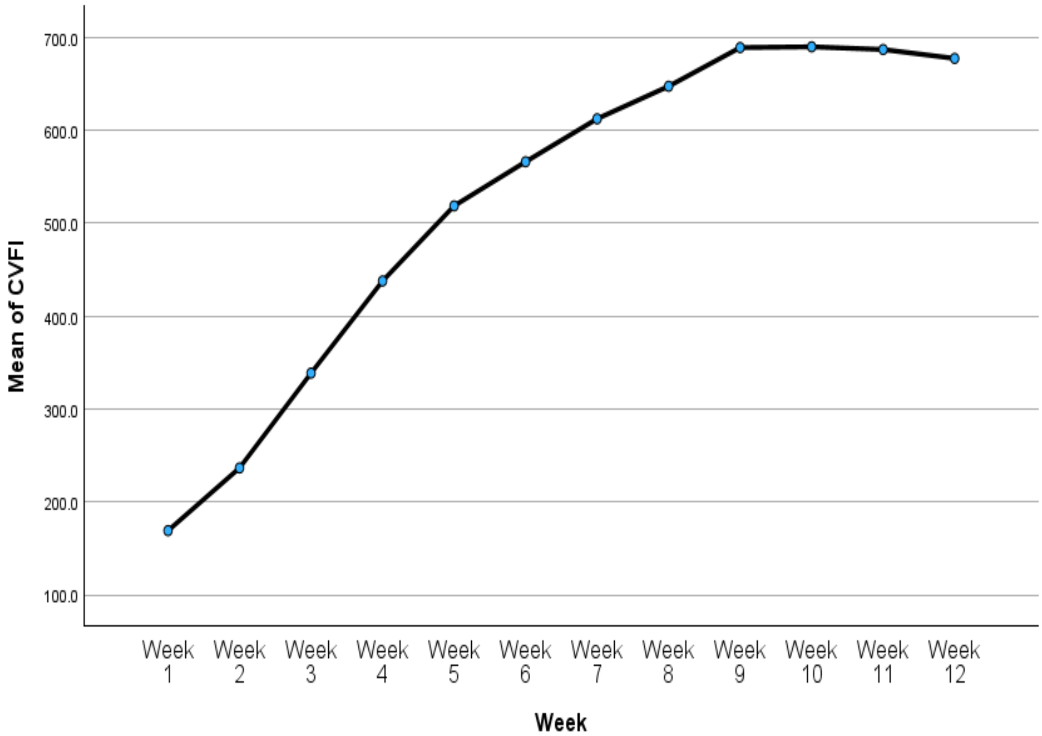


Figure 4.1: Mean of CVFI for all diet feed systems across 12 weeks

Source: Own analysis

CWG measures the total weight increase in body weight of the chickens over a 12-week period. Table 4.5 and Table 4.6below display the total weight gain by a single chick. To determine the total weight gain per chick, we measured the total weight of gain for 50 chickens on a weekly basis and then divided this total by the number of chickens, which is 50.

Table 4.5: Average Cumulative Weight Gain, g (CWG) for 1 Chick Fed with Six (6) Diet Feed Systems (Cycle 1)

Diet Feed System	**Week**												**Total (W1 – 12)**	**Rank**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**		
F1	90.8	108.4	105.2	117.2	167.2	265.2	230.0	304.4	256.0	225.6	232.0	263.0	2365.0	5
F2	90.6	85.4	112.8	145.5	162.1	270.0	236.0	307.0	249.2	235.8	240.0	268.2	2402.6	3
F3	93.0	97.8	106.8	158.8	141.6	172.0	251.0	289.6	254.4	223.2	209.2	226.8	2224.2	6
F4	88.8	96.8	95.2	158.4	181.2	237.6	216.0	352.4	237.6	244.0	198.0	270.6	2376.6	4
F5	90.2	105.0	96.0	147.6	153.6	287.8	259.2	324.8	277.2	160.8	242.8	285.0	2430.0	2
F6	89.8	110.6	88.8	123.6	193.6	283.8	264.2	332.2	256.0	198.2	243.6	277.6	2462.0	1
Average	**90.5**	**100.7**	**100.8**	**141.9**	**166.6**	**252.7**	**242.7**	**318.4**	**255.1**	**214.6**	**227.6**	**265.2**	**2376.7**	

Please take note that the weight growth total shown above is for 50 chicken samples per treatment.

Source: Own Analysis

Table 4.6: Average Cumulative Weight Gain, g (CWG) for 1 Chick Fed with Six (6) Diet Feed Systems (Cycle 2)

Diet Feed System	Week												Total (W1 – 12)	Rank
	1	2	3	4	5	6	7	8	9	10	11	12		
F1	80.0	102.8	90.0	135.0	143.6	275.0	275.8	267.8	254.0	223.7	192.3	270.1	2310.1	5
F2	81.6	103.2	92.0	135.0	145.0	279.0	278.0	270.8	276.0	225.0	195.0	271.4	2352.0	3
F3	85.2	98.0	90.0	120.0	140.4	259.9	274.8	212.4	253.4	222.8	188.7	260.8	2206.4	6
F4	85.2	102.4	82.8	137.0	144.0	278.8	277.4	270.1	254.0	227.0	193.2	273.0	2324.9	4
F5	83.2	102.8	90.4	138.0	154.4	279.9	282.6	270.9	254.0	228.5	196.3	279.0	2360.0	2
F6	81.2	108.4	89.2	140.0	165.2	281.3	283.2	278.4	264.4	230.4	199.6	286.8	2408.1	1
Average	**82.7**	**102.9**	**89.1**	**134.2**	**148.8**	**275.7**	**278.6**	**261.7**	**259.3**	**226.2**	**194.2**	**273.5**	**2326.9**	

Please take note that the weight growth total shown above is for 50 chicken samples per treatment.

Source: Own Analysis

Based on Table 4.5 and Table 4.6 above, the average total chicken weight for a 12-week cycle in Cycle 1 and 2 is 2.377kg and 2.327 kg, respectively. In both Cycle 1 and Cycle 2, chickens fed with diet feed systems 2 (*Pokok Ketum Ayam*), 5 (Organic Acid), and 6 (Yellow Pigment) had higher weights than the average chicken weight, while diet feed system 4 (Crude Palm Kernel Oil) produced chickens with weights close to the average. On the other hand, chickens fed with diet feed systems 1 (Control Feed) and 3 (Black Soldier Fly) had lower weights than the average chicken weight.

Table 4.7: ANOVA Results Chicken Body Weight Data Across Different Diet Feed Systems for Cycle 1 and Cycle 2

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Cycle 1					
Between Group	4374.000	5	874.800	12.893	0.001< α 0.01
Within Group	4478.000	66	67.848		
	8852.000	71			
Cycle 2					
Between Group	4233.667	5	846.733	13.465	0.001< α 0.01
Within Group	4150.333	66	62.884		
	8384.000	71			

Source: SSPN Output

In ANOVA (Analysis of Variance), “between-group” and “within-group” refer to the two sources of variability that are compared to determine whether there are statistically significant differences among group means:

a) Between-group variation: This measures how much the group means differ from the overall mean. It reflects the variation caused by the treatment (e.g., different diet feed systems). If the group means are very different, the between-group variation will be large.

b) Within-group variation: This measures how much the individual data points within each group differ from their own group mean. It reflects random variation or error not explained by the treatment. If individuals within each group vary a lot, the within-group variation will be large.

Based on the Table 4.7 above, the one-way ANOVA for both Cycle 1 and Cycle 2 reveals a statistically significant effect of diet feed systems on total chicken body weight, underscoring the pivotal role that feed selection plays in growth outcomes. With F-statistics of 12.893 for Cycle 1 and 13.465 for Cycle 2, coupled with p-values less than $\alpha = 0.01$, the analysis confirms that at least one diet feed system resulted in a significantly different impact on body weight compared to the others. These findings strongly emphasise the critical importance of selecting the right feed to optimise growth performance in poultry.

Table 4.8: Post-hoc (Tukey's HSD) Pairwise Comparisons for Cycle 1

Feed (I)	Feed (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval
F1	F2	-1.33333	3.36275	0.999	-11.2033 to 8.5367
F1	**F3**	-11.50000*	3.36275	**0.013**	-21.3700 to -1.6300
F1	**F4**	-15.00000*	3.36275	**0.000**	-24.8700 to -5.1300
F1	**F5**	-17.83333*	3.36275	**0.000**	-27.7033 to -7.9633
F1	**F6**	-20.33333*	3.36275	**0.000**	-30.2033 to -10.4633
F2	**F3**	-10.16667*	3.36275	**0.040**	-20.0367 to -0.2967
F2	**F4**	-13.66667*	3.36275	**0.002**	-23.5367 to -3.7967
F2	**F5**	-16.50000*	3.36275	**0.000**	-26.3700 to -6.6300
F2	**F6**	-19.00000*	3.36275	**0.000**	-28.8700 to -9.1300
F3	F4	-3.50000	3.36275	0.902	-13.3700 to 6.3700
F3	F5	-6.33333	3.36275	0.421	-16.2033 to 3.5367
F3	F6	-8.83333	3.36275	0.105	-18.7033 to 1.0367
F4	F5	-2.83333	3.36275	0.958	-12.7033 to 7.0367
F4	F6	-5.33333	3.36275	0.611	-15.2033 to 4.5367
F5	F6	-2.50000	3.36275	0.976	-12.3700 to 7.3700

Source: SPSS Output

Table 4.9: Post-hoc (Tukey's HSD) Pairwise Comparisons for Cycle 2

Feed (I)	Feed (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval
F1	F2	-1.08333	3.23738	.999	-10.59 to 8.42
F1	**F3**	-12.00000*	3.23738	**.006**	-21.50 to -2.50
F1	**F4**	-14.75000*	3.23738	**.000**	-24.25 to -5.25
F1	**F5**	-17.25000*	3.23738	**.000**	-26.75 to -7.75
F1	**F6**	-19.91667*	3.23738	**.000**	-29.42 to -10.41
F2	**F3**	-10.91667*	3.23738	**.015**	-20.42 to -1.41
F2	**F4**	-13.66667*	3.23738	**.001**	-23.17 to -4.16
F2	**F5**	-16.16667*	3.23738	**.000**	-25.67 to -6.66
F2	**F6**	-18.83333*	3.23738	.000	-28.34 to -9.33
F3	F4	-2.75000	3.23738	.957	-12.25 to 6.75
F3	F5	-5.25000	3.23738	.587	-14.75 to 4.25
F3	F6	-7.91667	3.23738	.156	-17.42 to 1.58
F4	F5	-2.50000	3.23738	.971	-12.00 to 7.00
F4	F6	-5.16667	3.23738	.604	-14.67 to 4.34
F5	F6	-2.66667	3.23738	.962	-12.17 to 6.83

Source: SPSS Output

Table 4.8 and Table 4.9 above present the results of the post-hoc analysis using Tukey's HSD, which reveal important insights into the relative performance of the diet feed systems. The analysis demonstrates that diet feed system 6 consistently yields the highest body weight in both Cycle 1 and Cycle 2, significantly outperforming the other systems (with mean differences of 20.33 in Cycle 1 and 19.92 in Cycle 2, p-values less than $\alpha = 0.01$). The bold black highlights in Table 4.8 and Table 4.9 indicate the 8 pairs of diet feed systems that show statistically significant differences in body weight at both the $\alpha = 0.01$ and $\alpha = 0.05$ significance levels.

In contrast, diet feed systems 1 and 2 show no significant difference in performance in either cycle (with p-values of 0.999, exceeding $\alpha = 0.01$), suggesting their comparable but less effective role in promoting growth. Diet feed system 3 performs moderately better than systems 1 and 2 but still falls short of the results observed with diet feed system 6. Diet feed systems 4 and 5 demonstrate intermediate effectiveness, outperforming systems 1 and 2, but are still behind diet feed system 6 in terms of promoting optimal growth.

Overall, the findings strongly position diet feed system 6 as the most effective option for enhancing chicken growth, while diet feed systems 1 and 2 emerge as the least effective choices in this study.

Table 4.10: ADG and FCE for 1 Chick Fed for Six (6) Diet Feed Systems (Cycle 1 and Cycle 2)

Diet Feed System	Average Daily Gain, g for 1 Chick		Feed Conversion Efficiency	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2
F1	28.155	27.501	2.738	2.740
F2	28.602	28.000	2.674	2.683
F3	26.479	26.267	2.895	2.905
F4	28.293	27.677	2.701	2.699
F5	28.929	28.095	2.469	2.475
F6	29.310	28.668	2.530	2.533

Source: Own Analysis

Based on Table 4.10 above for both Cycle 1 and Cycle 2, diet feed system 6 (Yellow Pigment) resulted in the highest chicken weight, with daily weight gains of 29.31 g in Cycle 1 and 28.67 g in Cycle 2. In contrast, diet feed system 3 (Black Soldier Fly) produced the lowest chicken weight over the 12-week periods, with daily weight gains of 26.479 g in Cycle 1 and 26.267 g in Cycle 2.

Regarding feed efficiency, the results remained consistent across both cycles. Diet feed systems 5 (Organic Acid) and 6 (Yellow Pigment) were identified as the most efficient, outperforming the other systems. Additionally, diet feed systems 2 (*Pokok Ketum Ayam*), 4 (Crude Palm Kernel Oil), 5 (Organic Acid), and 6 (Yellow Pigment) showed greater efficiency compared to diet feed system 1 (Control Feed). However, diet feed system 3 was found to be less efficient than diet feed system 1.

Based on these findings, the Specific Objectives (1) and (2) of this study were successfully achieved: (1) describing the different diet feed systems for native chicken meat production, and (2) determining the feed efficiency of the six diet feed systems based on cumulative voluntary feed intake (CVFI), cumulative weight gain (CWG), average daily gain (AVG), and feed conversion efficiency ratio (FCE).

The next phase, Specific Objective (3), aimed at analysing the relationship among the six diet feed systems, chicken age, and body weight for native chicken meat production, was achieved through the use of unit-root testing, multiple regression analysis, panel data analysis and model evaluation.

4.4 Unit Root Test

A unit root test is a statistical procedure used to assess whether a time series dataset is stationary or non-stationary. Stationary data maintains consistent statistical properties, such as mean and variance, over time, simplifying analysis and modelling. In contrast, the presence of a unit root indicates non-stationarity, meaning the data follows a random trend and does not revert to a fixed mean (Herranz, 2017).

Table 4.11 below presents the results of the Dickey-Fuller test (ADF) and Phillips-Perron (PP) test, which were conducted to assess the stationarity of the data from Cycle 1 and Cycle 2.

Table 4.11: Unit Root Tests Results for Data of Cycle 1 and Cycle 2

Item	Dickey-Fuller test (ADF) - T-statistics				Phillips-Perron (PP) test - T-statistics			
	Cycle 1		Cycle 2		Cycle 1		Cycle 2	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
Body Weight	-0.0866 ns	-51.1419***	-0.0805 ns	-51.0456***	-0.0186 ns	-77.0872***	-0.0789 ns	-76.0656***
Age	-0.4796 ns	-60.1568***	-0.4485 ns	-60.1105***	-0.4753 ns	-60.1533***	-0.4453 ns	-60.0023***
F1	-6.6589***	-59.9674***	-6.5864***	-59.5467***	-7.0439***	-59.9674***	-7.0123***	-59.5421***
F2	-6.6099***	-59.9667***	-6.5678***	-59.5407***	-7.0259***	-59.9667***	-7.0113***	-59.5411***
F3	-6.6099***	-59.9667***	-6.5678***	-59.5407***	-7.0439***	-59.9667***	-7.0123***	-59.5411***
F4	-6.6099***	-59.9667***	-6.5864***	-59.5467***	-7.0439***	-59.9667***	-7.0123***	-59.5411***
F5	-6.2836***	-59.9674***	-6.4864***	-59.9674***	-6.6784***	-59.9674***	-6.6134***	59.5421***
F6	-6.6099***	-59.9667***	-6.5678***	-59.5407***	-7.0439***	-59.9667***	-7.0123***	-59.5411***

Note: *p-value ≤ 0.10; **p-value ≤ 0.05; ***p-value ≤ 0.01; ns = not significant (p-value > 0.1)

Source: Eview Output

Based on results in Table 4.11 above, it is evident that most of the data are stationary at the level, as indicated by the significant results (p-value ≤ 0.01). Therefore, level data is utilised for the subsequent multiple regression and panel data analysis. This approach is advantageous as stationary variables exhibit stability and consistency, which simplifies interpretation and modelling. By using level data directly, we preserve the original scale and interpretation of the variables, avoiding potential issues associated with differencing, such as the loss of information and complications in interpretation. Furthermore, employing level data streamlines the analysis process and reduces the need for additional transformations or adjustments to achieve stationarity, ensuring a more straightforward and robust model.

4.5 Multiple Regression Analysis

Before panel data analysis, this study uses multiple regression analysis as a preliminary analysis to evaluate the link between the independent variables — age and different diet feed systems — and the dependent variable, which is the chicken's body weight. This analysis considers all diet feed systems and measures the relationship between changes in the independent variables and changes in the body weight of the chicken.

Age and various diet feed systems are the independent variables. The analysis's primary goal is to comprehend the variables that affect chicken body weight, with a focus on the bird's weight. Age is included as one variable to account for its potential influence on chicken body weight over time, allowing for a more precise evaluation of the impact of the various diet feed systems.

To effectively account for the presence or absence of specific diet feed systems, the study utilizes dummy variables. These binary indicators take the value of 1 when a particular diet feed system is in use and 0 when it is not. This approach allows for the isolation and assessment of the individual impact of each diet feed system on chicken body weight relative to all other diet feed systems, enhancing the precision of the analysis. In this study, six (6) models are generated based on each diet system to eliminate the issue of multicollinearity among the diet feed system variables. Each model provides insights into how a specific diet feed system affects chicken body weight.

Eviews 12, a software tool, was employed for the multiple regression analysis, offering the necessary tools and functions to conduct the analysis and evaluate the significance and strength of variable relationships. The analysis was conducted using a dataset containing 3600 data points per cycle. Each data point represents individual chickens or measurements taken at different time intervals, ensuring that statistically sound conclusions can be drawn regarding the influence of diet feed systems and age on chicken body weight.

Table 4.12 and Table 4.13 below shows the six (6) Diet Systems Formula to derive the chicken body weight in the form of equation below:

$$\text{Body Weight}_t = C + \beta_1 \text{Age}_{t-1} + \beta_2 \text{Feed}_{t-1} \quad (4.1)$$

Table 4.12: Preliminary Analysis for Multiple Regression of Six (6) Diet Systems for Cycle 1

Description	F1	F2	F3	F4	F5	F6
$\beta_1 Age_{t-1}$	+0.0312	+0.0307	+0.0312	+0.0312	+0.0312	+0.0312
t-stat	[6.6081]***	[4.8350]***	[18.0618]***	[6.384]***	[8.4118]***	[11.0112]***
$\beta_2 Feed_{t-1}$	- 0.010	+ 0.0123	- 0.07	+ 0.0015	+0.0297	+0.0447
t-stat	[-2.0148]**	[2.5087]**	[14.4842]***	[0.3014]^{ns}	[6.0065]***	[9.0814]***
C	-0.3329	-0.3399	-0.3229	-0.3349	-0.3349	-0.3421
R^2	0.7787	0.7785	0.7799	0.7787	0.7789	0.7792
Adjusted R^2	0.7786	0.7785	0.7797	0.7785	0.7786	0.7791
Relation of diet feed system & body weight	Negative	Positive	Negative	Positive	Positive	Positive
RMSE	0.1112	0.1112	0.1081	0.1112	0.1107	0.1100
MAE	0.0959	0.0958	0.0897	0.0957	0.0950	0.0946
MAPE	31.4918	31.4662	31.3390	31.4637	31.4541	31.4553
U-Theil Statistics	0.0420	0.0420	0.0409	0.0420	0.0418	0.0416

Note: *p-value ≤ 0.10; **p-value ≤ 0.05; ***p-value ≤ 0.01; ns = not significant (p-value > 0.1)

Source: Own Analysis

Table 4.13: Preliminary Analysis for Multiple Regression of Six (6) Diet Systems for Cycle 2

Description	F1	F2	F3	F4	F5	F6
$\beta_1 Age_{t-1}$	+0.0307	+0.0307	+0.0307	+0.0307	+0.0307	+0.0307
t-stat	[4.6537]***	[4.8350]***	[14.5825]***	[4.4875]***	[5.3379]***	[8.9445]***
$\beta_2 Feed_{t-1}$	- 0.0086	+ 0.0123	- 0.0647	- 0.0016	+0.0192	+0.0434
t-stat	[-1.751]*	[+2.5087]**	[-13.487]***	[-0.3314]^{ns}	[3.9052]***	[8.9342]***
C	-0.3364	-0.3399	-0.327	-0.3375	-0.3375	-0.3451
R^2	0.7785	0.7785	0.7795	0.7785	0.7786	0.7790
Adjusted R^2	0.7784	0.7783	0.7794	0.7785	0.7786	0.7789
Relation of diet feed system & body weight	Negative	Positive	Negative	Negative	Positive	Positive
RMSE	0.1099	0.1099	0.1073	0.1100	0.1097	0.1088
MAE	0.0927	0.0924	0.0874	0.0926	0.0921	0.0913
MAPE	33.9705	33.9502	33.7677	33.9548	33.9387	33.8744
U-Theil Statistics	0.0424	0.0424	0.0414	0.0425	0.0424	0.0420

Note: *p-value ≤ 0.10; **p-value ≤ 0.05; ***p-value ≤ 0.01; ns = not significant (p-value > 0.1)

Source: Own Analysis

For diet feed system 1, the chicken body weight equation's variation was almost 78% explained by the explanatory variables. Keeping all factors equal, an increase in age of one day has an average positive impact on an increase in body weight of 0.03 kg with statistical significance at the $\alpha = 0.01$ level. 1 unit [refer to Table 4.3 and Table 4.4 for the cumulative voluntary feed for the diet feed system] of diet feed system 1 increases, on average, has negative effect on increasing the body weight by 0.0086 to 0.01kg of weight with statistical significance at the level 0.05 and 0.10 level in the Cycle 1 and Cycle 2, when compared to other feed systems.

For diet feed system 2, the chicken body weight equation's variation was almost 78% explained by the explanatory variables. Keeping all factors equal, an increase in age of one day has an average positive impact on an increase in body weight of 0.03 kg with statistical significance at the $\alpha = 0.01$ level. 1 unit [refer to Table 4.3 and Table 4.4 for the cumulative voluntary feed for the diet feed system] of diet feed system 1 increases, on average, has positive effect on increasing the body weight by 0.0123kg of weight with statistical significance at the level 0.05 in both Cycle 1 and Cycle 2, when compared to other feed systems.

For diet feed system 3, the chicken body weight equation's variation was almost 78% explained by the explanatory variables. Keeping all factors equal, an increase in age of one day has an average positive impact on an increase in body weight of 0.03 kg with statistical significance at the $\alpha = 0.01$ level. 1 unit [refer to Table 4.3 and Table 4.4 for the cumulative voluntary feed for the diet feed system] of diet feed system 1 increases, on average, has negative effect on increasing the body weight by 0.0647kg to 0.07kg of weight with statistical significance at the level 0.01 in both the Cycle 1 and Cycle 2, when compared to other feed systems.

For diet feed system 4, the chicken body weight equation's variation was almost 78% explained by the explanatory variables. Keeping all factors equal, an increase in age of one day has an average positive impact on an increase in body weight of 0.03 kg with statistical significance at the $\alpha = 0.01$ level. 1 unit [refer to Table 4.3 and Table 4.4 for the cumulative voluntary feed for the diet feed system] of diet feed system 4 increase has no statistically significant impact on the chicken body weight for both Cycle 1 and Cycle 2, when compared to other feed systems.

For diet feed system 5, the chicken body weight equation's variation was almost 78% explained by the explanatory variables. Keeping all factors equal, an increase in age of one day has an average positive impact on an increase in body weight of 0.03 kg with statistical significance at the $\alpha = 0.01$ level. 1 unit [refer to Table 4.3 and Table 4.4 for the cumulative voluntary feed for the diet feed system] of diet feed system 1 increases, on average, has positive effect on increasing the body weight by 0.0192kg to 0.0297kg of weight with statistical significance at the level 0.01 in both the Cycle 1 and Cycle 2, when compared to other feed systems.

For diet feed system 6, the chicken body weight equation's variation was almost 78% explained by the explanatory variables. Keeping all factors equal, an increase in age of one day has an average positive impact on an increase in body weight of 0.03 kg with statistical significance at the $\alpha = 0.01$ level. 1 unit [refer to Table 4.3 and Table 4.4 for the cumulative voluntary feed for the diet feed system], for the cumulative voluntary feed for the diet feed system] of diet feed system 6 increases, on average, has positive effect on increasing the body weight by 0.0434kg to 0.0447kg of weight with statistical significance at the level 0.01 in both the Cycle 1 and Cycle 2, when compared to other feed systems.

It is observed that in all models, the coefficients for chicken age (Age) are statistically significant at $\alpha = 0.01$ level (***), indicating a substantial positive relationship between age and body weight. In other words, for each additional day of age, there is a notable increase in the chickens' body weight.

The coefficients for the different diet feed systems (F1, F2, F3, F4, F5, F6) vary across the models:

1) For diet feed system 1 (Control Feed), it has a statistically significant negative effect on body weight in both cycles in comparison to other diet feed systems.
2) For diet feed system 2 (*Pokok Ketum Ayam*), it has a statistically significant positive effect on body weight in both cycles in comparison to other diet feed systems.

3) For diet feed system 3 (Black Soldier Fly), it has a statistically significant negative effect on body weight in both cycles in comparison to other diet feed systems.
4) For diet feed system 4 (Crude Palm Kernel Oil), it does not have a statistically significant effect on body weight in either cycle (p-value > 0.1) in comparison to other diet feed systems.
5) For diet feed system 5 (Organic Acid), it has a statistically significant positive effect on body weight in both cycles in comparison to other diet feed systems.
6) For diet feed system 6 (Yellow Pigment), it has a statistically significant positive effect on body weight in both cycles in comparison to other diet feed systems.

These results suggest that different diet feed systems have varying effects on chicken body weight. The direction (positive or negative) and statistical significance of these effects differ between diet feed systems. This implies that the choice of diet feed system can impact the body weight of native chickens.

The observation aligns with the feed conversion efficiency (FCE) ratio, suggesting that diet feed systems 2, 5, and 6 positively influence chicken body weight while requiring fewer feed ingredients. In contrast, diet feed system 3, in accordance with the feed efficiency results, demonstrates lower efficiency (as indicated by a negative relationship with chicken body weight at a significance level of 0.01) in both Cycle 1 and Cycle 2.

Model Evaluation

Model accuracy refers to the goodness of fit, which relates to how effectively the regression model replicates the known data. The performance of the model is evaluated based on the validity of its estimates, which is gauged by its estimation prowess. This ability is assessed using criteria such as RMSE, MAE, and U-Theil statistics.

Based on Table 4.12 and Table 4.13 above, the MAE values are low, and the RMSE values for the variables are below 1. Both RMSE and MAE can range from 0 to infinity, with lower values being preferable. Ultimately, all of the U-Theil statistic coefficient values are very close to 0, indicating that the regression models' estimation performance is satisfactory.

4.6 Panel Data Analysis for the Chicken Meat Growth Performance and the Six (6) Different Diet Feed Systems

Panel data, also referred to as longitudinal or cross-sectional time series data, is gathered from the same entities or subjects across several time periods. In this study, the growth of chickens in terms of body weight is tracked across different types of diet feed systems over a period of 12 weeks. Therefore, panel data analysis is used to assess the combined effect of cross-sectional (different diet feed systems) and period (different time periods) effects on chicken body weight.

As discussed in Section 4.5, multiple regression analysis was used as a preliminary analysis tool, which can be valuable for understanding relationships between variables. However, it may not fully address the unique challenges posed by panel data, particularly in understanding how different diet feed systems can impact chicken body weight across time periods. Consequently, the panel data analysis excludes age as an independent variable for the following reasons:

(1) Research Focus: In multiple regression analysis, age was included, and its statistically significant relationship with chicken body weight was confirmed. However, in the panel data analysis, the focus is more specific on understanding how different diet feed systems impact chicken body weight over time, assuming age remains constant.

(2) Model Simplicity: Panel data analysis often aims to develop parsimonious models that capture the most critical relationships while minimizing complexity. Excluding age helps create a more straightforward and interpretable model.

In the analysis, dummy variables were used for each diet feed system. Each diet feed system has its own dummy variable, which takes the value 1 when that specific diet is in use and 0 otherwise.

This approach allows for comparison of the effects of each diet feed system relative to the absence of that diet. Six (6) separate models are generated per cycle, each focusing on one diet feed system at a time, providing insights into how a specific diet feed system affects chicken body weight while controlling for other factors, including individual or time-specific effects.

4.6.1 Panel Model Selection

Table 4.14 below presents the results of selecting the types of panel models: Pooled Ordinary Least Squares (POLS) and Fixed Effect Model (FEM).

Table 4.14: Panel Model Selection

Tests	Statistic	Conclusion
Redundant Fixed Effect Test	Period Chi-Square (413.76; p-value 0.000; < $\alpha = 0.01$)	H_0 = POLS is preferable H_A = FEM is preferable **Reject H_0 = Period FEM is preferable.**

Source: Own analysis

Based on Table 4.14 above presents the results of selecting the types of panel models: Pooled Ordinary Least Squares (POLS) and Fixed Effect Model (FEM). The highly significant result (p-value 0) suggests the importance of the fixed effect being tested in explaining the variation in the dependent variable, which is chicken body weight. The specific fixed effect under consideration here, the period fixed effect, is crucial for accounting for unobserved factors that significantly influence the dependent variable. Cross-sectional fixed effects are not applicable as six (6) individual models are generated.

The random effect model is not chosen for this study because the primary goal is to estimate the influence of different diet feed systems on chicken body weight while controlling for unobserved time-specific effects. The fixed effects model controls for these time-specific variations by using dummy variables techniques, which helps isolate the true effect of the diet system on weight gain. Using a random effect model would lead to more generalized inferences about the population, which is unsuitable in this context. Also, the random effects model assumes unobserved heterogeneity is uncorrelated with explanatory variables, which is not valid in this setting due to likely time-varying influences on chicken weight (e.g., environmental factors, weather or management practices).

Each period fixed model provides valuable insights into how a specific diet feed system affects chicken body weight while accounting for other factors, including time-specific effects.

4.6.2 Panel Data Analysis Results for the Chicken Meat Growth Performance and the Six (6) Different Diet Feed Systems

Based on the Table 4.15 and Table 4.16 below, show that the panel data analysis reveals the same relationship between chicken body weight and the six diet feed systems as shown in the multiple regression analysis. Table 4.15 and Table 4.16 below present the panel data model results for the six diet feed systems, expressed in the equation below:

$$\text{Body Weight}_{ti} = C + \beta_1 \text{Feed}_{ti} \quad (4.2)$$

Table 4.15: Period Fixed Effect Panel Models Results for the Chicken Meat Growth Performance and the Six (6) Different Diet Feed Systems (Cycle 1)

	F1	F2	F3	F4	F5	F6
β_0	54.3034	54.1853	54.8038	54.2074	53.9721	53.8476
$\beta_1 \text{Feed}_{ti}$	-0.5009	0.2076	-3.5029	0.0751	1.4871	2.2341
t-stat	-0.6703^{ns}	0.2769^{ns}	-5.8812***	0.1001^{ns}	2.0519***	3.2309***
R^2	0.7968	0.7968	0.7980	0.7968	0.7970	0.7973
Adjusted R^2	0.7962	0.7962	0.7976	0.7962	0.7964	0.7967
	F1	**F2**	**F3**	**F4**	**F5**	**F6**
Normality Test's p-value	0.2653 ($> \alpha$ 0.05)	0.1567 ($> \alpha$ 0.05)	0.0564 ($> \alpha$ 0.05)	0.0583 ($> \alpha$ 0.05)	0.1562 ($> \alpha$ 0.05)	0.0522 ($> \alpha$ 0.05)
RMSE	2.1393	2.1460	1.7050	2.1472	2.0746	1.9794
MAE	1.3294	1.3614	1.3318	1.3580	1.3378	1.3388
MAPE	2.7475	2.6104	5.2429	2.5351	3.4298	4.0359
U-Theil Statistics	0.0161	0.0162	0.0129	0.0162	0.0157	0.0149

Note: ***p-value ≤ 0.01; ns = not significant (p-value > 0.1)

Source: Eview Output

Table 4.16: Period Fixed Effect Panel Models Results for the Chicken Meat Growth Performance and the Six (6) Different Diet Feed Systems (Cycle 2)

	F1	F2	F3	F4	F5	F6
β_0	52.9383	52.7637	53.4061	52.9353	52.7069	52.5048
β_1Feed $_{ti}$	-0.375	0.673	-3.1815	-0.3565	1.0135	2.2265
t-stat	-0.5975^{ns}	1.0796^{ns}	-6.7115***	-0.5679^{ns}	1.6466***	3.9845***
R^2	0.7977	0.7977	0.7987	0.7977	0.7978	0.7982
Adjusted R^2	0.7973	0.7973	0.7984	0.7973	0.7973	0.7978
Normality Test's p-value	0.1669 (> α 0.05)	0.1668 (> α 0.05)	0.1567 (> α 0.05)	0.1673 (> α 0.05)	0.1689 (> α 0.05)	0.1666 (> α 0.05)
RMSE	1.7966	1.7845	1.3570	1.7971	1.7620	1.5996
MAE	1.0715	1.1002	1.0767	1.0876	1.0523	1.0482
MAPE	1.9109	2.3054	4.5423	2.0707	2.3989	3.5114
U-Theil Statistics	0.0139	0.0138	0.0105	0.0139	0.0136	0.0123

Note: ***p-value ≤ 0.01; ns = not significant (p-value > 0.1)

Source: Eview Output

In both cycles, it is evident that diet feed systems 1 (Control Feed) and 3 (Black Soldier Fly) exhibit a negative relationship with chicken body weight, while diet feed systems 2 (*Pokok Ketum Ayam*), 5 (Organic Acid), and 6 (Yellow Pigment) demonstrate a positive relationship. Among these, feed systems 3, 5, and 6 show statistically significant relationships with chicken body weight at the α = 0.01 level. Additionally, all normality test p-values are greater than α = 0.05, indicating that the residuals are normally distributed.

In the period fixed effect model, the fixed effects for each period capture time-specific variations affecting chicken body weight. By including these fixed effects, any variation due to differences between periods is accounted for, allowing the significance of diet feed systems to reflect their effects on chicken body weight.

Based on the period fixed effect models, it is now clear that only diet feed systems 3, 5, and 6 have a statistically significant impact on chicken body weight, while others show slight or no effect, further confirming the findings from previous analyses. This suggests that diet feed system 5 and 6 have a more pronounced influence on growth performance, which may be due to the specific nutrients or additives they contain.

Panel Model Evaluation

Model accuracy refers to how well the regression model fits the known data and its ability to accurately estimate values. To assess this, three metrics are used: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and U-Theil Statistics. Based on Table 4.15 and Table 4.16 above, the RMSE values are all less than 2.2 and the MAE values are less than 1.5.

Both RMSE and MAE measure the average magnitude of prediction errors. RMSE gives more weight to larger errors, while MAE reflects the average absolute difference between predicted and actual chicken body weights. In practical terms, an RMSE below 2.2 and MAE below 1.5 indicate that the predicted chicken weights deviate very little from the actual measured values.

This level of accuracy is considered acceptable where minor weight fluctuations are common due to environmental and physiological factors.

Finally, the U-Theil Statistics values are all close to 0, further confirming that the panel models' forecasting performance is strong. In summary, the low error metrics suggest that the regression models offer reliable and accurate predictions of chicken body weight across different diet feed systems and time periods.

4.7 Residual Diagnosis (Graphical Methods)

Residual analysis for the data models involves critically examining the differences between the observed and predicted values, known as residuals. In this analysis, graphical methods such as plots and charts are employed to visualize the patterns and behaviours of residuals. By plotting residuals against independent variables, potential issues such as heteroscedasticity, outliers, and non-normality can be identified. These graphical examinations provide valuable insights into the validity of model assumptions and the quality of the model fit, enabling informed decisions about model refinement and data interpretation in panel data analysis.

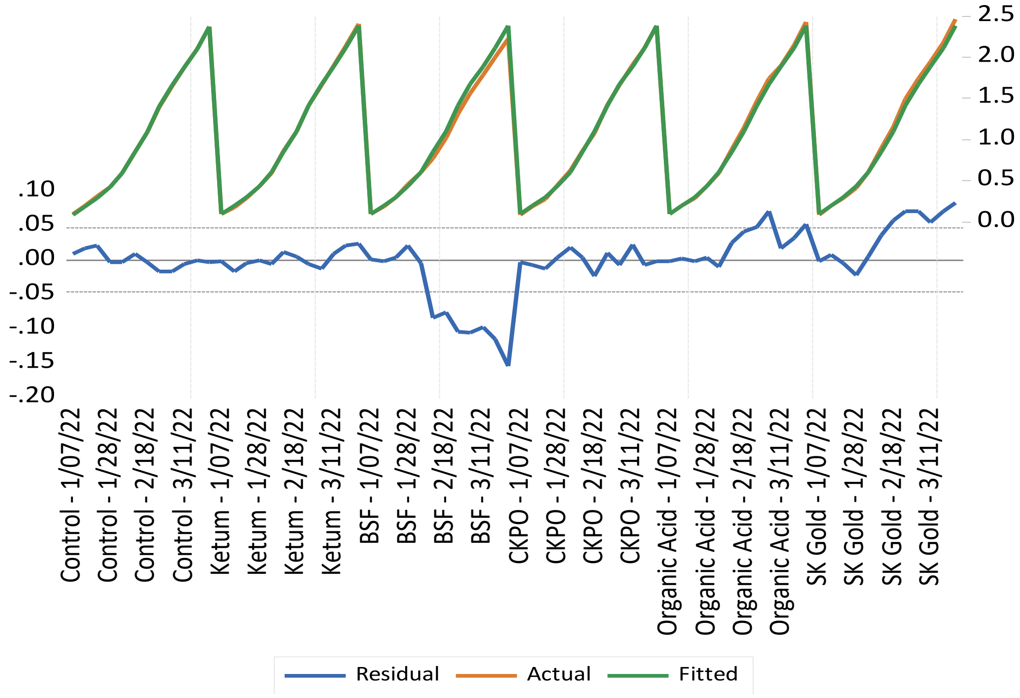


Figure 4.2: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 1 (Cycle 1)

Source: Eview 12

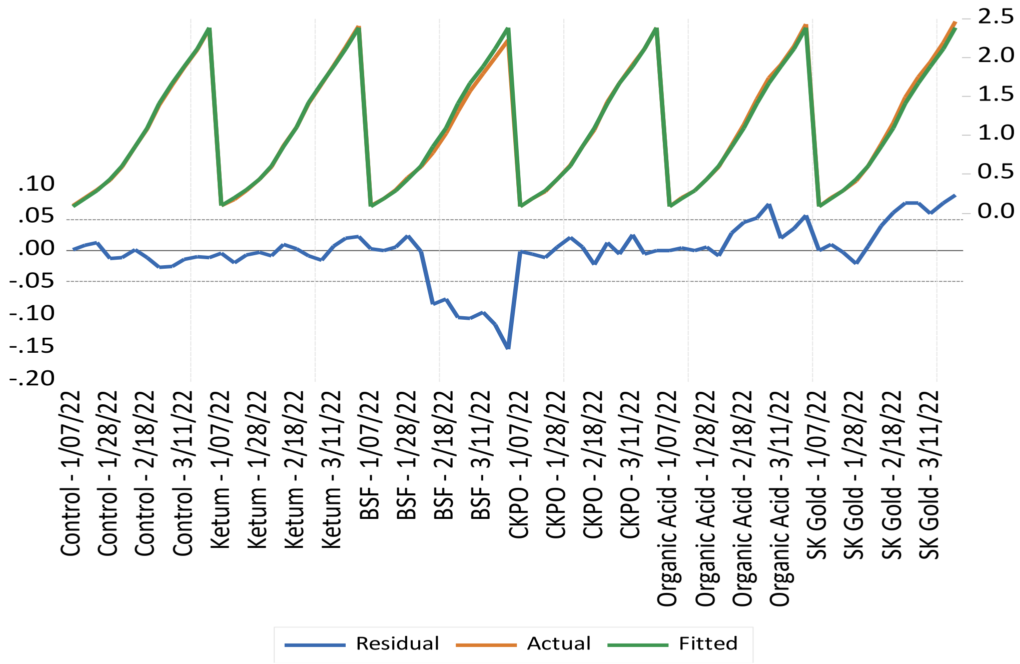


Figure 4.3: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 2 (Cycle 1)

Source: Eview 12

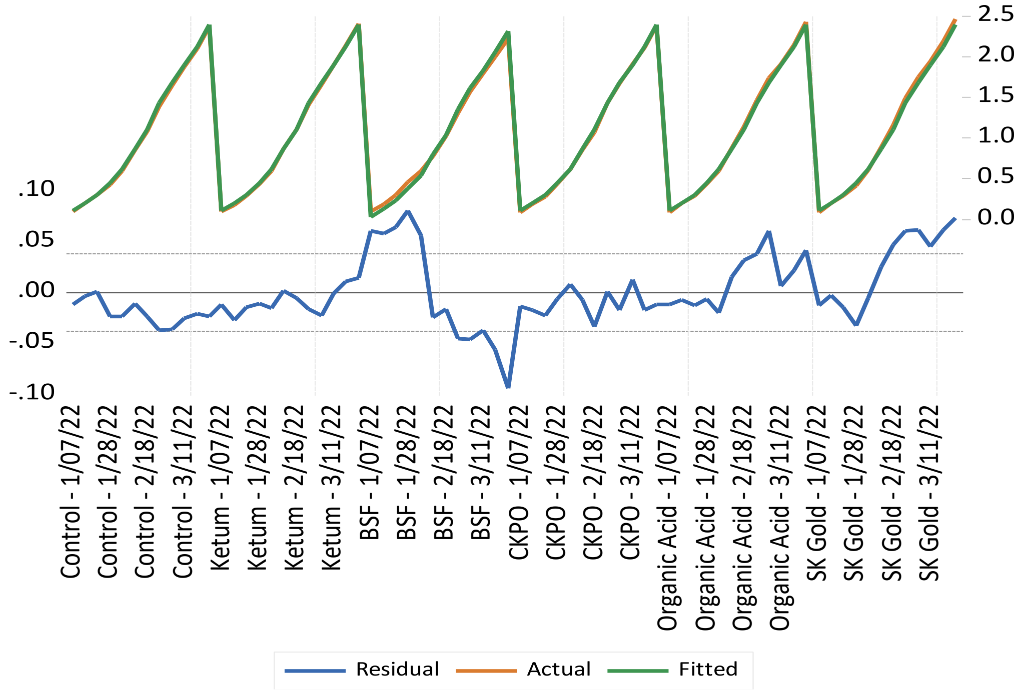


Figure 4.4: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 3 (Cycle 1)

Source: Eview 12

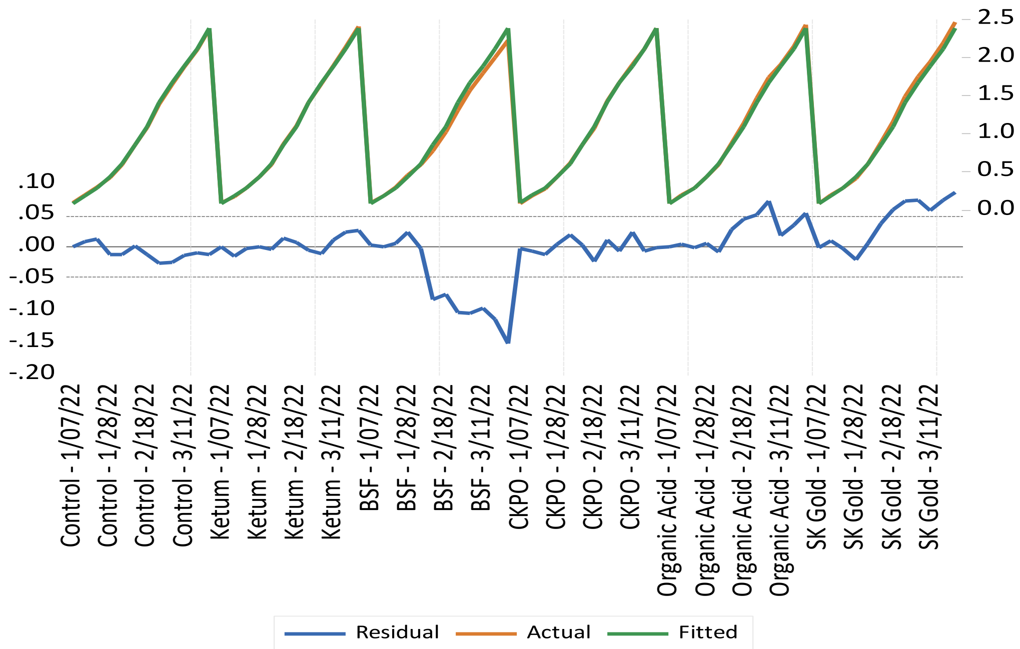


Figure 4.5: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 4 (Cycle 1)

Source: Eview 12

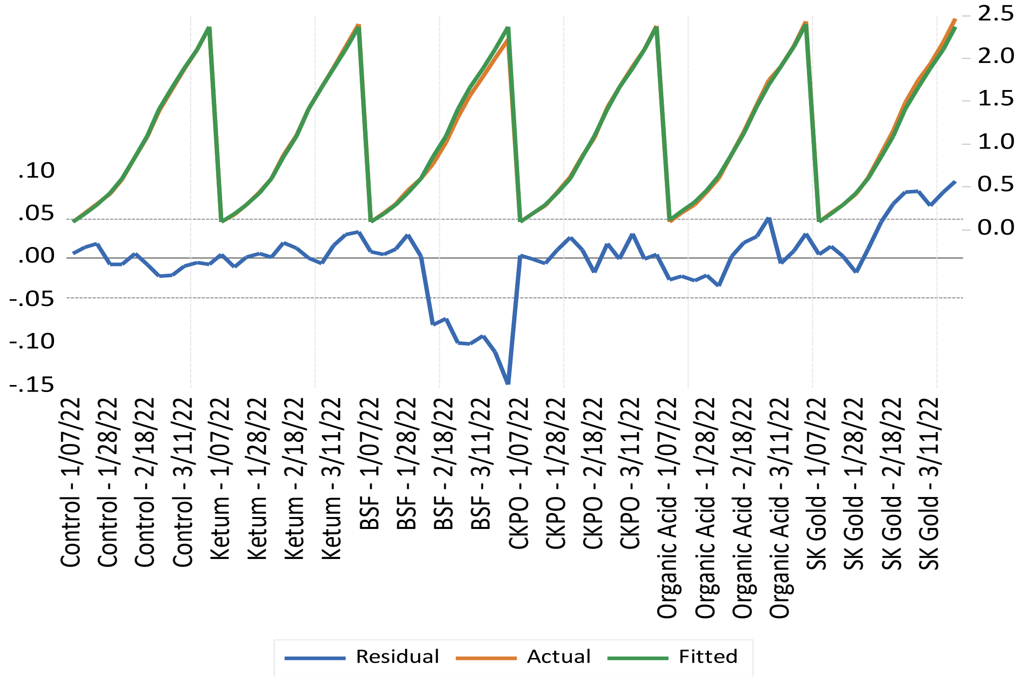


Figure 4.6: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 5 (Cycle 1)

Source: Eview 12

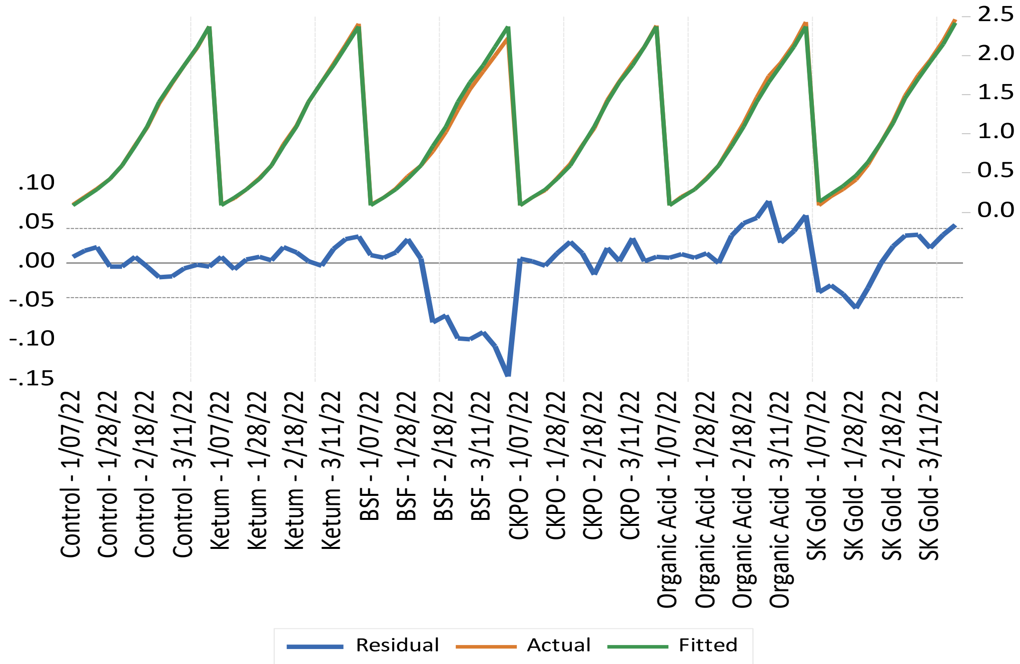


Figure 4.7: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 6 (Cycle 1)

Source: Eview 12

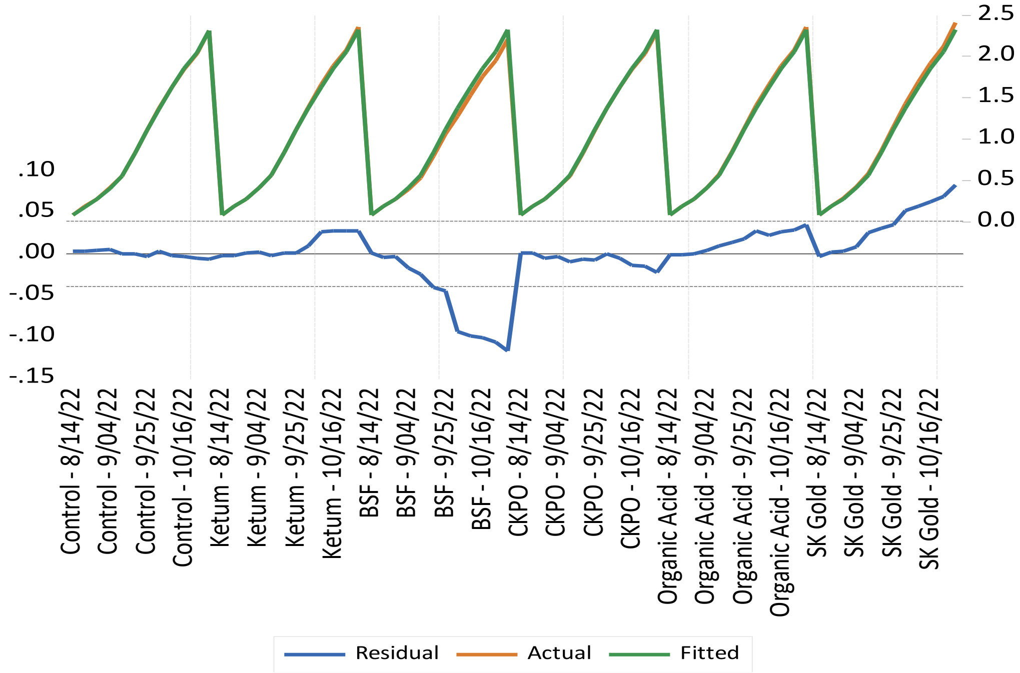


Figure 4.8: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 1 (Cycle 2)

Source: Eview 12

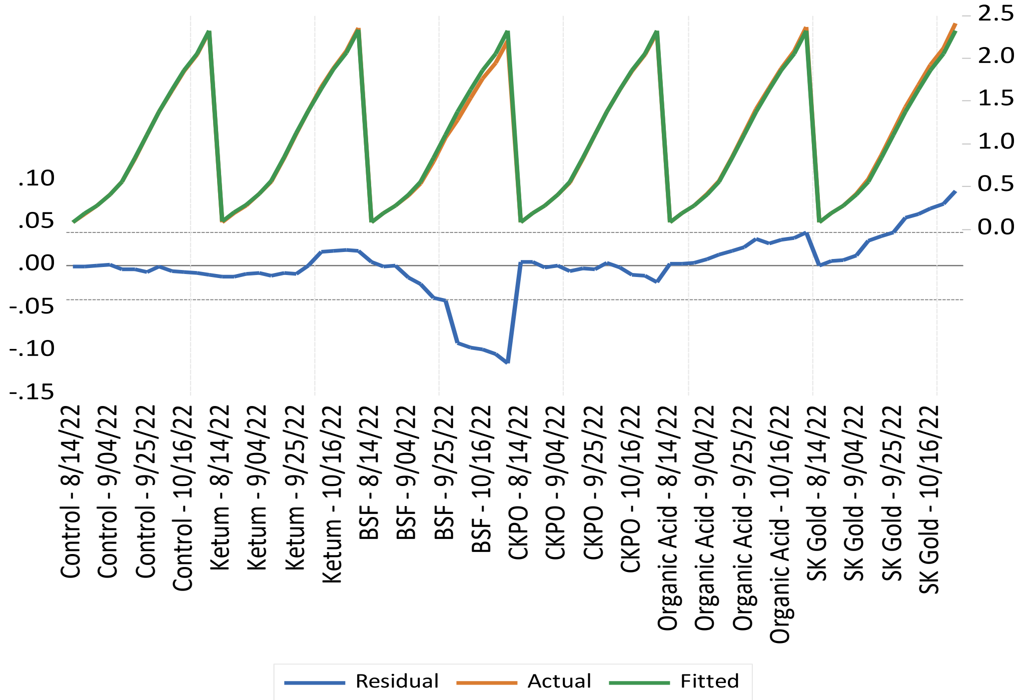


Figure 4.9: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 2 (Cycle 2)

Source: Eview 12

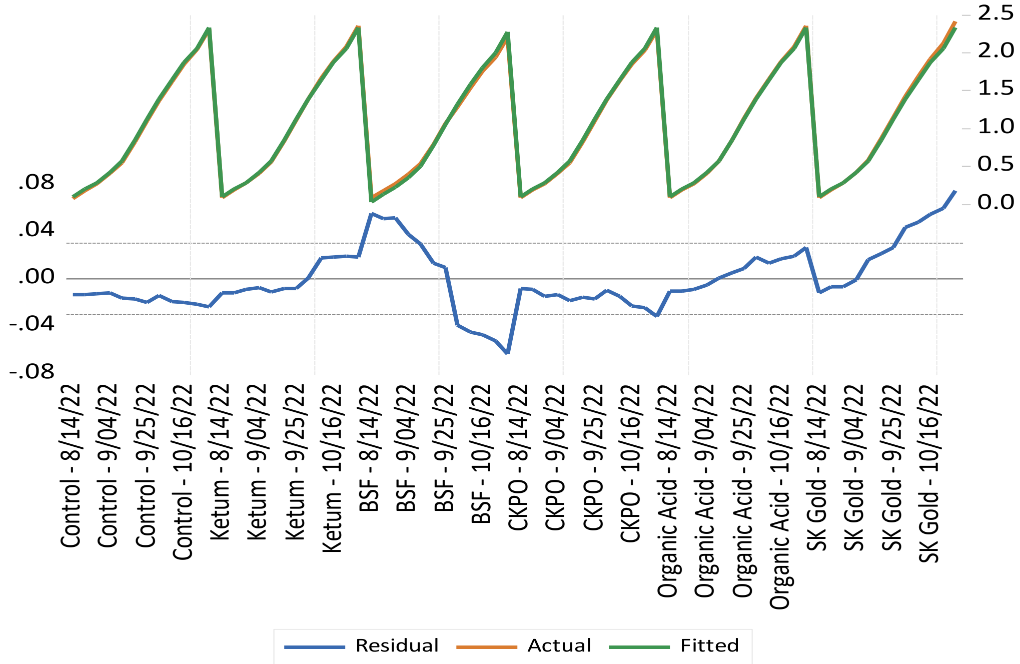


Figure 4.10: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 3 (Cycle 2)

Source: Eview 12

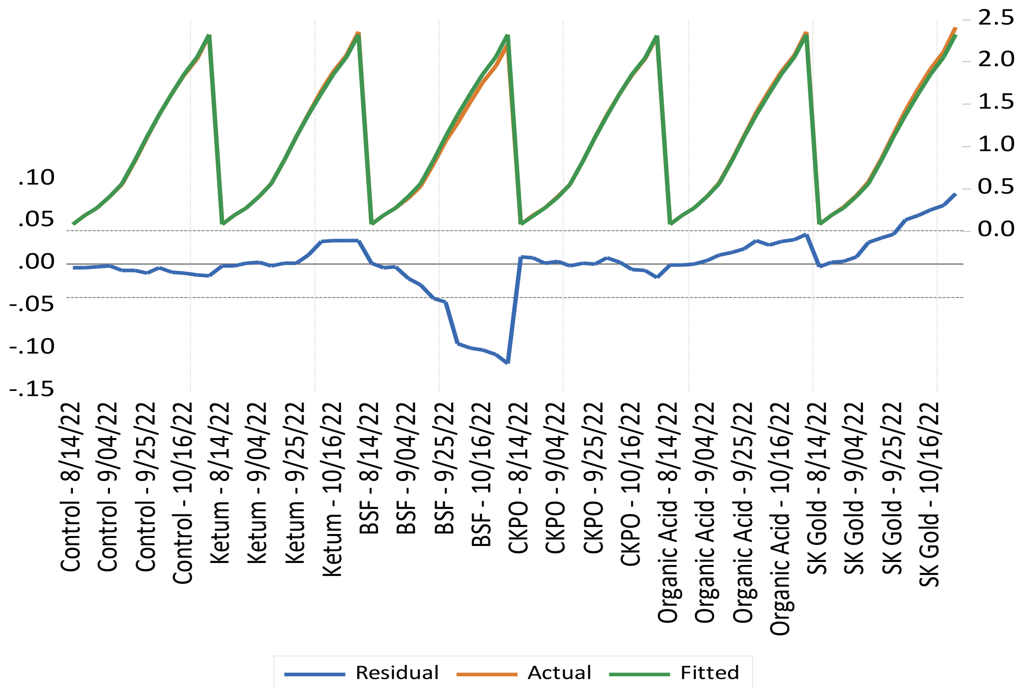


Figure 4.11: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 4 (Cycle 2)

Source: Eview 12

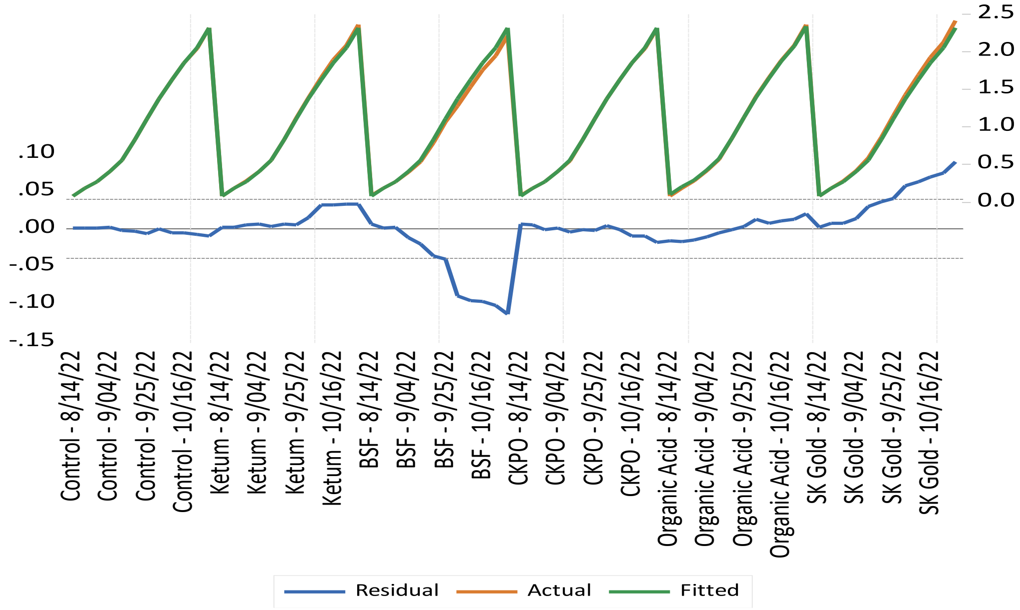


Figure 4.12: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 5 (Cycle 2)

Source: Eview 12

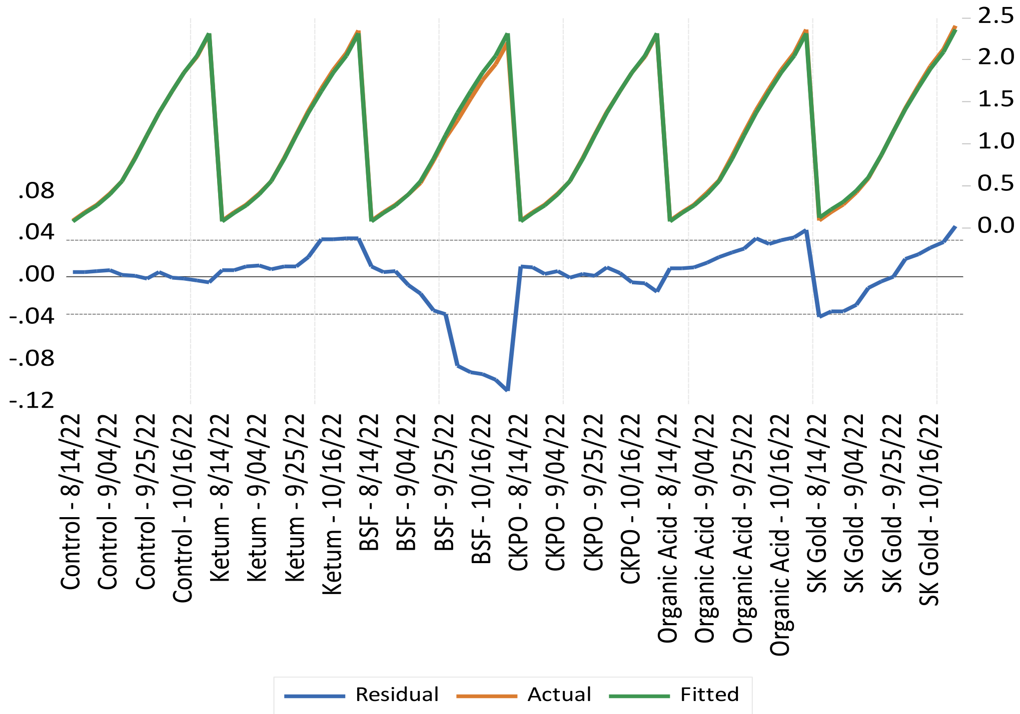


Figure 4.13: Graphical Examination of the Residual of the Actual and Fitted Models of the Chicken Body Weight and Diet System 6 (Cycle 2)

Source: Eview 12

Based on Figure 4.2 to Figure 4.13, it is observed that the residual lines for all models remain close to 0 (ranging from -0.2 to 0.2), which falls within the standard deviation range of ±2 for both Cycle 1 (refer Figure 4.2 to Figure 4.7) and cycle 2 (refer to Figure 4.8 to Figure 4.13). Therefore, the results are considered acceptable.

For the models, the error term should exhibit constant variance, meaning it must remain stable across all observations. This indicates that there is no evidence of heteroscedasticity in the error terms for both Cycle 1 and Cycle 2.

Next, we move to Specific Objective (4), which involves examining the profit level by evaluating the Benefit-Cost Ratio (BCR) of the six (6) different diet feed systems for native chicken meat production.

4.8 The Profit Level using the Benefit-cost Ratio (BCR) of the Six (6) Different Diet Feed Systems for the Native Chicken Meat Production

The benefit-cost ratio formula to compute the profit level for the native chicken meat production based on six (6) different types of diet system, as explained in Chapter 3 is: Benefit-cost ratio (BCR) = Total Revenue ÷ Total Cost. The total revenues received for Cycle 1 and Cycle 2 based on six (6) different diet systems are as per Table 4.17 below.

Table 4.17: Total Revenue for Six (6) Different Diet Systems

Diet Feed System	Average chicken weight (kg)	Number of Chicken (no)	Unit Price (RM/kg)	Revenue (RM)
	A	B	C	D = A x B x C
Cycle 1				
F1	2.3650	50	17	2,010.25
F2	2.4026	50	18	2,162.34
F3	2.2242	50	20	2,224.20
F4	2.3766	50	20	2,376.60
F5	2.4300	50	20	2,430.00
F6	2.4620	50	20	2,462.00
Cycle 2				
F1	2.3101	50	17	1,963.59
F2	2.3520	50	18	2,116.80
F3	2.2064	50	20	2,206.40
F4	2.3249	50	20	2,324.90
F5	2.3600	50	20	2,360.00
F6	2.4081	50	20	2,408.10

Source: Own analysis

The total cost of production for Cycle 1 and Cycle 2 includes the chicken cost, feed cost, vitamin cost and the labour cost. The fixed costs such as the machine cost and the rental cost for the farm are excluded from the calculation.

(1) The 7 days' chicken cost is RM 3.50 per chick. Hence, for 1 cycle, the chicken cost per diet system is 50 chicken x RM 3.50 = RM 175 per diet system per cycle.

(2) The feed cost is calculated based on the cumulative voluntary feed intake (CVFI) per chicken x 50 chicken x cost of feed per kg.

(3) The vitamin cost is RM 80 per diet system (for 50 chicken per cycle).

(4) There was 1 labour involved in handling this experiment for 3 months. 1 labour cost RM 1,500. The labour cost per cycle is RM 1,500 x 3 months = RM 4,500. Hence, RM 750 is calculated per diet system per cycle.

The total cost of production based on six (6) different diet systems are as per Table 4.18 below.

Table 4.18: Total Production Cost for Six (6) Different Diet Systems

Diet Feed System	Total feed weight (kg)	Cost per feed (RM/kg)	Total feed cost (RM)	Chicken Cost (RM)	Vitamin + Labour Cost (RM)	Total Cost (RM)
	A	B	C = A x B	D	E	F = C + D + E
Cycle 1						
F1	323.75	2.20	712.25	175.00	830.00	1,717.25
F2	321.25	2.25	722.81	175.00	830.00	1,727.81
F3	322.00	2.70	869.4	175.00	830.00	1,874.40
F4	321.00	2.34	749.54	175.00	830.00	1,754.54
F5	300.00	2.60	780	175.00	830.00	1,785.00
F6	311.50	2.43	755.39	175.00	830.00	1,760.39
Cycle 2						
F1	316.50	2.20	696.30	175.00	830.00	1,701.30
F2	315.50	2.25	709.88	175.00	830.00	1,714.88
F3	320.50	2.70	865.35	175.00	830.00	1,870.35
F4	313.75	2.34	732.61	175.00	830.00	1,737.61
F5	292.00	2.60	759.20	175.00	830.00	1,764.20
F6	305.00	2.43	739.63	175.00	830.00	1,744.63

Source: Own analysis

Based on the data above, the benefit-cost ratio can be calculated. The Benefit-Cost Ratio for the six (6) diet systems is calculated as Table 4.19 below:

Table 4.19: Benefit-Cost Ratio Table for Six (6) Diet Systems

Diet System	Total Revenue	Total Cost	BCR
Cycle 1			
F1	2,010.25	1,717.25	1.17
F2	2,162.34	1,727.81	1.25
F3	2,224.20	1,874.40	1.19
F4	2,376.60	1,754.54	1.35
F5	2,430.00	1,785.00	1.36
F6	2,462.00	1,760.39	1.40
Cycle 2			
F1	1,963.59	1,701.30	1.15
F2	2,116.80	1,714.88	1.23
F3	2,206.40	1,870.35	1.18
F4	2,324.90	1,737.61	1.34
F5	2,360.00	1,764.20	1.34
F6	2,408.10	1,744.63	1.38

Based on the Table 4.19 above, it has been observed that all diet feed systems exhibit higher cost-effectiveness when compared to the diet feed system 1 (Control Feed). Diet feed system 1 appears to be the least cost-effective among all options, with a benefit-cost ratio (BCR) ranging from 1.15 to 1.17.

In contrast, diet feed system 6 (Yellow Pigment) emerges as the most cost-effective choice for native chicken meat production, boasting a BCR ratio ranging from 1.38 to 1.40 across both Cycle 2 and Cycle 1. Diet feed system 2 (*Pokok Ketum Ayam*) also demonstrates favourable cost-effectiveness, with a

BCR ratio in the range of 1.23 to 1.25.

Moreover, diet feed systems 4 (Crude Palm Kernel Oil) and 5 (Organic Acid) have proven effective in enhancing the profit margins of native chicken meat producers. Both of these systems yield BCR ratios of 1.34 to 1.36. These findings underscore the economic advantages associated with specific diet feed systems in the context of native chicken meat production.

It is important to note that the cost analysis presented in Table 4.18 is based on the current market prices of feed, chicken, vitamins and labour during the study period. However, these prices are subject to fluctuation due to various external factors such as changes in supply and demand, inflation, transportation costs and seasonal variations in raw material availability. For example, an increase in the price of key feed ingredients like corn or soybean meal would directly raise the overall feed cost, which is a major component of the total production cost.

Such price volatility can affect the economic feasibility of each diet feed system and consequently influence the profitability of native chicken meat production. Farmers and industry stakeholders should therefore consider the potential for price changes when making decisions about feed formulation and budgeting. Future cost analyses may need to incorporate sensitivity testing or scenario planning to account for these uncertainties and to better assess the resilience of different diet feed systems under varying market conditions.

4.9 Hypothesis Testing

Based on

Table 4.20 below, the first hypothesis explored the impact of six different diet feed systems on chicken feed efficiency, measured by CVFI (Cumulative Feed Intake), CWG (Cumulative Weight Gain), BWG (Body Weight Gain), and FCE (Feed Conversion Efficiency). The results showed that Diet Feed Systems 2, 4, 5 and 6 improved feed efficiency compared to the control group (Diet Feed System 1), with their null hypotheses rejected and alternative hypotheses supported. However, Diet Feed System 3 did not show an improvement, as its null hypothesis was not rejected.

The second hypothesis examined the relationships between the diet feed systems, chicken age, and body weight using regression and panel data analysis. Significant relationships were identified for Diet Feed Systems 3 (negative relationship), 5 and 6 (positive relationship) supporting their respective alternative hypotheses. In contrast, no significant relationship was found for Diet Feed Systems 1, 2, and 4, as their null hypotheses were not rejected. These mixed results suggest that certain feed systems have a stronger influence on body weight development over time than others.

The third hypothesis tested the profitability of native chicken meat production under each feed system using the Benefit-Cost Ratio (BCR). All six diet feed systems yielded profitable outcomes, with average BCRs ranging from 1.16 to 1.39, indicating that the revenue exceeded the costs in all cases. Diet Feed

System 6 showed the highest profitability (BCR: 1.39), followed closely by Systems 5 and 4. These findings confirm that native chicken farming using any of the six diet systems can be financially viable, with some systems offering superior returns.

Table 4.20: Hypothesis Testing

Ref	Hypothesis	Decision	Remarks
1)	H_A1: The selected diet feed system will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.		
	H_A1_1: Diet feed system 2 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.	Reject H_01_1.	Supported.
	H_01_2: Diet feed system 3 will not improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio. H_A1_2: Diet feed system 3 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.	Do not reject H_01_2.	Rejected.
	H_A1_3: Diet feed system 4 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.	Reject H_01_3.	Supported.
	H_A1_4: Diet feed system 5 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.	Reject H_01_4.	Supported.
	H_A1_5: Diet feed system 6 will improve the	Reject	Supported.

Ref	Hypothesis	Decision	Remarks
	chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.	H_01_5.	
2	H_02: There is no relationship among the different diet feed systems, chicken age and body weight for native chicken. H_A2: There is relationship among the different diet feed systems, chicken age and body weight for native chicken.		
	H_02_1: There is no relationship between diet feed system 1, chicken age and body weight for native chicken. H_A2_1: There is relationship between diet feed system 1, chicken age and body weight for native chicken.	Do not reject H_02_1.	Rejected.
	H_02_2: There is no relationship between diet feed system 2, chicken age and body weight for native chicken. H_A2_2: There is relationship between diet feed system 2, chicken age and body weight for native chicken.	Do not reject H_02_2.	Rejected.
	H_A2_3: There is relationship between diet feed system 3, chicken age and body weight for native chicken.	Reject H_02_3.	Supported.
	H_02_4: There is no relationship between diet feed system 4, chicken age and body weight for native chicken. H_A2_4: There is relationship between diet feed system 4, chicken age and body weight for native chicken.	Do not reject H_02_2.	Rejected.
	H_A2_5: There is relationship between diet feed system 5, chicken age and body weight for native chicken.	Reject H_02_5.	Supported.
	H_A2_6: There is relationship between diet feed	Reject	Supported.

Ref	Hypothesis	Decision	Remarks
	system 6, chicken age and body weight for native chicken.	H_02_6.	
3	H_03: There is no profit for native chicken meat production farmers, calculated using the benefit-cost ratio (BCR) (ratio less than 1) using different diet feed systems. H_A3: There is profit for native chicken meat production farmers, calculated using the benefit-cost ratio (BCR) (equals or more than 1) using different diet feed systems.		
	H_A3_1: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 1.	<u>Reject</u> H_03_1.	Average BCR: 1.16
	H_A3_2: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 2.	<u>Reject</u> H_03_2.	Average BCR: 1.24
	H_A3_3: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 3.	<u>Reject</u> H_03_3.	Average BCR: 1.185
	H_A3_4: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 4.	<u>Reject</u> H_03_4.	Average BCR: 1.345
	H_A3_5: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using diet feed system 5.	<u>Reject</u> H_03_5.	Average BCR: 1.35
	H_A3_6: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (ratio less than 1) using Diet System 6.	<u>Reject</u> H_03_6.	Average BCR: 1.39

4.10 Conclusion

The findings of this comprehensive study on native chicken meat production and diet feed systems reveal several important insights. Firstly, the study highlights the crucial role of diet composition in influencing chicken growth performance, particularly its impact on body weight. It identifies specific diet feed systems that show a significant relationship with chicken body weight and age. Notably, some feed systems, when properly formulated, demonstrate substantial improvements in growth rates and overall profitability.

While most results aligned with expectations, one notable exception was Diet Feed System 3. Unlike the other diets, it did not produce a significant improvement in chicken feed efficiency compared to the control group (Diet Feed System 1). A possible explanation is that the inclusion rate of certain ingredients in this diet may not have been optimal to support growth. The balance of key nutrients might have been insufficient or poorly proportioned. Future research should consider adjusting these ingredient levels to determine whether performance can be improved through reformulation.

This unexpected result illustrates that even small changes in feed composition can significantly influence outcomes. It underscores the importance of ongoing testing and refinement when developing effective feed systems for native chickens. Understanding and addressing such anomalies not only strengthens the reliability of the study but also provides valuable guidance for researchers and farmers aiming to enhance feed efficiency and production performance.

The study also emphasizes the potential benefits of incorporating novel dietary additives, such as Organic Acids and Yellow Pigments, to further enhance chicken growth. Overall, the research offers meaningful insights into optimizing feed systems for sustainable and efficient chicken meat production. These findings present practical opportunities for application within the poultry industry, as well as a foundation for further academic exploration in animal nutrition and agricultural sciences.

Importantly, the Benefit-Cost Ratio (BCR) analysis shows that all alternative diet feed systems can improve profitability for chicken farmers when compared to the control feed. This suggests that adopting these improved diets can help farmers increase their income while ensuring a steady supply of chicken meat to meet rising market demand. However, it should be noted that the cost calculations are based on current market prices during the study period, which may fluctuate due to external factors such as raw material availability and inflation; such variations could impact overall production costs and profitability. Future analyses could benefit from incorporating these price fluctuations to better assess economic resilience.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter is to conclude the study on the framework development for chicken growth performance, feed efficiency and profitability for native chicken farmers based on different diet systems in Malaysia.

Within this chapter, a summary of the statistical analysis is presented, along with the major findings from the study as discussed in Chapter 4. At the end of this chapter, there is a recommendation for additional research to complement the findings of this study, along with an explanation of the study's limitations and implications.

5.2 Summary of Statistical Analysis

Based on the findings from Chapter 4, it is demonstrated that there are improvements in chicken growth performance using different diet feed systems. This is evident from higher body weights and better growth rates for Diet feed system 2 (*Pokok Ketum Ayam*), 4 (Crude Palm Kernel Oil), 5 (Organic Acid) and 6 (Yellow Pigment). The findings showed that diet feed system 6 consistently achieved the highest chicken body weight growth, while both diet feed systems 5 and 6 demonstrated superior feed efficiency.

Based on the multiple regression and panel data analysis carried out for the study, it is observed that most of the diet feed systems exhibit varying degrees of positive or negative correlation with the native chicken's body weight, in comparison with other diet feed systems.

1) Diet feed system 1 (Control Feed): In both Cycle 1 and Cycle 2, diet feed system 1 exhibits a negative impact on chicken body weight, in comparison with other diet feed systems based on multiple regression and panel data analysis. This suggests that using the Control Feed leads to a decrease in chicken body weight over time compared to other diet feed systems. However, the impact is statistically significant at $\alpha = 0.05$ level only in Cycle 1 based on multiple regression method. Panel data analysis shows the impact is not statistically significant.
2) Diet feed system 2 (*Pokok Ketum Ayam*): Diet feed system 2 shows a positive effect on chicken body weight in both cycles based on multiple regression and panel data analysis. This means that using *Pokok Ketum Ayam* as a feed system tends to increase chicken body weight compared to other diet feed systems. The impact is statistically significant in both cycles based on multiple regression method. Panel data analysis shows the impact is not statistically significant.
3) Diet feed system 3 (Black Soldier Fly): Diet feed system 3 was not able to yield significant body weight in both cycles, in comparison to other diet

feed systems. Using Black Soldier Fly as a diet feed system leads to a considerable reduction in chicken body weight, in comparison to other diet feed systems. The impact is statistically significant in both cycles based on multiple regression method and panel data analysis.

4) Diet feed system 4 (Crude Palm Kernel Oil): Diet feed system 4 has a relatively neutral effect on chicken body weight, in comparison to other diet feed systems. While there are slight variations in the coefficients, the impact is not statistically significant in either cycle based on multiple regression method and panel data analysis.
5) Diet feed system 5 (Organic Acid): Diet feed system 5 positively affects chicken body weight in both cycles. It contributes to an increase in chicken body weight, in comparison to other diet feed systems and this impact is statistically significant in both cycles, based on multiple regression method and panel data analysis.
6) Diet feed system 6 (Yellow Pigment): Diet feed system 6 has the most significant positive effect on chicken body weight among all diet feed systems. Using Yellow Pigment as a diet feed system substantially increases chicken body weight, in comparison to other diet feed systems and this impact is statistically significant in both cycles based on multiple regression method and panel data analysis.

In short, the choice of diet feed system plays a crucial role in determining the chicken's body weight. Diet feed systems 5 and 6 consistently lead to increased body weight, while diet feed system 3 does not help to improve chicken growth performance compared to other diet feed systems based on the study. Diet feed system 4 appears to have a neutral impact on chicken body weight in comparison to other diet feed systems because the results are quite near to the mean data.

Despite the above, it is observed that the locally produced supplements, such as *Pokok Ketum Ayam*, Black Soldier Fly, Crude Palm Kernel Oil, Organic Acid and Yellow Pigment (Brand: SK Gold), have been proven to improve the profitability of the native chicken meat business. All BCR ratios for diet feed system 2, 3, 4, 5 and 6 exceeded the control feed. From a profitability perspective, diet feed system 6 emerged as the most economical choice across both 12-week production cycles.

5.3 Discussions of Major Findings

Chapter 4 reveals the findings for the study of the development of chicken growth performance, feed efficiency and profitability. The major findings found are related to the three (3) hypotheses set up in Chapter 3:

5.3.1 Hypotheses (1)

Hypotheses (1) were relating to Objective (2) on chicken feed efficiency.

H_A1_1: Diet feed system 2 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

It is found that diet feed system 2 – *Pokok Ketum Ayam* supported H_A1_1**,** i.e. diet feed system 2 will improve the chicken feed efficiency compared to the control feed. This is supported by various recent empirical studies by Nasarudin et al. (2024), Libatique (2021) and Mosbos, Espina & Bestil (2016)**.** Kathiraser et al. (2024), on the other hand, generally support diet feed system 2 will improve the chicken growth performance but only with small percentage (1%) inclusion of the plant.

H_A1_2: Diet feed system 3 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

It is found that diet feed system 3- *Protein Larva Askar Hitam*, supported H_01_1**,** i.e. diet feed system 3 will not improve the chicken feed efficiency compared to the control feed. This is supported by recent empirical studies by Murawska et al. (2021), Pietras et al. (2021) and Schiavone et al. (2018) which confirmed the findings of the diet feed system 3 - *Protein Larva Askar Hitam* did not influence the growth performance by inclusion of black soldier fly. Facey et al. (2023) also confirmed that lower levels of Black Soldier Fly (lower than 25%) can promote growth, while higher inclusion can hinder it. Brah et al. (2024) found that 4% Black Soldier Fly inclusion improved body weight and feed efficiency, while higher levels (12% and 16%) did not. Mat et al. (2022) similarly concluded that a 4% insect meal inclusion does not compromise chicken growth.

H_A1_3: Diet feed system 4 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

It is found that diet feed system 4 – Crude Palm Kernel Oil (CPKO) supported H_A1_3**,** i.e. diet feed system 4 will improve the chicken feed efficiency compared to the control feed. This is supported by recent empirical studies by Yendou-Gname et al. (2024), Long et al. (2019), Rahman et al. (2010) and Adrizal et al. (2011).

H_A1_4: Diet feed system 5 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

It is found that diet feed system 5 – Organic Acid supported H_A1_4**,** i.e. diet feed system 5 will improve the chicken feed efficiency compared to the control feed. This is supported by recent empirical studies by Roy et al (2024), Elnaggar, & El-kelawy (2024), Islam et al. (2024), Ebeid & Al-Homidan (2022), Sobotik (2021), Adhikari et al. (2020), Aljumaah, et al. (2020) and Sabour et al. (2019).

H_A1_5: Diet feed system 6 will improve the chicken feed efficiency in comparison to the control feed (diet feed system 1) based on CVFI, CWG, BWG and FCE ratio.

It is found that diet feed system 6 – Yellow Pigment supported H_A1_5, i.e. diet feed system 6 will improve the chicken feed efficiency compared to the control feed. This is supported by recent empirical study by Wang (2023) Mazur-Kuśnirek et al. (2019).

5.3.2 Hypotheses (2)

Hypotheses (2) were relating to Objective (3) on the relationship among chicken age, diet systems and the chicken body weight.

H_A2: There is relationship among the different diet feed systems, chicken age and body weight for native chicken.

It is found that Diet feed systems 3, 5 and 6 supported H_A2, i.e the diet feed system has relationship with the different diet feed system, chicken age and body weight for native chicken. Based on the co-efficient values obtained from the multiple regression and panel data models, the findings are as follow:

(1) For diet feed system 1, it has a negative effect on body weight in both cycles, in comparison to other diet feed systems. The impact varies in both cycles and different analysis. Panel data results show the relationship is not statistically significaroynt.

(2) For diet feed system 2, it has a positive effect on body weight in both cycles, in comparison to other diet feed systems. The impact varies in

different analysis. Panel data results show the relationship is not statistically significant.

(3) For diet feed system 3, it has a statistically significant negative effect on body weight in both cycles, in comparison to other diet feed systems, based on both multiple regression and panel data analysis.

(4) For diet feed system 4, it does not have a statistically significant effect on body weight in either cycle (p-value > 0.1), in comparison to other diet feed systems, for both multiple regression and panel data analysis.

(5) For diet feed system 5, it has a statistically significant positive effect on body weight in both cycles, in comparison to other diet feed systems, for both multiple regression and panel data analysis.

(6) For diet feed system 6, it has a statistically significant positive effect on body weight in both cycles, in comparison to other diet feed systems, for both multiple regression and panel data analysis.

These results suggest that different diet feed systems have varying effects on chicken body weight. The direction (positive or negative) and statistical significance of these effects differ between diet feed systems. This implies that the choice of diet feed system can impact the body weight of native chickens.

This is supported by many previous studies have been carried out on particular chicken diet feed system, e.g. different inclusion of *Pokok Ketum*, palm oil, etc. The results are similar to those obtained in the feed efficiency studies and explained in Section 5.3.1 (Nasarudin et al., 2024; Kathiraser et al., 2024; Yendou-Gname et al., 2024; Roy et al., 2024; Saminathan et al, 2022;

Libatique, 2021; Morbos et al., 2016). Also, study by Gultom et al. (2021) confirmed that chicken age has significant relationship with the chicken growth performance.

5.3.3 Hypotheses (3)

Hypotheses (3) were relating to Objective (4) on the profitability for native chicken meat production farmers using different diet feed systems.

H_A3: There is profit for native chicken meat production farmers, calculated using the Benefit-cost ratio (BCR) (equals or more than 1) using different diet feed systems.

It is found that all diet feed systems supported H_A3, i.e. there is profit for native chicken meat production farmers using different diet feed systems. All diet feed systems can generate Benefit-cost ratio (BCR) more than 1 in this study and exceed the BCR ratio for the control feed system. This is supported by the study of Nasarudin et al. (2024), Wantasen et al. (2024), Waithaka et al. (2022), Gbigbi & Isiorhovoja (2022) and Libatique (2021) who found that cost of feed can significantly affect the profitability of the chicken production business.

While all six diet feed systems demonstrated profitability with Benefit-Cost Ratios (BCRs) exceeding 1.0, indicating economic viability, a deeper analysis reveals variation in the degree of effectiveness across the systems. Diet feed systems 5 (Organic Acid) and 6 (Yellow Pigment) consistently delivered superior performance outcomes, enhancing both growth efficiency and profitability. These findings suggest that feed systems incorporating functional additives can significantly improve production metrics. However, the widespread adoption of such systems may be constrained by cost, availability or the level of technical knowledge required among smallholder farmers. Thus, policy initiatives and extension services should consider subsidizing or supporting the distribution of these effective feed additives, especially in rural farming contexts.

Conversely, although diet feed system 3 (Black Soldier Fly protein) generated a BCR greater than 1, its negative impact on feed efficiency and body weight highlights a potential mismatch between profitability and productivity. This suggests that profitability alone may not be a sufficient indicator for feed system effectiveness. The quality, processing method and inclusion rate of insect meal should be further investigated to optimize its use. A one-size-fits-all approach may not be appropriate and farmers should be encouraged to align feed strategies with specific production goals, whether focused on growth rate, meat quality or cost minimization.

Overall, these findings emphasize the need for a balanced evaluation framework that integrates economic returns with biological performance and operational feasibility. Stakeholders, including feed manufacturers, agricultural policymakers and training providers, should collaborate to improve access to scientifically tested, performance-verified feed solutions.

Extension programs could play a key role in translating these findings into practice by offering technical support, cost-benefit awareness and performance monitoring tools tailored to different farm sizes and production models.

5.4 Implication of the Study

This study has useful implications for poultry farmers, policymakers and key players in the chicken meat industry. It analysed six different types of diet feed for native chickens and offers insights to improve growth, lower costs and encourage more sustainable production.

For poultry farmers, the findings offer practical guidance on choosing effective local feed additive options that can boost chicken growth and reduce feeding costs. This can help small and medium-sized farmers improve productivity, manage resources better and increase their profits in a competitive market.

For policymakers, the study provides clear data that can help in designing support schemes or farm subsidies to promote sustainable feed choices and better farming practices. These insights can also assist in developing national strategies to improve food security, reduce dependency on imported feed and support local agriculture.

For industry players such as feed suppliers, veterinarians, and agricultural advisors, the results show which types of feed can improve health and growth performance. With this knowledge, they can create better products, offer more targeted advisory services and innovate feed solutions based on local resources.

For the academic community, this study contributes empirical data that can support future research in animal nutrition, agricultural economics and sustainable farming. Researchers can use the feed types, performance measures and methodology as a reference point for further trials, while lecturers and students can adopt this case study in coursework or agricultural training programs.

Finally, the study promotes awareness about animal welfare and sustainable farming, which is important to today's consumers who want healthy food produced responsibly. The findings can help farmers adopt better practices that meet both market demand and ethical standards, building long-term trust with buyers and consumers.

While this study focuses on native chicken farming in Malaysia, the core insights, such as the use of cost-effective local feed additives and their impact on growth and profitability, have broader relevance. Similar rural or semi-commercial poultry farming models in other developing countries, especially across Southeast Asia, Africa, and Latin America, face comparable challenges with feed costs, sustainability and productivity. The findings can be adapted to other regions by substituting with locally available feed resources and conducting localized trials. This offers potential for international collaboration and knowledge transfer to improve small-scale poultry farming globally.

5.5 Limitations of Study

While the chicken meat study makes valuable contributions to our understanding of native chicken meat production, it is essential to acknowledge its limitations.

First and foremost, the study exclusively focuses on native chicken meat production, omitting consideration for broiler chickens or other poultry species. This narrow scope restricts the generalizability of the findings to a specific subset of poultry farming and further research is needed to explore the diverse challenges and opportunities presented by different poultry categories. Further research is needed to explore the diverse challenges and opportunities presented by different poultry categories.

Secondly, the study is confined to the examination of six (6) different diet feed systems, i.e. Control Feed, *Pokok Ketum*, Crude Palm Kernel Oil (CPKO), *Protein Larva Askar Hitam*, Organic Acid and SK Gold - Yellow Pigment. This limitation stems from resource constraints and a focus on additives that are locally produced. Consequently, the findings may not encompass the full spectrum of dietary options available for optimizing chicken growth.

Thirdly, this study primarily centres around the business and economics aspects of native chicken meat production, with a particular emphasis on diet feed systems. While this focus is crucial for understanding the economic implications of different feeding approaches, it comes with the limitation of excluding detailed nutritional assessments. Nutritional factors, including the composition of feeds and their impact on chicken health and meat quality, are vital considerations in poultry farming. However, in the interest of maintaining a clear focus on the economic dimensions of poultry production, this research does not delve into the intricate details of nutritional studies.

Another limitation to consider is the study's duration, which spans only two cycles of 84 days each. While this timeframe allows for valuable insights into short-term growth patterns, it may not capture the longer-term effects of diet feed systems on native chicken meat production. A more extended study duration could yield additional information regarding the sustainability and consistency of the observed effects.

Lastly, the study primarily focuses on growth performance and does not consider the quality of the meat or consumer preferences due to the limitation of time.

Moreover, potential biases may have influenced results, including uncontrolled confounding factors such as temperature variations, farm management differences and resource availability. These factors may affect the applicability of findings to broader contexts. Future research can be conducted to include the consumer acceptance assessments to provide a more holistic understanding of the implications of different diet feed systems on the poultry industry.

5.6 Recommendations for Future Research

Based on the limitations of this study, this section sets up a recommendation for future research that can delve deeper into the intricacies of poultry nutrition and sustainable production.

One of the primary recommendations for future research is to broaden the scope of poultry studies. While this research focused on native chicken meat production, future investigations should encompass a wider range of poultry species, including broiler chickens and other avian varieties. Each species poses unique challenges and opportunities and understanding their specific dietary requirements and growth patterns is crucial for advancing the poultry industry.

Second, to achieve a more comprehensive understanding of dietary factors influencing poultry growth, future research should prioritize detailed nutritional analyses. This includes investigating the chemical composition of various diet feed systems, assessing essential nutrient levels and exploring nutrient bioavailability and metabolism within poultry. Experimental studies testing the efficacy of specific additives like vitamins, minerals and supplements under controlled conditions would provide robust data to optimize feed formulations.

Furthermore, extending the duration of research studies is another key recommendation. While short-term growth patterns are essential, it is equally critical to assess the long-term effects of diet feed systems on poultry production. Poultry farmers need insights into how dietary choices impact not only growth rates but also sustainability and consistency over extended periods. Conducting longitudinal studies that track poultry development, health and meat quality over several production cycles can yield valuable data for both academia and industry.

In addition, poultry farming ultimately serves consumers and their preferences and expectations should not be overlooked. Future research should incorporate sensory evaluations and consumer acceptance assessments to gauge the quality and palatability of chicken meat produced under different diet feed systems. Understanding consumer perceptions and preferences can guide poultry producers in delivering products that align with market demands.

By expanding the scope of research to include various poultry species, conducting comprehensive nutritional analyses, extending study durations and prioritizing consumer-centric assessments, future research endeavours can contribute significantly to the poultry industry's growth and evolution. These recommendations pave the way for a more sustainable, efficient and consumer-friendly poultry farming future.

5.7 Conclusion

In summary, this research into chicken growth performance, feed efficiency, and profitability, focusing on six different diet feed systems for native chicken farming in Malaysia, yields several important insights. Our statistical analysis reveals that certain diet feed systems, particularly Diet Feed Systems 5 (Organic Acid) and 6 (Yellow Pigment), lead to improved chicken growth performance, as evidenced by higher body weights and enhanced growth rates. Diet Feed System 6 consistently stands out as the most promising, delivering the highest growth performance across the tested cycles.

Moreover, the use of locally produced supplements, including *Pokok Ketum Ayam*, Black Soldier Fly (*Protein Larva Askar Hitam*), Crude Palm Kernel Oil, Organic Acid and Yellow Pigment (Brand: SK Gold), enhances the profitability of native chicken meat production. These feed systems offer a cost-effective alternative to commercial feeds. The high Benefit-Cost Ratios (BCRs) demonstrated in the study support their economic viability for small and medium-scale farmers aiming to reduce feed costs and improve returns.

From a policy standpoint, these findings support the introduction of agricultural support programs to promote local feed innovations. Government agencies and agricultural departments could play a role in providing funding, incentives or training for poultry farmers to adopt these alternative feed strategies. Policies that encourage sustainable farming practices and reduce dependence on imported feed materials will further strengthen the local poultry industry.

In terms of industry application, feed manufacturers can explore the potential of mass-producing the most effective feed additives identified in this study.

Poultry advisors and veterinary service providers can also use this data to provide targeted feeding recommendations that improve chicken performance while lowering production costs.

However, it’s essential to acknowledge the study’s limitations. This research exclusively focuses on native chicken meat production, limiting the generalizability of the findings to other poultry species such as broiler chickens or layers. Additionally, resource constraints allowed for the evaluation of only six diet feed systems, primarily featuring locally available additives. This may not represent the full range of dietary innovations currently available in the global market. Furthermore, the study centered on the business and economic impacts of feeding systems, without exploring the nutritional composition or long-term health effects on chickens.

Looking ahead, future research should expand to include other poultry species to understand how different diet systems impact their growth and meat quality. Studies should also conduct detailed nutritional analyses to evaluate the specific nutrient contents of each feed component. Longer-term studies covering multiple production cycles are recommended to observe effects on sustainability, chicken health and meat consistency over time. Importantly, consumer preference studies, such as taste tests or sensory evaluations, should be integrated to assess market acceptance and better align production with consumer expectations.

Our findings and recommendations provide a strong foundation for continued improvements in poultry farming. They support more informed decision-making by farmers, policymakers, and industry players, and contribute toward building a more sustainable, profitable, and consumer-oriented poultry sector in Malaysia.

These insights not only benefit the Malaysian poultry industry but can also serve as a reference model for small-scale poultry production systems in similar economies worldwide, making this research relevant on a broader scale.

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APPENDIX

Table 1: Summary of Empirical Reviews of Development of Growth Performance, Feed Efficiency, Profitability Framework for Native Chicken Meat Production based on Different Diet Systems

Descriptions	Authors / Year	Methodology	Variables	Results & Findings
Diet feed system 1: Different physical form of feed	Idan et al. (2021)	900 male broiler chicks, averaging 38 g at birth, were randomly distributed into 36 floor pens (25 chickens per pen). They were divided into 4 diet feed systems, with 9 pens per diet. From days 1 to 21, the chickens were fed one of the following diets: (1) T1: Mash for 21 days. (2) T2: Crumbles for 7 days, then mash for 14 days. (3) T3: Crumbles for 14 days, then mash for 7 days. (4) T4: Crumbles for 21 days. From days 22 to 42, all chickens were switched to a traditional mash meal.	Body weight (BW), average daily gain (ADG), average daily feed intake (ADFI) and feed conversion efficiency ratio (FCE)	The findings suggest that feeding broiler chicks crumbled instead of mash diet for at least 7 days improved BW, ADG, ADFI and FCE.
	Omede and Iji (2018)	324 male Ross 308 broiler chicks, one day old, were divided into groups, with 9 chicks per replication and 6 replications per group. They were fed the following diets for the first 10 days after hatching: (1) T1: 0% processed soy protein product	Body weight, average daily gain, average daily feed intake and feed conversion	Chicken fed crumbled diets had higher body weight gain and feed intake between hatch and 24 days than those fed with mash diets.

Descriptions	Authors / Year	Methodology	Variables	Results & Findings
		(PSP). (2) T2: 50 g/kg processed soy protein product (PSP). (3) T3: 100 g/kg processed soy protein product (PSP). The diets were provided in either mash or crumbled form.	efficiency ratio	
Feed 2: Various percentage of inclusion of the *Trichanthera Gigantea* Leaf Meal (TGLM)	Nasarudin et al. (2024)	The chickens were split into three groups: (1) T1: Fed a conventional corn-based diet. (2) T2: Fed a formulated diet containing palm kernel cake (PKC). (3) T3: Fed a formulated diet with both PKC and *Trichantera gigantea*. Body weight was measured every five days for a total of 42 days.	Chicken growth performance	By day 20, chickens on D3 showed the highest weight (780.0g), similar to previous studies using premium-grade PKC feed (785-800g). Growth performance was consistent across all diets until day 25, after which the commercial feed showed a slight advantage. The results suggest that adding *Trichantera gigantea* to PKC-based feed boosts nutrient intake and promotes better growth, highlighting its potential to improve locally sourced animal feed while maintaining efficiency.
	Kathiraser et al. (2024)	120 four-week-old male Ayam Saga birds were randomly divided into four treatment groups with each group had six replicates,	Chicken body weight gain and feed	The results indicated that birds fed with 1% *Trichantera gigantea* and the control group had significantly

Descriptions	Authors / Year	Methodology	Variables	Results & Findings
		with five birds per replicate. (1) Control: No *Trichantera gigantea*. (2) 1% *Trichantera gigantea*. (3) 3% *Trichantera gigantea*. (4) 5% *Trichantera gigantea*. The birds were fed the respective diets for an eight-week trial until they reached 12 weeks of age. Measurements recorded included: body weight, feed intake, body weight gain, feed conversion efficiency ratio and carcass yield.	conversion efficiency ratio	higher ($p<0.05$) final body weight and weight gain compared to those given 3% and 5% *Trichantera gigantea*. Additionally, both the 1% supplementation and control group showed better feed conversion efficiency.
	Libatique (2021)	The chickens were divided into four (4) feeds, each of which was repeated three times with ten (10) chickens: (1) T1: Control Home-mixed Feeds (HF) + 0% TGLM. (2) T2: HF + 5% TGLM. (3) T3: HF + 10% TGLM. (4) T4: HF + 15% TGLM.	Body weight, average daily gain, average daily feed intake and feed conversion efficiency ratio	From the 1st to 3rd week, a non-significant result was observed. Between the fourth and sixth week of the trial, there was a notable difference in the body weight of the chickens, their cumulative feed intake and their feed conversion efficiency ratio between 10% and 15% TGLM. Despite this, 15% TGLM revealed a significant result for the broiler's feed conversion efficiency ratio.
	Morbos et al. (2016)	A 2 x 4 factorial design was used, with three replicates and four chickens per replicate. 96 three-month-old native chickens of both	Body weight, average daily gain, average	The results showed that when TGLM supplementation increased, cumulative voluntary feed intake

Descriptions	Authors / Year	Methodology	Variables	Results & Findings
		sexes were randomly assigned to four feed schemes: (1) 0% TGLM supplementation. (2) 5% TGLM supplementation. (3) 10% TGLM supplementation. (4) 15% TGLM supplementation. The diet feed systems were provided for 13 weeks in a semi-confinement setting.	daily feed intake and feed conversion efficiency ratio	(VFI) increased as well. The increase is highly significant for 15% TGLM especially at weeks 10, 11 and 12. There was a decreasing trend in cumulative weight gain (CWG) with increasing TGLM level, while differences were not significant except at weeks 4 and 7. The effects of varied levels of TGLM supplementation on average daily gain (ADG) were not significant and feed conversion efficiency ratio (FCE) decreased as TGLM level increased and was only substantially low with a 15% level at week 7.
Feed 3: various type of insect meals	Cattaneo et. al. (2025)	108 Lohman Brown hens were housed in 27 cages (9 replicates per treatment, 4 birds per pen) and monitored from 16 to 34 weeks of age. The hens were divided into three groups: (1) Control group: Standard commercial diet. (2) Experimental group 1: Diet supplemented with 15% live BSFL (based on expected daily feed intake, DFI). (3) Experimental group 2: Diet supplemented	Age, egg quality	The inclusion of up to 30% BSFL in the diet did not negatively affect egg and eggshell quality attributes or the chemical composition of the eggs. However, BSFL supplementation altered the fatty acid (FA) profile in egg yolk compared to the control group.

Descriptions	Authors / Year	Methodology	Variables	Results & Findings
		with 30% live BSFL (based on expected daily feed intake, DFI).		
	Brah et al. (2024)	250 day-old broiler chicks were randomly divided into 25 groups and fed diets containing: (1) 0% full-fat BSFLM. (2) 4% full-fat BSFLM. (3) 8% full-fat BSFLM. (4) 12% full-fat BSFLM. (5) 16% full-fat BSFLM. The feeding trial lasted 49 days, and key metrics such as feed intake, economic efficiency, and carcass quality were evaluated.	Feed intake, economic efficiency (chicken weight and feed cost) and carcass quality	Increasing BSFLM inclusion levels significantly reduced feed intake. The best live weight and feed conversion efficiency ratio (FCE) were observed in the 4% BSFLM group, though differences were not statistically significant. Economically, the control diet had the highest feed cost and lowest efficiency. While carcass yield remained unaffected, the 16% BSFLM group showed poorer performance. A 12% full-fat BSFLM inclusion was identified as the optimal level for improving zoo-economic outcomes, providing a cost-effective protein source for broiler feeds.
	Ahmad et al. (2024)	A feeding trial was carried out on 280 one-day-old village chicks, which were divided into four groups and fed diets containing: (1) 0% black soldier fly larvae (Control), (2) 5% black soldier fly larvae (T1), (3) 10% black soldier fly larvae (T2),	Chicken growth performance and nutritional composition	Chickens on Diet T3 (15% larvae inclusion) achieved the highest weight gain (1231.45 g) and the most efficient feed conversion efficiency ratio (2.03). These results indicate that incorporating

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		(4) 15% black soldier fly larvae (T3). The trial lasted 70 days, with each group having seven replicates of 10 birds.		15% black soldier fly larvae in village chicken diets can improve growth performance without adverse effects.
	Kierończyk et al. (2023)	A total of 400 one-day-old male Ross 308 broilers were assigned to four diet feed systems: (1) a basal diet without dietary fat (HI0), (2) a diet enriched with 30 g/kg of BSF larvae fat (HI03), (3) a diet enriched with 60 g/kg of BSF larvae fat (HI06), (4) a diet enriched with 90 g/kg of BSF larvae fat (HI09).	Chicken body weight	Broilers fed the HI06 diet showed optimal growth performance, suggesting that a 60 g/kg inclusion level effectively supports broiler development.
	Facey et al. (2023)	A total of 1,152 one-day-old male Ross × Ross 708 chicks were divided into 48 pens and fed one of six diets (n = 8 per diet). The diets included: (1) a standard corn-soybean meal diet with 0% BSFLM, (2) a diet with 12.5% BSFLM replacing soybean meal, (3) a diet with 25% BSFLM replacing soybean meal, (4) a diet with 50% BSFLM replacing soybean meal,	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	On day 10, chickens fed diets with 12.5%, 25%, and 0+AGP showed significantly higher body weight gain ($P<0.01$) than those on 0%, 50%, and 100% inclusion levels. During the starter phase, lower Black Soldier Fly meal inclusion levels may provide growth benefits comparable to antibiotics.

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		(5) a diet with 100% BSFLM replacing soybean meal, (6) a 0% BSFLM diet treated with coccidiostat (70 mg Narasin/kg) and antibiotic (55 mg Bacitracin Methylene Disalicylate/kg) (0+AGP). Black soldier fly oil was used for energy fortification in the other diets, while soy oil was used in the 0% BSFLM diet. Key metrics like body weight, feed intake (FI), body weight gain (BWG), and feed conversion efficiency ratio (FCE) adjusted for mortality were evaluated. Organ weights were recorded on days 24 and 49.		
	Mat et al. (2022)	A total of 360 one-day-old chicks were divided into four diet feed systems and fed different amounts of Defatted Black Soldier Fly Larvae (Def-BSFL) for a six-week experimental feeding period. The groups were: (1) a control group with 0% BSFL, (2) T1 with 4% BSFL, (3) T2 with 8% BSFL, (4) T3 with 12% BSFL. At the end of the trial, blood samples were	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	Finisher-stage birds on the control and T1 diets had higher feed intake than those on T2 and T3 diets. During the 6-week trial, the T1 group achieved the highest weight (1043.8 ± 65.9 g). Additionally, birds on T1 (1.1 ± 0.0) and T3 (0.9 ± 0.1) diets exhibited better feed conversion efficiency rates than those on the control (1.7 ± 0.1) and T2 (1.8 ±

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		taken from three chickens in each treatment group to determine the plasma contents.		0.3) diets.
	Waithaka et al. (2022)	This research investigated the growth performance of improved indigenous chickens (IIC) fed diets containing different levels of Black Soldier Fly Larvae (BSFL) meals. The BSFL meal inclusion rates were: (1) 0% (Diet0), (2) 5% (Diet1), (3) 10% (Diet2), (4) 15% (Diet3), (5) 20% (Diet4). These levels of BSFL meal were used as substitutes for expensive fish meal in chick and grower diets.	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	The study found that diet significantly influenced the chicks' average daily weight gain, feed conversion efficiency ratio, and feed intake. However, except for the growers' average daily feed intake, diets had no significant effect on average daily weight gain or feed conversion efficiency ratio.
	Murawska et al. (2021)	The experiment involved 384 male Ross 308 broilers raised until 42 days of age and assigned to four diet feed systems: (1) a control diet (HI0), (2) a diet where soybean meal (SBM) protein was replaced with HI protein at 50% (HI50), (3) a diet where SBM protein was replaced with HI protein at 75% (HI75), (4) a diet where SBM protein was replaced with HI protein at 100% (HI100).	Growth performance and slaughter characteristics of broiler chickens	Replacing more than 50% of soybean meal (SBM) protein with full-fat HI larvae meal negatively affected broiler body weight and feed conversion efficiency. While feed conversion efficiency remained favourable with up to 75% replacement, it worsened at 100% replacement. Final body weights were lower in the experimental groups, highlighting

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				the negative impact of higher larvae meal inclusion on growth performance.
	Pietras et al. (2021)	For the experiment, 160 male broiler chicks were used. At three weeks of age, the chicks were randomly assigned to five different diet feed systems, with four replication pens and eight chicks per pen. The following nutritional diet feed systems were used: (1) Corn soybean meal as the control diet (CON), (2) substituting low-alkaloid yellow lupine seeds (Lup; Lup - SBM group) for 60% SBM, (3) substituting full-fat silkworm (Bombyx mori) pupae insect meals for 100% of SBM (Lup - BMM), (4) substituting full-fat mealworm (Tenebrio molitor; Lup - TMM) insect meals for 100% of SBM, (5) substituting full-fat mealworm (Zophobasmorio; Lup - ZMM) insect meals for 100% of SBM.	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	Broiler chickens fed diets containing lupine combined with soybean meal, silkworm, or mealworm showed no significant differences in final body weight (42 days) or daily weight gain (21–42 days) compared to those on a soybean meal diet. However, the Lup-ZMM group had lower body weight and growth than other groups. Despite this, broilers on the Lup-TMM diet achieved the highest feed conversion efficiency ratio (FCE).
	Schiavone et al. (2018)	At 21 days of age, 120 male Ross 308 broiler chickens were randomly divided into three experimental groups, with five repetitions and	Chicken growth performance	On day 48, 15 chickens from each group were slaughtered. The study found that dietary inclusion of

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		eight chickens per pen. The groups were fed: (1) a control diet (C) containing 68.7 g/kg of soybean oil, (2) the HI50 group, where half of the soybean oil was replaced with black soldier flies, the HI100 group, where all of the soybean oil was replaced with black soldier flies.		black soldier fly had no significant effect on growth performance.
	Hwangbo et al. (2009)	A total of 600 one-day-old Ross broiler chicks were randomly divided into five groups and fed: (1) a basal diet, (2) a diet supplemented with 5% insect, (3) a diet supplemented with 10% insect, (4) a diet supplemented with 15% insect, (5) a diet supplemented with 20% insect.	Chicken growth performance and meat quality of broiler chickens	Results indicated that 10–15% insect inclusion significantly enhanced weight gain, dressing percentage, and muscle yield ($p<0.05$), while feed conversion efficiency ratio remained unchanged. Additionally, lysine and tryptophan levels in breast muscle increased, with no notable differences in meat colour, liver weight, or abdominal fat. These findings suggest that 10–15% insect supplementation effectively improves broiler growth and carcass quality.
Feed 4: Various percentage of palm oil inclusion	Yendou-Gname et al. (2024)	A total of 240 broilers were divided into four groups and fed diets containing: (1) 0% palm oil, (2) 1% palm oil,	Feed efficiency and chicken growth	The results indicated that feed intake rose with increased palm oil inclusion, with the highest average daily weight gain observed in the

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		(3) 2% palm oil, (4) 3% palm oil.	performance	2% and 3% palm oil groups. Feed conversion efficiency ratio improved with 1% and 2% palm oil supplementation.
	Long et al. (2019)	For a 42-day feeding trial, 208 one-day-old female Sanhuang chickens were randomly assigned to four groups, each containing four replicates with 13 chickens per replicate. The diet feed systems included: (1) a control diet with no palm oil, (2) a diet with 2% palm oil, (3) a diet with 4% palm oil, (4) a diet with 6% palm oil.	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	Chickens fed diets with 4% and 6% palm oil showed a reduced average daily feed intake (ADFI) and feed-to-gain ratio (F/G) from days 22 to 42. However, from days 1 to 42, these diet systems resulted in higher average daily growth (ADG) compared to the control. These findings suggest that including 4% and 6% palm oil in the diet may enhance growth.
	Adrizal et al. (2011)	A total of 180 48-week-old native laying hens were divided into 180 cages (1 hen per cage). Diets were assigned to 15 cages at random. The experimental diets included a factorial combination of three levels of Palm Kernel Meal (PKM): (1) 0% PKM, (2) 15% PKM, (3) 30% PKM.	Egg production, feed conversion efficiency, or egg weight	The study found that the inclusion levels of palm oil meal had no significant impact on egg production, feed conversion efficiency, or egg weight. Additionally, the egg quality of chickens fed 15% or 30% palm kernel meal was nearly identical.
	Rahman et al. (2010)	The study involved 300 day-old Hubbard Classic broiler chickens, which were fed diets	Chicken body weight, daily	Broilers fed diets with 2% and 3% palm oil had live weights of 1791g

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		with varying levels of palm oil (2%, 3%, 4%, and 5%). Between the 2nd and 4th weeks of the trial, the inclusion of 4% palm oil in the diet showed a positive impact on the chickens' growth.	chicken weight gain, feed conversion efficiency ratio	and 1777.67g, respectively, showing a 4% and 3% increase compared to the control group. A similar trend was observed in live weight gain, and the addition of palm oil also significantly boosted feed intake.
Feed 5: Effect of inclusion of organic acid	Roy et al (2024)	A total of 150 Cobb 500 chicks were divided into five groups: (1) a control group (T0), (2) three OA-supplemented groups: - T1: citric acid, - T2: formic acid, - T3: acetic acid, (3) an AGP group (T4: oxytetracycline hydrochloride).	Chicken growth performance	Over 28 days, both organic acids (OAs) and antibiotics growth promoters (AGPs) significantly improved feed conversion efficiency ratio (FCE) compared to the control ($p<0.01$). Birds in the OA groups (T1, T2, T3) showed significantly higher body weight gain (BWG) than the control and AGP groups ($p<0.05$), with T1 and T3 achieving the best FCE ($p<0.01$). These results suggest that OAs can effectively replace AGPs in broiler diets, although their effectiveness varies depending on the specific type used.
	Elnaggar, & El-kelawy (2024)	A total of 210 Cobb 500 chicks were divided into seven groups, with diets supplemented	Chicken growth	The study found that organic acid supplementation improved final

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		with varying levels of organic acids. Weekly weight, feed intake, and growth parameters were recorded.	performance and economic efficiency	body weight, weight gain, and feed conversion efficiency ratio. Additionally, dressing percentage increased and abdominal fat decreased across all treatment groups. These findings suggest that incorporating organic acids in broiler diets enhances growth performance and production efficiency, making it a viable alternative to antibiotic growth promoters.
	Islam et al. (2024)	Five hundred Ross-308 male chicks were divided into five diet feed system: (1) a negative control (NC), (2) a positive control with Enramycin (PC), (3) OA supplementation, (4) EO supplementation, (5) a combination of OA and EO. The feeding trial lasted 42 days, divided into starter and finisher phases.	Chicken growth performance	The results indicated that organic acids (OA), essential oils (EO), and their combination significantly improved body weight gain and feed conversion efficiency ratio compared to the control group, while feed intake remained unchanged. Additionally, nutrient digestibility and metabolisable energy were enhanced in the supplemented groups.
	Ebeid & Al-Homidan	Documents review.	Chicken body weight, daily	The ban on antibiotics as growth promoters is largely due to

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	(2022)		chicken weight gain, feed conversion efficiency ratio	concerns about antibiotic resistance and antibiotic residues in poultry products. As a result, organic acids (OA) have emerged as a promising alternative for promoting growth, meeting the increasing demand for antibiotic-free and organic poultry products.
	Sobotik et al. (2021)	A total of 648 Cobb 700 male broiler chicks were randomly assigned to one of four diet feed systems: (1) Basal control diet (CON), (2) CON diet with added synbiotic (PoultryStar; 500 g/MT; PS), (3) CON diet with PS in the starter phase and enhanced organic acid (Biotronic PX Top3 US; 500 g/MT; BPX) in the grower and finisher phases (PS1+BPX2), (4) CON diet with PS in the starter and grower phases and BPX in the finisher phase (PS2+BPX1).	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	The study found no significant differences in overall body weight or body weight gain between the PS, PS1+BPX2, and PS2+BPX1 groups. However, these groups consistently had higher body weight compared to the control group (CON) on days 14, 28, 35, and 42. Both PS and PS2+BPX1 improved the feed conversion efficiency ratio (FCE) compared to the control group from day 1 to 14 and day 1 to 28. The findings suggest that supplementing broiler diets with synbiotics or synbiotics plus organic acids can enhance growth performance.
	Adhikari et al.	800 one-day-old Cobb500 male chicks were	Chicken body	During the grower phase, the feed

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	(2020)	assigned to five diet feed systems: (1) a negative control diet without Salmonella Typhimurium (ST) challenge (NC), (2) a positive control diet with ST challenge (PC), (3) three diets with organic acid mixtures at 0.3%, 0.6%, and 0.9% concentrations along with ST challenge. The treatments were distributed across 20 pens, each containing 40 chicks, with four replicates per treatment. On day 4, chickens were challenged with 107 CFU/mL of nalidixic acid–resistant ST (STNAR).	weight, daily chicken weight gain, feed conversion efficiency ratio	conversion efficiency rate (FCE) was significantly reduced in the group receiving a 9% organic acid mixture compared to the positive control (PC). No significant effects on body weight or body weight gain (BWG) were observed in both the starter and grower phases. However, in the finisher phase, the nonchallenged group (NC) showed higher BWG than the PC ($P < 0.05$), with no significant differences in BWG among the NC and groups fed with organic acid mixtures.
	Aljumaah et al. (2020)	Chickens were divided into 4 groups and fed with the following diet feed systems: (1) T1: a negative control (without supplementation), (2) T2: a positive control challenged with S. Typhimurium without an organic acid blend, (3) T3: a group supplemented with an organic acid blend, (4) T4: chickens fed with an organic acid blend and challenged with Salmonella.	Chicken body weight, daily chicken weight gain, feed conversion efficiency ratio	The study concluded that organic acids positively impact chicken growth performance and can improve the feed conversion efficiency ratio, particularly when chickens are exposed to bacteria.

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	Sabour et al. (2019)	A total of 390 one-day-old Ross 308 broiler chicks were randomly assigned to 6 diet feed systems, each consisting of 13 chicks and 5 replicate pens. The 42-day study involved a baseline diet supplemented with or without organic acid (OA) at 0 or 1 g/kg, and two types of fiber (rice hull [insoluble fiber] or sugar beet pulp [soluble fiber]; 0 or 30 g/kg), as well as their combinations.	Chicken growth performance	The study found that dietary supplementation with organic acids (OA) enhanced broiler performance, and the combination of OA with rice hulls further improved humoral immune responses.
Feed 6: Effect of inclusion of beta-carotene and vitamin E	Wang et al. (2023)	Hens were fed diets containing either 120 mg/kg (βc-L) or 240 mg/kg (βc-H) of β-carotene, and their chicks, once hatched, were fed the same diet.	Chicken growth performance	The study showed that β-carotene supplementation significantly enhanced body weight at 21 days and tibia length at 42 days, promoting overall better growth performance in chickens.
	Mazur-Kuśnirek et al. (2019)	A total of 120 Ross 308 broilers were used in the experiment, with 6 diet systems, 10 replications, and 2 chickens per replication. The chicks were tested with the following diet systems, with and without vitamin E and PP supplementation: (1) Group I (negative control) – no supplementation (2) Group II (positive control) – no supplementation (3) Group III – supplementation with 100 mg	Chicken growth performance	The study found that chickens fed with dietary supplementation of antioxidants, particularly polyphenols (PP), showed better growth performance, including improved body weight, body weight gain, and feed intake, up to 28 days of age.

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		vitamin E/kg (4) Group IV – 200 mg vitamin E/kg (5) Group V – 100 mg vitamin E/kg and 100 mg PP/kg (6) Group VI – 200 mg PP/kg Broiler chicks aged 21–35 days were exposed to a higher temperature (34°C for 10 hours daily) in groups II–VI.		
Chicken Growth performance	Saragih et al. (2024)	A total of 100 *Kampung Unggul Balitbangtan* (KUB) chickens, including both males and females, were monitored from hatching to nine weeks of age. They were fed BR-1 JAPFA Comfeed and had ad libitum access to mineral water. Every week, body weight was measured for a random sample of 20 chickens.	Age and chicken growth performance	The study found that *kampung* chickens reached their optimal body weight growth rate between 42 and 45 days of age, with rapid growth occurring between 35 and 49 days post-hatch. This highlights the importance of proper nutritional management from hatch to 49 days to maximise their growth potential.
	Gultom et al. (2021)	The study utilized *Sentul* and *Merawang* chickens as research subjects. A total of 41 males and females from each breed were included in the experiment. Data collected included body weight and body weight gain from 1-day-old chicks (DOC) to 3 months of age. The t-test was used to compare the	Age	The study found that at 2 months of age, there was no significant difference ($P>0.05$) in body weight between male and female Sentul chickens. However, a significant difference was observed at 3 months ($P<0.05$).

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		average differences, while the correlation test was employed to explore the relationship between body weights.		Both males and females gained the most weight in the first two months. The strongest correlation between body weights for a given age occurred between 1-2 months, suggesting that body weight at 1 month is a reliable indicator for body weight selection.
	Chu et al. (2020)	A multivariate statistical model was constructed to estimate the genetic parameters influencing body weight (BW) of broiler chickens during weeks 1 to 6 of age in a commercial farming setting. The model's development was guided by its ability to predict breeding values, which were assessed using a cross-validation approach based on half-sibling correlations. To account for differences in variance between male and female chickens, the model applied separate standardization procedures for BW data across sexes, thereby accommodating heterogeneity in variance structure.	Age, chicken body weight	These findings support the idea that chicken age is a key factor in understanding and predicting body weight trends, and that age-specific feed and genetic strategies may be needed to optimize growth.
	Tamzil, Ichsan, & Taqiuddin (2015)	A 3 × 7 factorial experiment under a Completely Randomized Design was conducted using three chicken lines: laying-type cockerels, kampong chickens, and	Age, type of chicken, chicken body weight	Age significantly influenced body weight gain, carcass weight, feed efficiency, and carcass part percentages, showing that growth

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		Arabic chickens. Each line had 63 day-old chicks, divided into groups of 7, housed individually. Chickens were observed and measured weekly for feed intake and body weight from weeks 4 to 10. At each week, one chicken per group was randomly selected for carcass analysis, including carcass weight and percentage of parts (drumstick, thigh, wing, breast, back).		performance improves with age. A significant interaction between chicken line and age was found for body weight gain, indicating that growth response to age varies by chicken type.
Initial chicken weight	Patbandha et al. (2017)	The study involved three groups of chicks—low, medium, and high—at Junagadh Agricultural University in Gujarat. The researchers investigated how various factors such as day-old chick weight, length, the ratio of weight to length squared (BMI), the ratio of weight to length, and shank length influenced the growth performance of 76 colored broiler chickens.	Chicken Growth performance - chick weight, length, ratio of weight to length square (BMI), ratio of weight to length and shank length	The study concluded that during the early growth phase (up to two weeks), the weight of chicks on day 1 had a significant impact on the live body weight of coloured broilers. However, chick body mass index (the ratio of chick weight to length squared) and shank length did not influence the post-hatch growth performance of coloured broilers.
	Michalczuk et al. (2011)	A total of 728 Ross 308 chicks were used in the study. The chicks were housed on litter in compartments, with eight cubicles randomly assigned. At one day old, the chicks were marked for identification. Each bird's body weight was recorded individually on days 1,	Chicken final weight	For rearing, Ross 308 chicken broilers should be selected with a body weight of more than 40g. By day 42, smaller chicks tend to have a lower body weight compared to larger birds, but they

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		8, 15, 22, 29, 36, and 42. The data was then divided into three groups, each consisting of 91 chicks, for statistical analysis. The chicks were grouped based on their one-day body weight: group 1 had chicks weighing ≤39g, group 2 had chicks weighing between 40g and 42g, and group 3 had chicks weighing >42g.		exhibit the fastest growth rate.
Profitability	Wantasen et al. (2024)	Data was gathered in the Kayuwatu and Tounelet villages of Indonesia through surveys and interviews with 60 farmers during April and May 2023.	Factors affecting profits	The regression model showed that 58.3% of profit variation was explained by costs related to chicken purchasing, corn feed, bran, medicine and vitamins, labour, and electricity, while 41.7% was influenced by other unaccounted factors. Significant impacts on profitability ($p<0.05$) were found in chicken purchasing, electricity, and corn feed costs, while bran, medicine, vitamins, and labour costs did not significantly affect profitability.
	Supriya et al. (2024)	A total of 160 day-old Vencobb 430Y broiler chicks were randomly selected and divided into five diet feed systems, each with four replicates of eight birds. The chicks were reared up to 42 days of age. The diet feed	Feed cost, profitability	The results showed that while organic acid supplementation did not significantly affect serum cholesterol or LDL levels in the birds, the FSBM (T2) group

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		systems were as follows: (1) Basal diet with corn-soybean meal (control) (2) Control diet with 100% replacement of soybean meal by FSBM (3) Control diet supplemented with 0.05% probiotics (4) Control diet supplemented with 0.1% organic acids (5) Control diet supplemented with both probiotics and organic acids		experienced lower production costs and higher net profit gains due to reduced feed costs. This was followed by the organic acid group (T4), probiotic group (T3), control (T1), and combination group (T5).
	Nasarudin et al. (2024)	Journal review	Profit (Return on cost)	The inclusion of 15% *Trichantera gigantea* in broiler feed resulted in the highest return on cost, suggesting it as an economically beneficial addition to broiler diets.
	Waithaka et al. (2022)	This research investigated the growth performance of improved indigenous chickens (IIC) fed diets containing different levels of Black Soldier Fly Larvae (BSFL) meal. The inclusion rates of BSFL meal were 0% (Diet0), 5% (Diet1), 10% (Diet2), 15% (Diet3), and 20% (Diet4), with BSFL meal serving as a substitute for expensive fish meal in both chick and grower diets.	Profit margin, cost-benefit ratio	The study found that feeding birds Black Soldier Fly Larvae (BSFL) meal resulted in the highest cost-benefit ratio (2.12) in Diet 4. The incorporation of BSFL meal as a replacement for up to 20% of fish meal proved to be a cost-effective and successful alternative without compromising the growth performance of indigenous

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				chickens (IIC). This suggests that BSFL meal could be a valuable component in poultry feed production, potentially reducing feed costs while maintaining optimal production and lowering the cost of meat and egg products.
	Gbigbi & Isiorhovoja (2022)	A multistage sampling technique was employed to select 120 farmers, and data was collected from them using a structured questionnaire. Descriptive and inferential statistics were used to analyse the data. The research assessed profitability using the budgetary technique, analysing indicators such as net income, profit margin percentage, and return per naira invested: • Net farm income = TR − TC • Profit margin % = (Net income / Total income) × 100 • Returns per naira invested = Total income / Total cost Where: • TR = Total revenue • TC = Total cost • TFC = Total fixed cost • TVC = Total variable cost	Cost of feed, chicken cost and labour cost	The research showed that feed costs accounted for the largest proportion of expenses in exotic chicken production at 34.28%, followed by labour costs at 23.29% and the cost of day-old chicks at 14.11%. The least expensive component was rent on generators, contributing only 0.93% to the overall costs.

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	Rifky (2016)	A total of 100 contract (Buy Back) broiler producers were randomly selected from the Kurunegala, Puttalam, and Kalutara districts. The profit function approach was used to conduct a cost and return analysis of different sizes of outgrower broiler producers. The analysis included quantitative variables such as feed conversion efficiency ratio (FCE), mortality rate (percentage per flock), input quantity, average body weight (kg/bird), and broiler farming engagement (hours/month).	Factors affecting the profitability of contract	The study concluded that increasing input quantities can boost profits by reducing operating costs, such as feed, day-old chick transportation, electricity, and labour costs. This approach helps in optimizing production and improving overall profitability.