A Description of the Chemical and Physical Growth of New Zealand White and Chinchilla Rabbits

By

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PREFACE

The candidate conducted the research presented in this thesis while affiliated with the Discipline of **Animal and Poultry Science**, School of Agricultural, Earth and Environmental Sciences within the College of Agriculture, Engineering, and Science at the University of KwaZulu-Natal in Pietermaritzburg, South Africa under the supervision of Dr. Z. T. Rani-Kamwendo. The study's contents have not been presented in any manner to another university, and unless explicitly acknowledged in the text, the reported results are attributed to the investigations conducted by the candidate.

Signed ……. Date: 1st February 2024

Adenike Adetutu Eniwaiye (Candidate)

As supervisor of the candidate, I agree to the submission of this dissertation.

08/ 02/ 2024

Signed: ……. Date: …….

Dr Z. T. Rani-Kamwendo

DECLARATION

I, ENIWAIYE Adenike Adetutu, declare that:

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Dr Z. T. Rani-Kamwendo

DEDICATION

I dedicate this dissertation to the Almighty God, the Author, and the Finisher of my faith. You knew all that I went through in the process of the work, and you kept me strong to the end. It can only be you.

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General Abstract

This study investigates two key aspects in animal science: (i) describing the growth potential and chemical composition of two commercially bred rabbit strains, in order to optimize the composition of their feed based on variables predicted by simulation modelling; (ii) testing the hypothesis that the allometric relationship between body parts remains consistent across different strains, sexes, and body protein levels. In other words, the research assesses whether animalscientists have faced challenges in modifying the proportional relationship between the weight of different body parts of rabbits and their body protein weight. The primary goal of the study was to outline the physical and chemical transformations in the body composition of two commercially bred rabbit breeds, namely New Zealand White and Chinchilla, over a 126-day growth period. The key focus was on investigating how the growth performance of developing rabbits is affected by sex and age,considering the influence of body protein. Moreover, the research examined alterations in growth and variations in the physical and chemical elements of the body.

To achieve the objectives, series of studies were conducted: In this experiment, a total of 220 rabbits, consisting of both New Zealand White and Chinchilla strains, were utilized. Weekly weighing of 100 rabbits from each strain were conducted, starting from day 14 (due to the fragility of the kittens at birth) and continuing until day 140, in order to assess the growth potential of each rabbit. Additionally, samples were collected from 120 rabbits from each strain at specific ages: day 14, 21, 28, 35, 42, 56, 70, 84, 112, and 140. Before slaughter, the animals underwent weighing to determine their weight exclusive of internal organs. Post-slaughter, their weight was measured again to discern the weightof internal organs, skin, and the weight without the skin. The dissected body parts were weighed,labeled, and stored in a freezer for subsequent thawing and mincing. The specimens were then subjected to freeze-drying to extract water content. Following this, they underwent further grinding before being analyzed for protein, lipid, and ash.

Moreover, the Gompertz equation was applied to individual body parts and the protein weight of each body component. The parameters of the Gompertz equations were defined as the final weight of these components, their rate of maturation, and the time required to achieve the peak growth rate of each component. By utilizing data from each individual rabbit, allometric regressions were employed to establish the relationship between the weights of physical and chemical components. The natural logarithm of body protein weight served as the independent variable, while the natural

logarithm of body component weight served as the dependent variable.

A significant allometric relationship was found between body weight and pelt weight, as the weight growth process occurs continuously from birth to maturity. Body weights and chemical composition of males and females (bucks and does) of the two strains remained similar throughout the trial. Mature body weights for both strains (New Zealand White and Chinchilla) at 140 days averaged 1760 g and 1558 g; mature body protein weights averaged 95 g/kg and 61 g/kg; and mature body lipid contents averaged 40 g/kg and 55 g/kg, respectively. Rates of maturing per day of body weights for males and females of both strains averaged 0.0241 and 0.251; pelt-free, 0.0294 and 0.0251, and body lipid was 0.0441 and 0.0225, respectively. The rates for body protein differed between New Zealand White females and Chinchilla females (0.0172 vs 0.0256/d). Separate equations were needed for males and females to describe the allometric relationships between lipid and protein in the pelt-free body. The rate of maturing of pelt in the New Zealand White was higher in females than in males (0.0249 vs 0.0214/d), and the mature weight was lower in females than in males (45vs 52 g/kg), respectively. Common values of the sexes for both strains are represented when therewere no apparent variations in the constant terms and regression coefficients. The saddle weights,regardless of the protein content in both sexes of the New Zealand White, can be described by a single constant term of 1.0193, and a lower single constant term value of -1.1070 in the Chinchillarabbit. The goodness of fit (R^2) for both strains was highest in the saddle with 0.974 and 0.957 inthe New Zealand White and Chinchilla *gigantas* rabbits, respectively, while it was lowest (0.922) in the pelt of New Zealand White and hindlimb (0.892) of the Chinchilla *gigantas* rabbits. Sexes differed in the allometric relationships of all component parts measured in both breeds. A common relationship between the two strains could be used to predict the weights of all rabbit major component parts. Further studies are recommended to confirm the findings of this study.

Keywords: Chemical, Chinchilla, Components, Physical, New Zealand white, Rabbits.

Thesis Output

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Eniwaiye, A. A., Rani, Z. T. and Gous, R. M.A description of the growth of the major body components of 2 breeds of rabbits.

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List of Abbreviations

BASH – Body ash

BLIPD – Body lipid

BP – Body protein

BPm – Body protein at maturity

BWTR – Body water

CFI – Controlled feed intake

d – day

DFI - Desired feed intake

EBPW – Empty body protein weight

EE – Effective energy

exp - Exponential

F - Female

f – Function of

G – Gram

G/ kg – Gram per kilogram

Kg – Kilogram

ln – Logarithm

M – Male

M.E – Metabolizable energy

M.J – Mega Joules

N – Nitrogen

NS – Not significant

NZW – New Zealand White

P – Probability

R.M.S. – Residual mean square

R^2 – Residual square

RFI – Restricted feed intake

SEM – Standard error of means

SE – Significant error

Wm – Water at maturity

WT – Weight

CHAPTER 1

GENERAL INTRODUCTION

1.1. Background

Although not widely regarded as one of the most popular animals globally, the rabbit does possess a crucial role in enabling sustainable production of animal protein. A meat's general acceptability depends largely on its qualities, which can be chemical or physical and can vary depending on pre-slaughter (feeding, environment, age, gender) and post-slaughter (pH, chemical composition) conditions of the animal (Emmans, 1986). Age and slaughter weight of the animal have a significant effect on the carcass quality (Dalle Zotte, 2002). There are also different influences of sex on these characteristics (Cavani *et al*., 2000). Emmans (1987) highlighted that a model simulation may be useful to nutritionists and geneticists in improving production efficiency and profitability. To assess performance and dietary requirements in varied circumstances, this method considers a number of factors, including genetics, environment, and nutrition. When trying to predict the impact of various physical and chemical elements on potential growth, several factors come into play, such as adverse conditions, stocking density, and welfare (Emmans and Kyriazakis, 1995). The key components of the pelt- free body, namely protein, water, ash, and lipid, exhibit growth curve that can be described by Gompertz functions of time, all with the same rate of maturity (B); A + C*exp (-exp (-B*(X -M))).The variables in the mentioned equation correspond to the weights of the chemical components when they reach maturity (Emmans and Fisher, 1986).

Understanding the development patterns and growth rates of animals is crucial for the meat industry, as it enables the practice of selective breeding to optimize the rate of tissue formation (Ibanez-Eschriche and Blasco, 2011).This information can also be employed to establish the ideal slaughter age (Knizetova *et al*., 1991).To investigate and assess animal growth, growth curves are frequently utilized, which involve examining individual growth patterns. Differential equations are commonly used to model these growth curves, with the goal of obtaining a biologically relevant interpretation (Arango and Van Vleck, 2002). Since the weight accumulation of protein, ash, lipid, and water is allometrically connected to the empty body protein weight (EBPW), it can be used as a reference point to compare and forecast the growth of body component weights. Although

biological tissue growth exhibits a sigmoidal trend, the progression of empty body growth becomes evident as these components accumulate (Huxley, 1932; MacDonald *et al*., 2002). The relationship among different tissues and components reveals insights into the body's development and growth (Emmans, 1989; Ferguson, 2006). Throughout the growth process, the body's proportions undergo consistent changes; this phenomenon of non-isometric scaling is referred to as allometry.

The word "potential" is used in the conventional sense, suggesting that there had to be a potential before the "actual" could be seen. The actual growth data, which reflects the changing "potential" as a result of the current environment, can take many different forms. The growth that really takes place is a product of the animal's environment allowing its potential to be realized to varying degrees over time (Emmans, 2022). Any conceptual approach to forecasting needs and reactions involves predicting the potential outcomes of performance (Emmans and Fisher, 1986). A thorough explanation of potential must accurately address the systematic changes in the body's chemical and physical composition that take place during the process of growth. A growing animal's form or state changes as it progresses toward maturity, regardless of whether limiting or non-limiting conditions are present. An augmentation in body weight generally aligns with an increase in carcass weight and the weight of its individual components. During this time period, there has been a substantial change in all of the major chemical components, namely protein, water, ash, and lipids (Fisher, 1983) and in all of the physical components, as well, e.g., the pelt, the fore and hind limbs, the bones, the head, etc. (Murawska *et al*., 2015). A thorough explanation of potential growth must accurately address the systematic changes in the body's chemical and physical composition that take place during the process of growth. A growth function can be employed to illustrate the presence of protein within the body, facilitating the connection between the growth of body water, body ash, body lipid, and body protein. This connection can then be used to determine the comprehensive rate of body growth, following the approach outlined by Emmans (1989). The growth trend of body protein can be elucidated using a similar methodology as applied to weight.Two approaches are available for predicting the growth of the remaining chemical components inthe body. The first involves utilizing hypothesized allometric relationships between different body parts while the second entails directly estimating their growth parameters using nonlinear approaches (Emmans and Fisher, 1986; Emmans, 1989).

Male and female New Zealand White and Chinchilla *gigantas* rabbits were compared using the Gompertz nonlinear regression model to estimate body growth, identified as the most suitable

model for representing rabbit growth by Casta *et al*. (2013). The Gompertz model employs three parameters—initial weight, mature weight, and rate of maturity—to create a quadratic function over time. Utilizing a growth curve over an animal's entire life is considered more accurate. Mathematical models for predicting reactions to production technique adjustments and maximizing profitability have garnered significant attention. Evaluating the potential rate at which animals can grow and the constraints imposed by alterations in body protein composition is crucial in developing a rabbit growth model (Emmans, 1987).

Various research findings have indicated a robust correlation between linear body measurements and actual weights of farm animals, providing insights into performance, productivity, and carcass quality (Ige et *al*., 2006). The distinction between prospective growth (theoretical) and observed growth (under normal conditions) is significant in growth research. As knowledge about animals expands, modelling becomes increasingly vital for organization and assessment. Growth models, increasingly favoured in the industry, enable more accurate predictions of rabbit performance based on potential growth rates. Simulation models prove useful when estimating the growth rate of carcass parts.

Allometric equations, dependent on the protein composition of the body, are employed to predict the weight of various carcass components. It was essential to determine the degree of differences in the physical constituents at a comparable protein weight throughout the body. This was crucial for meeting the experiment's objectives in constructing a growth model capable of more accurately anticipating potential fluctuations in these. To achieve this, study was conducted with New Zealand White and Chinchilla *gigantas* rabbits under identical diet and climatic conditions, investigating the impact of gender and age on allometric relationships between variousphysical and chemical components and their body protein content.

1.2 Justification

Although there is a lack of research on the chemical and physical changes in rabbits as they grow, accurately predicting the rate of growth and body composition of rabbits continues to be a persistent challenge in animal production (Emmans, 1987). Fortunately, this problem can be solved by using simulation models that can determine animal performance. These models, which have been built through many decades of scientific advancement, are crucial for illuminating the

variables affecting livestock performance. The implementation of growth models has spread widely across the poultry industry. This makes it possible for nutritionists and geneticists to predict animal performance by taking certain diets or exposure to certain feeding schedules into account. Utilizing simulation models could enable farmers to optimize their productivity and financial gains. In addition to benefits relating to animal performance, creating a simulation model can also have other significant benefits, especially when animals are included in the research process. For simulation models to effectively assess the prospective development of the physical and chemicalmakeup of rabbits across diverse conditions, accurate determination of carcass component growth rates becomes exceedingly significant. The rabbit growth model utilizes allometric equations to predict the weights of diverse carcass components, considering the influence of body protein weight. To refine the population response model, it was essential to ascertain the degree of variation in the weights of biological components at consistent body protein levels. This determination is crucial for achieving a more accurate estimate of the potential fluctuations in theseweights. The objective of this study is to contribute to a broader initiative aimed at constructing amechanistic model of rabbit growth. With this objective, this study evaluated how gender and age impact the growth performance of New Zealand White and Chinchilla rabbits,along with exploring the allometric relationships between the body's physical and chemical components and body protein.

1.3 Objectives

The primary aim of this research was to assess how sex and age impact the growth performance of developing rabbits, specifically focusing on the New Zealand White and Chinchilla breeds, and considering the influence of body protein. Additionally, the study explores variations in growth and changes in the physical and chemical components of the body, includingmoisture, ash, fat, and protein. By examining the weights of these components in relation to each rabbit's protein content, the research determined the allometric relationships and draw comparisons between the two breeds and their sexes.

The specific objectives were:

1. To assess the physical characteristics of New Zealand White and Chinchilla *gigantas* rabbits usingallometric measurements.

2. To allometrically assess how sex and age affect the physical and chemical components of New Zealand white and Chinchilla *gigantas* rabbits.
3. To assess the possible development and chemical makeup of New Zealand White and Chinchilla *gigantas* rabbits (including moisture, ash, lipid, and protein), considering the impact of internal protein weight, through utilization of the Gompertz equation.
4. To describe the current research being conducted to create a mechanistic model of rabbit growth as part of a bigger initiative to increase animal production using simulation modeling.

1.4 Hypotheses

1. The physical characteristics of New Zealand White and Chinchilla *gigantas* rabbits using allometricmeasurements are similar.
2. As the *ln*-body protein weight increases, the growth of the chemical body component (moisture, ash, lipid, and protein) changes in a significant manner.
3. A simulation-based mechanistic model of rabbit growth will enhance animal productivity by identifying the fundamental biological mechanisms and determining the most effective management approaches.
4. Mechanistic modelling can be used with the assistance of a simulation model to increase animal production.

CHAPTER 2

REVIEW OF LITERATURE

Predicting the Growth, Body Composition and Desired Feed Intake of Rabbits

2.1 Introduction

Knowing the amount of food that a developing rabbit will take when fed feeds with varying compositions and the nutrients it will require throughout its growth phase are essential for optimizing the feeding of rabbits. As relatively little pertinent research has been done with rabbits to estimate their requirements, the first of these, forecasting nutrient requirements, has been based on ideas utilized in the chicken sector (Iji *et al*., 2003). Although this has been successfully accomplished for pigs and poultry (Ferguson *et al*., 1997), there haven't been many attempts to predict food intake by rabbits using the principles outlined by Emmans (1981). The prediction of food intake is dependent on the animal's potential rate of growth (Emmans, 1981, 1989).

Several factors, including nutrition, genetics, environment, and maturation stage, play a role in the intricate relationships between food intake and the chemical and physical composition of the body (Gous, 1998; de Lange *et al.,* 2003). Models simulating body weight gain or chemical body composition, solely based on protein deposition, may accurately represent animals on a well-balanced ad libitum diet. However, if animals are provided with imbalanced feeds, these models may introduce systematic errors (Emmans and Kyriazakis, 1995). This is due to the possibility that the values of other model-considered factors, such as physical body weight, ad libitum food intake, heat loss, and maintenance, could significantly affect how well these models predict the future.

According to Brody (1945), regression equations connecting live weight to age were the first models of animal growth. The first animal growth models that connected food intake to growth performance were created in the late 1950s and early 1960s. Static models were utilized to determine the energy and protein requirements of animals at particular body weights (Blaxter, 1962; ARC, 1965). Animal body composition can be manipulated through nutrition. According to Walter *et al.* (1996), animal productivity depends on giving animals a diet that is balanced and knowing how those nutrients are used metabolically. Both the deposition of body fat and protein and the maintenance of essential living activities require energy. A certain amount of fat is

necessary in farm animals' bodies, even though excessive levels are undesirable. The body uses fats and carbohydrates as the best sources of substrate for body fat synthesis and as a metabolic fuel, although proteins are also frequently used in this capacity. The fact that animals accelerate their growth in response to more nourishment has long been known. Much like it does with many other biological relationships, the law of diminishing returns applies in this instance (Walter *et al*., 1996). According to Ferguson *et al*. (1994), Emmans and Kyriazakis (1999), and Wellock *et al*. (2003), an account of an animal's potential growth must also address the systematicalterations that take place in the body's chemical and physical makeup.

Several mathematical functions have been applied to explain the growth pattern at different stages of life (Parks, 1982; Von Bertalanffy, 1957; Brody, 1945; Gompertz, 1825). Emmans (1989) states that the Gompertz function is the most appropriate and useful function when defining the potential of the animal, rather than its actual growth, as is necessary when estimating feed intake using Emmans' (1981) theory. Potential growth can be described by just three characteristics, each of which has biological significance. Potential growth peaks at roughly 0.368 g/kg of the animal's adult weight and then decreases to zero at maturity.

Consideration of growth models has been given to how to feed rabbits more effectively. According to reports, they can help determine effective feeding plans and maximize the age at which animals are slaughtered (Malhado *et al.,* 2009). Pre-existing models were created by fitting intake and growth curves to regressions; this allowed users to assess the effects of treatments on growth rate and to simulate trends (Bathaei & Leroy, 1996; Malhado *et al*., 2009). Redden *et al*. (2013) stated that in order to increase the accuracy and utility of a production model, it is advantageous to include additional production factors like feed intake and feeding efficiency. On the other hand, Schulze *et al*. (2013) noted that an animal's size and weight have an impact on feed intake. Emmans, (1997), Emmans and Kyriazakis (2001) suggest that it is more appropriate to see feed intake as an effect of potential growth rather than its source. It is naive to think that feeding programs can be successfully adjusted because the composition of the feed supplied has major influence on voluntary feed intake, as food intake is an input in most growth models. Therefore, feed intake needs to be considered an output rather than an input in a model (Emmans, 1981a). The Gompertz growth function must therefore be used to determine the animal's prospective growth rate in order to accurately anticipate feed intake (Emmans, 1981).

Hence, this review explains how to calculate the amounts of nutrients needed for development and maintenance, how to estimate the possible rates at which fat and protein are deposited during growth, and how body protein content can be used to predict body composition. This information serves as the foundation for the prediction of animal feed intake, which is then explored and a discussion of how simulation modeling can be used to forecast rabbit feed intake follows.

2.2 Nutrient Requirements for Maintenance and Growth

For upkeep and development, feed-derived energy, amino acids, and major and minor minerals are needed. Body size, ambient temperature, activity level, management technique (intense or extensive), and potentially animal breed are all factors that affect the maintenance component (Emmans, 1986). These nutrients are necessary for the growth of ash, fat, and protein, which happens only when the needs for maintenance are satisfied. If the genotype and condition of the animal are known, requirements for every nutrient can be computed for every day of the growth phase (Emmans, 1981). Understanding the values of the nutritional constants is crucial because it enables one to forecast the needs for the growth and maintenance of any genotype in any state when it is maintained in a thermo neutral environment. The challenge with nutrient need prediction is typically combining genetic characteristics with nutritional constant values; the feed's composition will then dictate the required feed intake. The amount of feed that will enable the potential output to be realized is the desired feed intake.

2.2.1 Maintenance Requirements

According to Emmans and Fisher (1986), the ratio of body protein content at maturity (BPm) and the animal's degree of maturity at that point (BPt/BPm) can be used to calculate the maintenance requirements for energy and each necessary amino acid. The required amount of dietary protein is determined by the coefficient of 0.008 grammes per kilogram of body weight for maintenance. Similarly, the energy need is determined by the coefficient of 1.63 megajoules per kilogram of body weight for maintenance. Emmans (1981) determined the feed's effective energy content. Animals require maintenance for a variety of reasons, including maintaining body temperature, repairing damaged tissue, breaking down food, and facilitating basic functions like breathing, eating, and drinking water (Dozier, 2003). The use of regression equations for energetic balance components—which can be ascertained using direct calorimetry, indirect calorimetry, and

carcass analysis—and calorimetric measurements, maintenance requirements have been established in feeding trials (Spratt *et al.*, 1996).

The daily requirement for each nutrient is determined by employing a factorial approach, which involves combining the requirements for development and maintenance (Emmans and Kyriazakis, 2001). The desired feed intake (DFI) for each nutrient can be calculated by comparing its required amount with the amount of that nutrient in the feed that is being offered. This allows one to identify which nutrient in the feed is the first-limiting nutrient. The animal will try to eat enough of the provided feed to satisfy its need for this first-limiting nutrient, in accordance with Emmans' (1981) idea, in an effort to always reach its full potential.

2.2.2 Growth Requirements

Based on an animal's condition and genetic description, one can estimate its rate of growth (Oldman and Emmans, 1990). To convert growth and fattening rates into rates of energy and protein supply, there is a need to establish an energy scale using nutritional constants to solve an energy issue. This will enable measurements of demand and feed resources on an identical scale (Emmans, 1991). It is considered that regardless of genotype and diet, the quantity of heat generated by bodily processes (excretion, fermentation, feces, growth, and fattening) is constant. Thus, the work that is done as a result of a feed increment includes the increment of heat.

Animals require six types of nutrition. Water, protein, vitamins, minerals, energy, and fatty acids are among them. Animal diets should be designed to provide the right amounts of energy, 10 amino acids, 12 minerals, 13 vitamins, and other nutrients in precisely the right proportions to meet the requirements of the animal for development, upkeep, and reproduction (Dozier, 2003).The minimal amount of a particular nutrient required when all other nutrients are providedin sufficient amounts to support normal growth and reproduction while also preventing the onset of symptoms of nutritional shortage is known as the nutrient's needs. According to the NRC (1994),expressing the amount of nutrients an animal needs each day is the most precise method.

2.3 Estimating Rates of Nutrient Deposition and Changes in Body Composition

While the modeling of growth in livestock animals has gained widespread recognition for its simplicity and applicability in recent years, the study of nutrient deposition rates in rabbits has

received limited attention (Black *et al*., 1995; NRC, 1996). To simulate feed intake and animal growth, making predictions about nutrient requirements, feeding programs, and environmental conditions, it is imperative to determine the potential growth rate of various genotypes (Gous *et al*., 1991; Hancock *et al*., 1995). Understanding changes in body condition over time requires accounting for feed intake, as modifications in the body result from nutrient inputs (Kemm *et al.*, 1991).

Quantitative explanations and theories about the mechanisms governing the growth response to feed intake are thus necessary. When determining feed intake allowances, both the quantity and quality of available feed must be considered, as they influence changes in carcass composition during animal growth (Kyriazakis and Emmans, 1992a, b). Whittemore (1986) emphasizes that feed intake, not time, should be the focus when analyzing growth responses. This approach is based on a linear phase that starts as feed supply increases, reaching a plateau representing the maximum protein development. Beyond this threshold, excess ingested food is converted into fat.

Providing animals with imbalanced feeds in relation to their nutritional needs' deviates from the optimal growth of chemical components in their bodies, such as water, protein, fat, and ash. In instances of low-protein feeds, animals tend to consume more of the nutrient limiting their growth potential, leading to an excess accumulation of body lipid (Gous *et al.*, 1990). Except for body lipid, the other chemical components remain relatively constant relative to body protein throughout the growth period, allowing for approximations of their weights based on the body protein weight at any given growth stage. Additionally, there exists a correlation between body protein weight and the weights of the body's physical components. According to Statt and Leeson (1987) and Attia *et al.* (1995), body weight growth linearly corresponds to increased energy allocation. The resulting equations can be employed to predict the weights of all chemical components (excluding lipid) and physical components of the body. These allometric relationships need to be established for each genotype or strain. Anticipating the rate of growth of body proteins is crucial for accurately predicting changes in the growth of all body components.

2.4 Estimation of Body Composition from Body Protein

The total amount of protein needed for the body's growth and maintenance is defined as the protein requirement. It is customary to ensure that the preservation of lipids, ash, and water does not rely

on any protein (Emmans, 1995). The activities of protein growth and the specific weight correlations among different body components during potential growth can be employed to characterize protein in the body and determine the growth of water, ash, and fat (Emmans and Fisher, 1986; Emmans and Oldham, 1988; and Emmans, 1989). According to the findings of Eits *et al.* (2002), animals need to grow in line with their prospective growth curve and consume a well-balanced diet without restrictions to maintain a consistent relationship between water, ash, and protein. The daily estimation of the potential growth rate of the animal's protein is genotype and condition dependent. Subsequently, it becomes possible to estimate the potential rates of development for other chemical components, facilitating the calculation of the necessary nutrient demand (Ferguson *et al*., 1993).

Kyriazakis and Emmans (1991) additionally demonstrated that animals would utilize their accumulated fat as an energy source when there is sufficient protein in their diet and when their lipid level surpasses the body's inherent lipid-to-protein ratio due to excessive eating. According to Emmans and Kyriazakis (1995), simulations focusing solely on protein deposition for body weight gain or chemical body composition may be accurate when applied to animals consuming balanced diets ad libitum. However, these simulations may contain systematic errors when applied to animals with low feed intakes or extreme protein-to-energy ratios. The allometric relationship between these components is applicable only during the animal's growth to its maximum potential in a thermoneutral environment. Factors like imbalanced feed, feed restrictions, feed digestibility, and sex can influence the rate at which lipid deposition occurs relative to protein deposition (Emmans and Oldham, 1988). Gous (1998) suggested using free-choice feeding systems to assess the growth parameters and allometric relationships of grounded/ mashed strains for a more accurate estimation of the mature lipid-to-protein composition of the strains.

2.4.1 Body Growth

Emmans (1995) suggests that when the body reaches its maximum development potential, there is a systematic shift in its composition, both chemically and physically. Hence, it becomes imperative to incorporate these adjustments when conducting a comprehensive analysis of potential performance requirements (Gous *et al*., 1999). Zoons *et al*. (1991) asserted that growth, a multifaceted phenomenon, is influenced by various environmental and genetic factors. Emmans (1986b) breaks down growth into two components: fat growth and normal growth, encompassing

protein, ash, water, and a minimal lipid quantity. As articulated by Emmans and Fisher (1986), conceptualizing an animal's body as an empty body and gut-filled mass offers insight. The most straightforward method to gauge body growth rate is by examining the actual weight change over time. The percentage of the body that is gut-filled is typically disregarded, but it should be measured because it varies depending on the time or treatment given to the chickens (Fisher, 1983). The amount of food consumed, and the make-up of the feed can be used to forecast gut fill.

2.4.2 Empty Body Weight and Composition

Deducting the gut fill from the body weight after plucking is known as the empty body weight. The four chemical components' relationships alter during growth to enable modifications in functional anatomy. The primary factor in most models is body protein, which determines the interactions between moisture, ash, and growth rates through allometric correlations. The examination of these relationships has been undertaken by researchers such as Emmans and Fisher (1986), Hancock *et al.* (1995), Gous *et al.* (1999), and Emmans *et al.* (2002). Taylor (1980) noted that the body's composition serves to define the animal's present state or condition, subsequently used to determine the growth rates of the remaining body components. This process involves achieving equilibrium in the allometric relationships between protein and ash, moisture, and lipid (Moughan *et al*., 1990). Taylor (1965) highlighted a distinct correlation between protein and non-protein components, asserting that the ratios of moisture and ash content concerning protein remain constant at any given stage of maturity. This implies that the structure of the empty body undergoes systematic alterations throughout its growth. An allometric function, under unrestricted growth conditions, can describe the relationship between protein weight and lipid, water, and ash, as formulated by AFRC (1991): Ct = a x Ptb (kg).

Where:

a = a scalar value

$b = (InC_m - InC_o) / InP_m - InP_o)$

C_m = mature component weight (kg)

C_o = component weight at birth (kg)

P_m = mature protein weight (kg)

P_o = protein weight at birth (kg)

Allometric relationships among feed components are applicable solely when the animal is attaining its maximum growth in an environment with optimal temperatures. The rate of lipid deposition relative to protein deposition can be influenced by various factors, such as sex, feed restriction, digestibility, and imbalanced feed (Emmans and Oldham, 1988). Gous (1998) and Gous *et al*. (1990) recommend employing free-choice feeding systems for a more precise estimation of the mature lipid-protein content of grounded/ mashed strains when assessing growth characteristics and allometric relationships. Contrarily, Eits *et al.* (2002) put forth an alternative perspective, suggesting that animals must grow in line with their potential growth curve while freely consuming balanced dietsto maintain the consistent relationship between water, ash, and protein. According to the hypotheses proposed by Kyriazakis and Emmans (1992), situations of restricted growth are expected to result in a decrease in protein and water deposition in line with their intrinsic allometric relationship.

2.4.3 Gut Fill Composition

The difference between the body weights when empty and when alive is known as eviscerated weight, as described in figure 2.1. Feeding characteristics, feeding time, and feeding level can all have an impact on it. In order to compute the weight gain of the body without feathers or fur, it is essential to estimate or have knowledge of the amount of food in the digestive system (gut fill). This information can be used in conjunction with the growth rate of the body without feathers or fur (empty body) to determinethe weight gain (Emmans, 1989). Emmans (1989) noted that, aside from genetic differences, considerable diversity stems from variations within and among eviscerations when partitioning meat, skin, giblets, abdominal fat, evisceration losses, blood and feather, and total carcass bone. As a result, establishing a mathematical correlation between these components proves challenging.Carcass bone weight can function as a physical indicator of size, similar to how body protein weight serves as a chemical indicator of size. This study identified a consistent correlation betweenthese two size indicators, as both body protein weight and carcass bone adhere to a Gompertz function (Emmans, 1989).

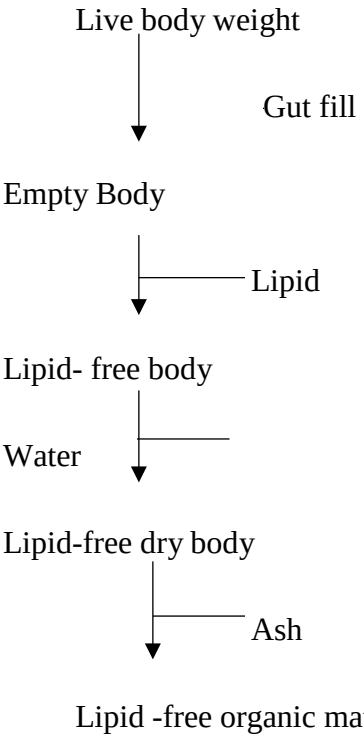

Figure 2.1: Schematic description of the body of a bird.

Source: Emmans and Fisher, 1986.

2.4.4 Physical Body Growth

The notion that an animal belonging to a specific species will reach its ultimate or mature size within a forecasted timeframe is a commonly acknowledged and practical concept (Parks, 1982); however, the optimal measurement scale for size remains undetermined. The concept of mature size can be quantified by incorporating protein weight in models of pig and poultry growth, as discussed by Emmans and Fisher (1986) and Knap (2000). Utilizing protein to ascertain mature size is essentially analogous to defining mature size as the weight of the mature body without lipids since the protein content of the mature body without lipids remains relatively constant (Emmans, 1998). Considering that the protein content of the mature lipid-free empty body remains rather stable (Emmans, 1998), employing protein as a surrogate for mature size is akin to defining mature size as the weight of the lipid-free empty body at maturity. Taylor *et al*. (1986) suggested adjusting the measured mature weight to account for a consistent 25% fat content to accurately represent the mature size. This is equivalent to implementing the suggestion of Taylor *et al.* (1986) but with

a fixed fat content of 0% when assessing mature size using weight without lipids. Differentiating between the concepts of mature fatness and mature size becomes simpler with the latter modification.

An animal's protein content in a model indicates its physiological age. Both protein and water content can be used as indicators of age since they both change predictably with physiological age. Though it does indicate some mineral storage, fat-free body weight would also be a good indicator of physiological age (Loewer *et al*., 1980a). According to Loewer *et al*. (1983), animals may regress in physiological age if there is (1) an inadequate intake of protein to meet maintenance requirements; (2) an inadequate intake of energy from excess fat and intake of protein; and (3) an inadequate intake of minerals from excess mineral stores and intake of protein.

2.4.5 Biological Body Growth

The biological growth composition, metabolic utilization of nutrients, and resource allocation are interrelated and undergo significant changes over the course of an animal's lifetime. In order to maintain homeostasis, organisms employ a variety of regulatory mechanisms to control the intake of chemicals (such as minerals, fatty acids, amino acids, etc.) and the excretion of waste products, even in turbulent environments (Nelson and Cox, 2000).

According to Lawrence and Fowler (1997), biological growth is a crucial characteristic of organisms that is difficult to define explicitly. Growth may distinguish between anabolic and catabolic processes in certain situations (Von Bertallanfy, 1957; Bastianelli and Sauvant, 1997), with each process having a distinct functional form. It has been demonstrated that this assumption is incorrect because it ignores how the growth curve's shape is influenced by the timing of maturation (Day & Taylor, 1997; Lester *et al*., 2004). A change in body weight is the most widely used indicator of biological growth, which is also defined as the process by which an animal grows larger over time. It can be measured in a variety of ways, including physical height or length. It is also explained in terms of the rate at which the main distinct chemical components of the tissues—such as water, minerals, lipids, proteins, and lipids-deposit. Growth can be useful in determining the best age for slaughter and effective feeding practices (Malhado *et al*., 2009). Throughout the course of an animal's life, both the rate of growth and the amount of feed consumed change according to the maturity stage of the animal.

Age-related changes in cell structure and function affect how the body is proportioned. Increases in length, size, and weight are not the only maturational changes that occur with growth; an orderly sequence of changes also involves the accretion of protein (Gous, 2001). Cell size and number increases are two aspects of the growth process. Early growth is primarily attributed to the process of hypertrophy, whereas later stages of growth—which vary depending on the tissue and species—are the consequence of hyperplasia. The intricate process isinfluenced by genetic, intrinsic, and extrinsic factors. The most important external factor influencing the growth of the body's various tissues is the makeup of the food supply, while the most significant intrinsic factor influencing the growth of the body's tissues is hormonal influence(Bellairs and Osmond, 2005).

Plotting an animal's body weight against time indicates that its biological growth from birth to maturity typically follows a sigmoidal growth curve (Owens *et al.,* 1993). The NRC (1998) determines growth needs based on data from Fox *et al*. (1992) and Tylutki *et al*. (1994). These factors include body size, the impact of dietary components, and the use of anabolicimplants. These sources also provide information on the anticipated adult size for breeding herd replacements and the projected weight at a certain final composition. Growth rate is known to increase during the young stage of development, also referred to as the "self-accelerating phase ofgrowth," and to level off as the animal gets closer to adulthood or begins to stimulate reproductivegrowth (Lester *et al.,* 2004).

2.4.6 Chemical Body Growth

Growth involves systematic changes in the body's chemical composition, which must be considered in any description of possible growth. Based on changes in the bird's chemical composition during growth, a broiler's potential growth rate can be calculated mathematically (Emmans and Kyriazakis, 1995). However, actual performance is always lower than potential, so these equations must be adjusted for this fact. The potential growth will be realized in practice under non-limiting conditions. Protein, water, and lipid are the three main chemical components, and it's possible that their prospective growth curves have the same shape. Except for reproductive tissues, all chemical and physical aspects of growth can be viewed as allometric functions of weight (Taylor, 1980). Taylor (1980) employed the following phrase:

$Y_1 = a. Y_2^b$

Where Y_1 = weight of component 1

Y_2= weight of component 2

Where Y_2 is body weight and the ratio (Y_1/ Y_2) at maturity is am, then a = am. $A^{(1-b)}$ where A is mature weight.

2.4.7 Inherent Fatness

An animal in an *ad libitum* system fed a balanced, non-constricting feed at maturity will, by definition, be in equilibrium. Its long-term averages will be stable, with potential short-term variations in weight, composition, and feed intake rate. Under these conditions, the observed level of fatness can be interpreted as a result of genetic inheritance and maturity. Throughout various growth stages, weights such as protein or lipid-free weights, when expressed as percentages of their weights at maturity, and their inherent fatness assessed under identical conditions, may be lower than their fatness at maturity. Typically, fatness tends to increase as the development level approaches maturity. Provided that the feed is given without any restrictions, allows for a balanced intake, and the environment is not excessively heated, the natural level of fatness, which depends on the level of maturation and degree of maturity, can be adequately met (Emmans, 1986).

2.5 Prediction of Feed Intake

To anticipate an animal's food consumption in an environment with unrestricted food availability, it is essential to initially gauge the rate of food intake in a setting where food is plentiful, and the diet is nutritionally well-balanced (Gous, 2002). The intended food intake, referred to as the rate of intake, is crucial for the animal to achieve its maximum development rate. It is hypothesized that the animal would consume food in order to satisfy its requirements, particularly when the feed supply is limited (Emmans and Fisher, 1986). Emmans (1997) discovered that the concept of "eating to requirement" has proven to be very successful in forecasting the voluntary food consumption of growing animals. The total amount of food required by an animal for growth and maintenance is what determines its total food intake requirement. Emmans and Kyriazakis (2001) provide a comprehensive explanation of the requirements' model. When food intake is limited, the

precision with which the constraints can be specified determines how accurate the model's prediction is (Yearsley *et al*., 2001). Putting the genetic variables and nutritional constant values together is the problem of predicting requirements; the feed's composition will then dictate the desired feed intake.

Once food intake is understood, various factors like the growth of body protein and its chemical and physical constituents can be anticipated. However, due to the dynamic nature of the environment, nutrition, and animal requirements, predicting feed intake poses challenges. The model forecasts feed intake based on factors such as the animal's physiological condition, sex, strain, and diet quality. It's crucial to delve deeper into the aspect of diet quality because it significantly influences growth rates, composition, and daily energy and protein needs. The intrinsic connection between an animal's physiological state and its inclination to store fat is closely tied to the quality of its diet (Kyriazakis and Emmans, 1991). The animal's current condition would reflect both its past nutritional intake and how it responded to its thermal surroundings. The animal can always use its body fat stores to some degree to supplement dietarymetabolizable energy (ME) when necessary, which is a crucial implication of the idea of maintaining a desired level of fatness (Fowler *et al*., 1980). On any given day, half of the total bodyfat is thought to be the maximum amount that can be used for energy. Body fat reserves can only be used during times when the lipid ratio (LR) is zero or less. Therefore, adhering to a minimum lipid-to-protein ratio, as suggested by several alternative models (Moughan *et al*., 1987; Pomar *etal.,* 1991), would hinder significant protein growth rates while facilitating gains in fat.

2.5.1 Desired Feed Intake (DFI)

To achieve its maximum growth rate, an animal must consume n units of the first limiting nutrient daily. To attain this potential growth rate with a food containing N g/d of the nutrient, the required feeding rate (F*) is determined by the equation F* x N = n. Assuming animals strive to reach their potential growth rate, the value of F* is termed "the desired feed intake," calculated as F* = n/N.

The potential energy for the animal comprises protein, fat, and carbohydrates absorbed, with their respective amounts summed up to provide digestible energy. The digestible energy consumed is allocated to energy storage, energy in urine, and heat loss, as outlined by Emmans (1981).

The rule governing feed intake is expressed by two definitions: Definition 1: Daily Feed Intake (DFI) equals the Ratio Quotient (RQ1) divided by the Feed Constraint Content (FC1) (1g/d). Definition 2: Cumulative Feed Intake (CFI) equals the Cumulative Animal Performance (CAP1) divided by the Feed Constraint Content (FCON1) (kg/d).

The overarching rule (Rule 1F) is that DFI should be less than CFI. Here, F1 denotes feed intake measured in kg/d; CAP1 represents the animal's capacity for the first limiting feed constraint, measured in units/d; FCON1 is the feed's content of the first limiting constraint, measured in units/kg; and RQ1 is the animal's requirement for the first limiting feed resource, measured in units/d.

Common limitations on feed intake include feed bulk (especially in ruminants on a forage-based diet) and heat loss capacity (particularly in monogastric ruminants fed highly digestible, imbalanced feeds). The calculation of RQ involves estimating maintenance, determining rates of lipid and non-lipid gain, and converting feed components (energy, protein, and other nutrients) into units of these functions (Emmans, 1995).

2.5.2. Controlled or Restricted Food Intake (CFI/ RFI)

Controlled food intake (CFI), or restricted food intake, involves purposefully decreasing the amount of food provided to an animal below the level of unrestricted food intake. The fundamental principles governing ad-libitum food consumption are presumed to remain applicable in this context, with the sole distinction being that daily food intake is confined by a predetermined quota. Despite imposed restrictions, protein growth can be achieved if an adequate amount of the most limiting element, such as an amino acid or energy, is present. In situations of energy scarcity, the allocation of energy does not necessitate a specific minimum ratio of lipids to proteins, as evidenced by previous models (Whittemore and Fawcett, 1976; Moughan *et al*., 1987; Pomar *et al*., 1991).

It is exceedingly uncommon for any animal, irrespective of its natural inclination for lean tissue development, to sustain its maximum protein deposition capacity when there is insufficient fat storage to meet the necessary energy demands in its diet (Kyriazakis and Emmans, 1991). Prudent

management is essential to prevent excessive depletion of body fat reserves beyond an appropriate level (Emmans, 1995). This emphasizes the imperative need for decisive actions in animal nutrition, ensuring the delicate balance between controlled food intake and optimal growth outcomes.

2.5.3. Potential Growth Rate

Potential growth refers to the maximum attainable rate at which an animal can increase in size when no factors impede its growth, influenced by its genetic traits and current condition. Ideal conditions for non-limiting growth encompass ad libitum food availability, nutrient contents meeting or exceeding required energy ratios, absence of intake constraints due to food volume or toxins, and absence of environmental factors like high temperature and disease that restrict intake (Emmans and Kyriazakis, 1999).

The concept of growth in organisms lacks a specific formal definition, emphasizing the need for a comprehensive understanding of systematic changes in the chemical and physical makeup of the body during growth (Lawrence and Fowler, 1997). Mathematical analysis has extensively explored the growth path from conception to maturity, resulting in various functional models aiming to predict growth rates across different life stages (Emmans, 1986). However, external factors influence mean growth, and actual growth may not always align with potential growth (Whittemore *et al.*, 1988).

The equation Potential growth rate = f(genotype, state) signifies the potential growth rate as a function of genotype and state. Selecting an appropriate function is crucial, with an acknowledgment that the function's viability hinges on providing an adequate description of genotype and state, which are interconnected (Emmans, 1995). Some inadequate functions have been used to depict potential growth due to their relative suitability in describing specific sets of observed growth data.

In predicting growth rate, a crucial aspect in nutrition, three possible approaches exist:

1. Prediction of the growth of the entire empty body.
2. Separate prediction of the growth of the four components.
3. Prediction of one component with the remaining three considered in relation to this base

component (protein).

The primary challenge is to predict the potential rate of protein growth, a problem initially identified by Whittemore and Fawcett (1976) in the context of pigs, though their solution may not be suitable for poultry or pigs. The selection of an appropriate function and providing an accurate description of genotype and state are intertwined challenges in addressing this issue as addressed in figure 2.2 (Emmans, 1995).

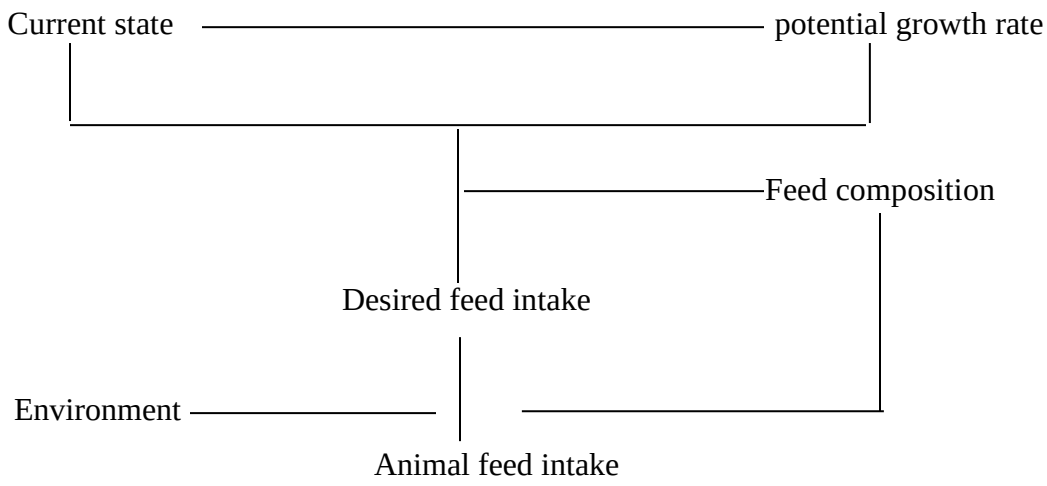

Figure 2.2: Selection by hens of a diet from a pair of feeds.
Source: Emmans, 1995.

2.5.4. Description of Growth Mathematically

Measurement of growth can be analyzed with respect to time (age) or to body weight (Gille, 2004). Mathematical equations are possible to define the changes in potential growth under non-limiting conditions (Emmans, 1987). The Gompertz equation adequately describes the development of chickens from birth to maturity, and it is often favoured over other growth equations because it describes growth, in terms of only three parameters rather than four, and each having a biological meaning: a starting weight (Wo), a mature weight (Wm) and a rate of maturity (Emmans, 1995). It is chosen based on its strong fit with the data and favourable mathematical characteristics, component (protein), specifically, its empirical nature rather than being generated from theoretical principles.

This suggests that the highest rate of growth happens at a consistent level of maturity. The essential feature of the growth function lies in its formulation of the connection between R and W, determining the growth rate at a particular maturity level. The Gompertz model, introduced by Gompertz in 1825, holds the advantageous quality of presenting the variable R as a simple function of W. As a result, R demonstrates a linear decline in correlation with the logarithm of W.

The Gompertz growth function can be defined by: Wt

$$= Wm. \exp(-\exp(-B(t - t^*))) \text{ kg}$$

Where: Wt = the corresponding measurement (weight) at time t (d)

Wm = the mature weight (kg)

t* = the time of maturity

B = rate of parameter (/d)

'exp' means 'e to the power of'

When t = t* then W = Wm/ e and the growth rate, dW/ dt, is at a minimum given by (dW/ dt); max = B. Wm/ e kg/day where B = (dW/ dt) max e/A day.

Another form of this equation, excluding t* and making use of Wo (weight at day – old) is:

$$Wt = Wm. \exp(-\exp((\text{In}(-\text{in}(Wo/ Wm))) - B.t))$$

To determine the parameters in the described equations, it is essential to raise animals of a similar breed or strain to their maximum potential and regularly measure their weight throughout the growth period (Gous, 1990; Martin, 1994). The challenge of predicting the rate of body growth can be approached through one of the following methods (Emmans and Fisher, 1986):

1. By forecasting the growth of the entire feather-free body (EFFB).
2. By separately forecasting the growth of the four chemical components of the empty body weight (water, lipid, protein, ash, and a small amount of carbohydrate).
3. By predicting the growth of one of these components and estimating the others in relation to this chosen component.

The majority of the body's growth-related components, excluding feathers, can be directly attributed to the body's protein weight (Gous, 1999). In other words, they have a shared rate of maturity (B). The Gompertz growth function can be employed to predict the increase of protein in the body. Given that the aforementioned condition is satisfied, the increase in water, ash, and lipid may be deduced from the protein weights. By summing the weights of these components on a daily basis during the growth period, it becomes feasible to predict the overall growth rate of the body without feathers. With the exception of feathers, all the physical elements of the broiler have a similar rate of maturity as body protein (Emmans and Fisher, 1986). Therefore, the growth rate of these components may be anticipated using the same method as the chemical components. The correlations between these factors are valuable for predicting the weights of different components during growth, as well as for comparing different genotypes. Additionally, they provide understanding of the changes that occur in birds as they mature (Gous, 2001). Allometrically related components are those that have the same rate of maturing, and allometry describes the mathematical relationship between the weight of a component and the weight of body protein.

2.6 Growth Functions

2.6.1. Criteria for possible growth functions

The Gompertz (1825), logistic (Robertson, 1908), Von Bertalanffy (1957), Black (Black *et al*., 1986), and Bridges (Bridges *et al*., 1986) functions are some of the growth functions identified through research that align with their specified conditions for evaluating growth. The following criteria are employed to characterize a superior growth function:

2.6.1.1 Fewer parameters are preferred

The simplicity of a function increases with a lower number of parameters, enhancing its comprehensibility and usability. Reduced error is likely in both its application and the estimation of parameter values. Preferably, growth functions should possess parameters that hold biological significance. While it is possible to fit a growth curve to data using numerous parameters, a greater number of parameters can obscure any meaningful biological association, emphasizing the importance of attributing biological meaning to the parameters of a growth function.

2.6.1.2. Functions in which growth will be seen as a continuous process

The prevailing belief is that potential growth unfolds as a continuous process, resulting in a unified growth curve and a corresponding smooth growth rate curve when plotted against size.

This can be restated as asserting that the animal's genetic composition remains constant throughout. The reported discontinuities in growth observed in certain data sets (Robertson, 1923; Brody, 1945) may simply indicate the impact of external factors that have prevented consistent expression of growth potential.

2.6.1.3. Functions with asymptotic values are preferred

The presumption that there is no inherent upper limit to an animal's size appears to be unreasonable. Introducing the concept of an upper limit to size, although challenging to quantify, enables the incorporation of a maturity degree (Taylor, 1980). This facilitates more straightforward comparisons of growth curves among species with varying upper limits to size. Functions that anticipate the growth rate approaching zero as size converges to both zero and its upper limit are preferable.

2.6.1.4. Functions that have a size at which growth rate is at a maximum are preferred.

Growth functions ought to anticipate a size where the growth rate stops increasing and begins to decline. This phenomenon arises from the inherent constraints of an animal having both an initial small size and an upper limit to its size. At a specific size, termed the "point of inflexion" (POI), the growth rate attains its maximum. Some describe the time at which the growth rate is at its peak as representing sexual maturity, and this occurrence transpires at a constant degree of maturity.

2.6.1.5. Functions that predict the relative growth rate will decrease continuously towards zero,as size increases are preferred.

The connection between R (growth rate) and W (size) governs the growth rate at a specific degree of maturity. The variable R, representing the rate at which an animal grows concerning its current size W, is defined as $R = (dW/dt) / W$, and it holds significant importance. It is reasonable to

assume that R will consistently decrease as W increases, as suggested by Emmans and Kyriazakis (1999). A straightforward correlation between R and W is preferable. Among various growth functions, the Gompertz function emerges as the most suitable for predicting potential growth. It meets all recommended criteria and enables close predictions to the upper limit size using parameters estimated from prenatal growth data. The Gompertz function also incorporates assumptions about the four chemical components of the body (protein, lipid, water, and ash), facilitating the description of potential growth through allometric relationships among these components (Emmans, 1988; Emmans and Kyriazakis, 1999).

2.6.1.6. Gompertz Growth Function

In order to calculate the mortality rates of humans, English mathematician Benjamin Gompertz created this function (Gompertz, 1825). Regarding growth mathematics, it is one of the most commonly used curves. It is defined by:

$$Wt = Wm. \exp(-\exp(-B(t - t^*))) \quad kg$$

Where:

Wt is the corresponding measurement (weight) at time t (d)

Wm is the mature weight (kg)

t* is the time (days, after hatching) at the point of inflection of the curve

B is a rate parameter (/ d)

'exp' means 'e to the power of'

2.7 Allometry

Allometry is known as "non-isometric scaling". Allometry is used to describe the morphological development of species and is based on the relationship between an organism's size and the size of any part of the organism. Allometric relationships have been seen in diverse situations and have been addressed with variable degrees of success, frequently attributed to physical limitations (Schmidt- Nielsen, 1991).

The allometric equation is usually plotted on an XY axis, with body size on X-axis and the size of the component on Y- axis. Allometry allows biological functions as it increases as a power of body size. Allometric equation is generally stated as:

$y = a. x^b$;

Where:

y = predicted size of body part

x = observed body or body protein weight

a and b = coefficients

Not all allometric comparisons are linear, however, when the variables are plotted on (natural) logarithmic coordinates, the result is a straight line, in which the exponent represents the slope of the regression (Schmidt- Nielsen, 1991). The equation that represents a non- linear function is:

$In\ y = In\ a + b\ In\ x$

In the above equation, the value of b for the different components of the body may be greater than, equal to or less than unity. Where $b < 1$, the ratio between the component weight and body protein decreases as protein weight increases, as in the case of body water. Where $b = 1$, as in the case of body ash, the ratio is constant, and the ratio increases when $b > 1$, as in the case of body lipid.

To obtain precise estimates of the mature size and maturation rate of genotypes, a Gompertz equation is applied to the body protein weight. This approach allows the prediction of the growth of both the chemical and physical components of the body based on the protein component. The allometric relationships among the various body components, as identified by Emmans and Fisher (1986), are utilized for these predictions.

2.8 Conclusion

How thoroughly the animal is characterized will affect how accurate any hypothesis describing animal growth and development is. To understand how an animal grows, some physical and chemical traits of the species must be quantified. Predicting the growth rate, chemical composition, and physical characteristics of an animal is a complex task due to intricate causal relationships influenced by factors like age, nutrition, environment, and the current physiological state marked by protein content. The interplay of these elements contributes to changes in the chemical and physical compositions of the body. Various factors, including nutrition, genotype, sex, andmaturity stage, influence the relationship between chemical and physical composition. Understanding these connections is crucial for optimizing production efficiency. Simulation models can accurately predict body weight gain or chemical body composition if animals are provided a balanced diet *ad libitum*. However, deviations such as minimal food intakes or imbalanced protein-to-calorie ratios may introduce systematic errors in predictions, highlighting the importance of accurate model variables, including maintenance, *ad libitum* food intake, body weight, age, and sex. Emmans and Kyriazakis (1995) propose evaluating individual growth first before assessing population variations as an effective approach to address the challenge of predicting animal growth.

CHAPTER 3

Description of the Potential Growth and Chemical Composition Changes that Occur During the Growth of the New Zealand White Rabbits

ABSTRACT

The study was conducted on New Zealand White male and female rabbits over a period of 126 daysto ascertain their potential growth rates, body composition for major body parts, and chemical components. A total of 220 New Zealand White rabbits, evenly distributed between males and femaleswere used for this investigation. One hundred (100) rabbits (50 males and 50 females) were used for potential growth rate which were weighed from day 14 to day 140 while twelve (12) rabbits, 6 males and 6 females were randomly selected at each sampling day 14, 21, 28, 35, 42, 56, 70, 84, 112 and 140 days for carcass analysis. Data for the averagelive weight and pelt-free body weight, protein, water, ash, and lipid content were collected. All statistical analyses were performed using GenStat 23rd edition (VSN International, 2023). Linear regression was employed in this study to establish the correlation between body components and body proteins. Despite females exhibiting a faster rate of maturity than males, when the Gompertz equation was individually applied to the growth data for both sexes, it revealed comparable body weights throughout the trial (0.0243 vs 0.0239). However, males displayed a higher mature weight of 315 g compared to females at 309 g. In terms of mature body composition, males had an average body protein weight of 1497 g, while females had 843 g. The mature body lipid contents averaged 252 g for males and 227 g for females. The daily rate of maturing per pelt-free body protein was 0.0103 for males and 0.0172 for females, while for body lipid, it was 0.0410 for males and 0.0471for females. Distinct equations were necessary for males and females to articulate the allometric relationship between body protein and lipid in the pelt-free body. The rate of maturing of pelts in females surpassed that in males (0.0249 *vs*. 0.0214/d), and the mature weight was lower for females (456 g) compared to males (523 g). While it is important to acknowledge that the growth parameter estimates derived from the aforementioned technique are unlikely to accurately reflect the animals' potential for growth, they nonetheless offer valuable insights into the recent approaches taken to promote rabbit growth.

Keywords: Age, Allometry, New Zealand White, Rabbits, Sex

3.1 INTRODUCTION

The New Zealand White rabbit is frequently utilized for both breeding meat rabbits and conducting laboratory experiments. Additionally, they enjoy widespread popularity as pets and are a common sight at exhibitions. Originating in California, this breed was developed from rabbits imported from New Zealand, and they typically exhibit substantial size. Their initial purpose was to cater to the needs of the meat and leather industry during the early 20th century. On average, they weigh between 4.5 and 5.5 kilograms (Dean, 2016). The New Zealand White rabbit rapidly became favoured for its exceptional meat-to-bone ratio, rapid growth rate, and ease of management, which contributed to its widespread popularity. Furthermore, its fur has been employed in the manufacturing of fur goods, although this facet of its breeding has declined over time due to shifting preferences in the fur sector.

Because rabbits have historically been chosen for growth, a lot of attention has been paid to their slaughter weight. Currently, a broad variety of rabbit is utilized, providing a range of products from the entire carcass to its component parts. Growth simulation, which is provided by slaughter maturation, benefits greatly from growth analysis. The potential growth rate of an animal refers to its maximum growth without being constrained by other factors (Emmans and Kyriazakis, 1999; 2000). When animals are grown under non-limiting conditions, potential growthcan be observed, which is assumed to reflect the genotype of the animal. The development of internal organs facilitates growth. Tumova and Chodova (2018) found that in confined chickens, there is a preference for the development of internal organs over muscles. Weight gain in the bodyis typically accompanied by weight gain in the carcass and its component parts. Although these conditions cannot be precisely defined, experiments with broilers (e.g., Hancock *et al*. 1995; Gous*et al*. 1996, 1999; Hruby *et al*. 1996) and pigs (e.g., Ferguson and Gous, 1993) have demonstratedthat suitable experiments can provide realistic estimates of potential growth parameters. At that point, the animal's capacity for growth depends on its existing condition. According to Murawska*et al.* (2015), as turkeys mature, their carcass composition changes in different sections of the carcass: the amount of muscle tissue rises, the amount of bone falls, and the amount of skin with subcutaneous fat stays constant.

In the current study, the Gompertz form is used to describe growth since it has been found to be a

reliable and useful method of describing a growing animal's potential. The above introduction points to the importance of knowing the potential growth and carcass chemical composition of New Zealand White rabbits. When growth rate and chemical composition are not limited, this information provides the basis for predicting growth rate and chemical composition changes. An investigation was conducted to determine the potential growth rates for major body parts and the carcass chemical composition of New Zealand White males and females' rabbit from days 14 (2 weeks) to 140 (20 weeks) of age.

3.2 MATERIALS AND METHODS

3.2.1 Study Site

The study was carried out at the Ukulinga research farm, affiliated with the University of KwaZulu-Natal (UKZN) in Pietermaritzburg, KwaZulu-Natal, Republic of South Africa (RSA). The farm is situated at approximately latitude 28° 24' E and longitude 30° 24' S, with an elevation of 775 meters above sea level. The terrain of the farm is characterized by a notable presence of diverse tree species, including Acacia Karroo, Acacia nilotica, and Acacia sieberiana. The local climate is marked by an average annual maximum temperature of 27.7°C, an annual minimum temperature of 8.9°C, and an average annual precipitation of 735 mm, with the majority falling during the summer season.

3.2.2 Animals and Experimental Design

A total of 220 New Zealand White rabbits, comprising an equal number of males and females, were used in this study over a period spanning 14 to 140 days. Male and female rabbits were raised separately in separate cages. 120 rabbits were employed for the sampling process and 100 were used to assess potential growth. Twelve rabbits, six males and six females, were randomly selected at each of the following time points: 14, 21, 28, 35, 42, 56, 70, 84, 112 and 140 days for the purpose of carcass analysis. The100 rabbits for potential growth were weighed from day 14 to day 140. Male and female rabbits were raised separately in separate cages for proper identification and to prevent indiscriminate mating.

3.2.3Animal Housing and Management

Each rabbit was tagged, and its initial body weight was recorded at the start of the experiment.

Subsequently, the rabbits were randomly allocated to wire cages situated in the rabbit house. These wire cages were chosen to provide ample ventilation, facilitating effective air circulation. To absorb urine, wood shavings were placed under the cages. A feeder was included in each cage, and it was positioned at a convenient height. Unrestricted access to a commercial pelleted food containing 16% protein, 18.9% crude fiber, and 2.1% fat was given to the rabbits also, the metabolizable energy (ME) content of this diet was 10.2 MJ/kg. Water was readily accessible through a nipple drinker situated within each cage, while pellets and hay were also provided without restrictions. All through the duration of the study, rabbits selected for potential growth assessment had their individual weights taken with an electric weighing scale on a weekly basis. On the other hand, measurementsof the body components of the rabbits used for sampling were made as they were being slaughteredat the abattoir on the stipulated sampling days (14, 21, 28, 35, 42, 56, 70, 84, 112 and 140 days).

3.2.4 Slaughtering Procedures

The rabbits were sent out to the Longleigh Poultry & Rabbit Abattoir, a licensed and registered local abattoir located at ERF 59 Bishopstowe, Pietermaritzburg. The rabbits were electrically stunned at this facility before the slaughtering procedure was carried out by trained abattoir workers.At the base of each ear, electrical stunner electrodes were positioned using this technique. In airedtravel cages within a closed truck that was properly aerated, rabbits were delivered to the slaughterhouse. Prior to the slaughtering process, each rabbit's weight was measured using an electrical weighing scale to determineits live weight. Subsequently, after the slaughtering was completed, the weight of the rabbit without its pelt was recorded to obtain the pelt-free weight. The weight of the pelt, internal organs(the stomach, heart, kidney, and liver), and eviscerated body parts (the head, fore and rear limbs, ribs, and saddle) were also determined. The units of measurement were all grams. The rabbits were suspended on a cutting hanger after the initial cut at the neck that followed electrical stunning on various slaughter days (14, 21, 28, 35, 42, 56, 70, 84, 112 and 140). The subsequent cut was typically made at the hind feet, running from one thigh to the other, and then the skin was carefullyremoved in a single piece.

3.2.5 Carcass Composition Parameters and Chemical Analysis

3.2.5.1 Moisture content

The body parts placed in bags were subsequently frozen until the mincing procedure was conducted. To ensure uniform samples, each component was individually processed through a meat grinder after thawing. The water content of these samples was then determined by freeze-drying them at -50°C using a Supermodulyo Freeze Dryer from Thermo Electron Corporation, Edwards, Asheville, NC. For moisture content calculation, 100 g subsamples from each minced rabbit carcass were weighed and freeze-dried for 72 hours until a stable weight was achieved. The weights of the samples were recorded, and moisture loss was calculated by applying the formula: (W1 - W2) / W1 * 1000 (AOAC 930.15). After freeze- drying, the samples were ground again, this time using an Ika A11 Basic coffee bean grinder (IkaWorks Brazil Ltda, Taquara, RJ, Brazil).

To calculate moisture content:

$$\frac{W_1 - W_2}{W_1} \times 1000$$

W_1 = Weight of the sample before freeze drying

W_2 = Weight of the sample after freeze drying

3.2.5.2 Ash determination

The determination of ash content followed the procedure outlined in AOAC (942.05). Crucibles with lids were dried in an oven set to 90 to 105°C overnight and then cooled in a desiccator. The combined mass (W1) of the crucible and lid was measured. Approximately 1g of a well-mixed dry sample was weighed (W2), comprising the crucible, cover, and sample. The crucible with the sample and cover was heated overnight to 550°C in the furnace. After cooling the furnace to below 200°C, the tray containing the crucibles was removed. The crucibles were then cooled in the desiccator, and their mass was measured after cooling (W3). The ash percentage was calculated as follows:

$$\text{Ash \%} = \frac{W_3 - W_1}{W_2 - W_1} x\ 100$$

Where:

W_1 = Crucible and lid mass

W_2 = Crucible with lid and sample mass

W_3 = Ashed crucible with lid and sample mass

3.2.5.3 Protein determination

In the protein analysis procedure, the nitrogen content of the sample was assessed using the N LECO analyzer employing the Dumas combustion technique. A 0.2g sample undergoes complete combustion at elevated temperatures (900-950℃) in the presence of 99.9% oxygen. The combustion generates byproducts such as water, carbon dioxide, nitrogen dioxide, and nitrogen oxides. The resulting gas stream is then subjected to thermoelectric coolers and chemical solvents to eliminate water vapor, oxygen, and carbon dioxide. Subsequently, the combustion byproducts are collected and allowed to reach equilibrium. The nitrogen is transformed into N2 as it traverses a heated copper column. The produced N2 is quantified using a thermal conductivity detector, and the protein content is determined by applying a known conversion factor of 6.25 (AOAC 992.15; AACC 46-30) based on the nitrogen concentration.

3.2.5.4 Lipid determination

Following the AOAC (920.39) guidelines, fat extraction was conducted using the Soxhlet method. Buchi fat beakers were dried in the oven overnight, and a thimble was placed on the balance and tared. The thimble was filled with approximately 5g of dried and finely powdered material, and its weight was noted as W1. To ensure proper drying of the sample, the thimble with the sample was then placed in the oven for one hour. The extraction stones and Buchi fat beaker were weighed, and the weight was recorded as W2. Each thimble was then paired with a flask, numbered accordingly. Petroleum ether was added to the beakers, filling them to about three-quarters, and the thimbles were sealed with cotton wool. Six thimbles were placed, one in each Soxhlet extractor, with the beakers on top of the heating areas. The system was tightly sealed, checked for leaks, and

the cooling water supply was turned on. The extraction process continued for four hours. Refluxed solvent, or fat-free solvent flow, was directed to collect in a container. Once it seemed that all flasks were solvent-free, the system was opened, and thimbles and beakers were removed. Remaining solvent was allowed to evaporate overnight with the thimbles and beakers on the bench. The beakers were then dried for an hour in a 90°C oven, cooled in a desiccator, and weighed. Their masses were recorded as W3. Crude fat (%) was calculated using the following formula:

$$\text{Crude fat \%} = \frac{W_3 - W_2}{W_1} \times 100$$

Where:

W_1 = Mass of a sample (g)

W_2 = Mass of the Buchi fat beaker (g)

W_3 = Mass of the Buchi fat beaker with extracted residue (g)

3.2.6 Statistical Analysis

The average live weight and pelt-free body weight, along with the protein, water, ash, and lipid contents, for all animals were computed using ANOVA for sex and sample age. All statistical analyses were performed using GenStat 23rd edition (VSN International, 2023). Linear regression ($y = a.\ x^b$) was employed in this study to establish the correlation between body components and body proteins. The weights of the chemical components were logarithmically transformed (natural logarithms, *ln*) to assess their allometric interactions.

3.3 Results

3.3.1 Growth Analysis

Table 3.1 show the average live weight values for each sex at various ages. Throughout the study, the growth rates of the two sexes were comparable; but, after day 35, males began to grow considerably faster than females. Over the course of the weighing period, the data showed a progressive and linear increase in the live weight ($P<0.001$). The rabbits' prospective growth rate

is obtained by examining each individual's body weight. At 140 days of age, the mean body weights attained by the two sexes were 1754 g for the females and 1766 g for the males; however, the males' averages were substantially larger ($P<0.001$) than the females. The Gompertz growth curve fully described growth in the female and male New Zealand White rabbits, respectively, as $R^2> 0.980$ and $R^2> 0.990$, according to an analysis of the individual potential growth weight data (Table3.5). Significant differences in the three parameters were found when fitting the Gompertz equation to these data for different age groups, requiring distinct equations for males and females.

Table 3.1: Average mean live weight (g) of male and female NZW rabbits from day 14 to days 140.

Age (days)	Males	Females	Mean
14	173	172	173
21	367	386	376
28	655	657	656
35	871	867	869
42	1158	1146	1152
49	1269	1253	1261
56	1486	1480	1483
63	1581	1574	1577
70	1669	1663	1666
77	1883	1880	1882
84	2090	2084	2087
91	2181	2167	2174
98	2277	2263	2270
105	2374	2360	2367
112	2489	2472	2480
119	2582	2563	2573
126	2690	2675	2683
133	2801	2797	2799
140	2953	2869	2911
Mean	**1766**	**1754**	**1760**

3.3.2 Weight of carcass components by sex and age (g)

Table 3.2: Mean live, pelt-free and head weights (g) of female and male NZW rabbits at 10 sampling ages.

	Live			Pelt-free			Head		
Age (days)	F	M	Mean	F	M	Mean	F	M	Mean
14	172	179	175	134	142	217	42	41	42
21	386	375	380	308	313	413	65	65	65
28	663	662	663	570	584	621	91	96	94
35	853	864	859	727	734	900	116	117	116
42	1148	1193	1170	942	995	1175	130	140	135
56	1506	1461	1484	1252	1256	1375	151	155	153
70	1566	1513	1540	1275	1332	1442	157	159	158
84	2094	2132	2132	1778	1801	1795	210	220	215
112	2292	2392	2392	1924	2020	2324	242	270	256
140	2454	2749	2749	2067	2287	2541	268	283	276
Mean	**1313**	**1352**	**1333**	**1098**	**1146**	**1280**	**147**	**155**	**151**
	Age	Sex	Age*Sex	Age	Sex	Age*Sex	Age	Sex	Age*Sex
P Value	***	ns	ns	***	ns	ns	***	ns	ns
SEM	51	22.8	7.1	44.65	19.97	63.15	6.32	2.82	8.93
RMS		15613			11964			239	

SEM: standard error of mean; RMS: residual mean square; F: female; M: male; ns: not significant

Table 3.3: Mean pelt, fore limbs, and hind limbs growth weights (g) of female and male NZW rabbits at 10 sampling ages

	Pelt			Fore			Hind		
Age (days)	F	M	Mean	F	M	Mean	F	M	Mean
14	38	37	38	42	41	42	38	37	38
21	73	71	72	65	65	65	73	71	72
28	93	78	85	91	96	94	93	78	85
35	126	130	128	116	117	116	126	130	128
42	198	206	202	130	140	135	206	198	202
56	205	224	215	151	155	153	224	205	215
70	234	238	236	157	159	158	234	238	236
84	316	331	324	210	220	215	316	331	324
112	367	373	370	242	270	256	367	373	370
140	387	463	425	268	283	276	387	463	425
Mean	**204**	**215**	**210**	**147**	**155**	**151**	**206**	**212**	**210**
	Age	Sex	Age*Sex	Age	Sex	Age*Sex	Age	Sex	Age*Sex
P-Value	***	ns	***	***	ns	ns	***	ns	***
SEM	10.83	4.85	15.32	6.32	2.82	8.93	10.83	4.85	15.32
RMS		704			239			704	

SEM: standard error of mean; RMS: residual mean square; F: female; M: male; ns: not significant

Table 3.4: Mean rib and saddle weights (g) of female and male rabbits at 10 sampling ages

	Rib			Saddle		
Age (Days)	F	M	Mean	F	M	Mean
14	18	22	20	23	28	26
21	45	49	47	57	58	58
28	57	61	59	105	112	109
35	76	76	76	146	148	147
42	105	116	111	189	190	190
56	222	226	224	250	254	252
70	236	239	238	271	294	283
84	266	277	271	406	418	412
112	288	293	290	480	501	491
140	310	384	347	504	568	536
Mean	**162**	**174**	**168**	**243**	**257**	**250**
	Age	Sex	Age*sex	Age	Sex	Age*sex
P- value	***	ns	ns	***	ns	ns
SEM	11.57	5.18	16.37	18.54	8.29	26.23
RMS	804			2063		

SEM: standard error of means; RMS: residual mean square; F: Female; M: Male; ns: not significant

Table 3.5: Gompertz parameters describing the potential growth of the male and female NZW rabbits.

	Females		Males	
Parameter	Mean	s.e.	Mean	s.e.
Age at maximum growth rate, (t*, d)	44.1	3.14	45.0	2.41
Rate of maturing, (g/ d)	0.0243	0.0038	0.0239	0.0028
Mature weight (g/ kg)	46.7	0.394	47.4	0.299
R^2	0.98		0.99	

Gompertz equation of the form A+C*exp(-exp(-B*(X-M)))

The mature weight for females (47 g) was identical to that of males (47 g), but the rate of maturing (B) for potential growth was considerably higher in females compared to males (0.00243 vs. 0.0239/d, respectively) (Table 3.5). The growth curves of male and female New Zealand White rabbits are depicted in Figure 1. When live weight was graphed against age on the same graph, both sexes exhibited nearly identical growth patterns following similar trajectories.

3.3.1.1 Pelt-free and pelt growth weight

Table 3.2 illustrates the impact of age and sex on pelt-free weight. Males and females exhibited distinct responses ($P<0.001$) across all growth stages, and age had a significant effect ($P<0.001$) across both sexes. Although there were no significant effects on sex and age*sex ($P>0.001$), numeric values were higher in males (1146g) compared to females (1098g). Pelt-free weight displayed a linear increase with age and sex. Significant differences ($P<0.001$) were observed in pelt weights between various ages and age*sex interactions. The head weight of the rabbits showed a significant correlation in females though with a lower value (147g) compared to the male (155g). There was no significant correlation ($P>0.001$) between the sex and age*sex interaction. Table 3.3 shows the mean weights formales and females at various sampling times. The weight of the females' pelts was greater than themales' at days 14 to 28. However, by day 35, the males' pelts had increased to 130 g/kg. Females had a lower mature pelt weight of 45 g/kg compared to males' 52 g/kg, but the rate of pelt maturation (B) was significantly higher in females (0.02496 vs. 0.02135) than the

males (Table 3.7).

3.3.3 Carcass Analysis

3.3.2.1 Fore and hind limbs growth weight

Table 3.3 shows how sex and age affect the fore and hind limbs. All growing ages saw different responses from the males and females of both body components. On the hind limbs, there was a significant age*sex interaction and a significant age effect ($P<0.005$) on the age of the two body components for both sexes. From day 28, the male rabbit's growth favored the female's, with a linear increase on the forelimbs observed in both sexes as the rabbits grew older. From day 14 to day 140, the hind limbs showed a progressive increase in both sexes, ranging from 38 g to 387 g for females and 37 g to 463 g for males, respectively. While the maturation rates of the male and female forelimbs were similar (0.02425 and 0.02626/d, respectively), the female's rate of maturation of the hind limbs was higher (0.03134/d) than the male's (0.02819/d, respectively) (Table 3.7).

3.3.2.2 Rib and saddle weights

Mean rib weight at different ages is shown in Table 3.4. Significant differences were evident in rib weight among all the ages ($P<0.001$) and not in sex and age*sex ($P>0.001$). The male had the highest rib weight at d-140 (384 g) against the female (310 g) at the same age. The saddle weight showed significant ($P<0.001$) linear relationship from d-14 to d-140 in both sexes as shown in Table 3.4. The sex and age*sex did not differ significantly ($P>0.001$) at all ages and similar saddle weights were recorded in both sexes. The highest saddle weight was recorded in the male, 568g against 504 g recorded in the female. The rib maturing rate of the female (0.03980/ d) is higher than that of the male (0.03389/ d) while the male saddle (0.02312/ d) reached maturity earlier than the female (0.02595/ d) respectively (Table 3.7).

3.3.4 Chemical composition of pelt-free body

On the average, a 14-day-old rabbit contained 819 g/kg water content, 103 g/kg protein, 54 g/kg lipid and 25 g/kg ash (Table 3.6). The pelt-free included the head, internal organs, fore and hind limbs, ribs and saddle body components, the pelt was excluded. Age and the interaction between sexand age are the primary factors affecting these results ($P<0.001$). The male's body protein

content fluctuated during growth, declining at day 42, increasing at day 84, and then declining at day 112.

In comparison to the males, the females exhibited reduced lipid, water, and ash levels and considerably ($P<0.001$) higher mature protein weights. There was no explanation for the observed inconsistency in body lipid. Throughout the growing period, the body's water content decreased linearly with time; these trends persisted for both sexes. In the d-14 and 21 for both sexes, the body ash content did not show any trend over time. From day 28 to day 70, there was more consistent trend, but from day 84 onward, it once again lost trend. The parameters for the Gompertz growth curves were calculated using the increasing weights of body protein in the pelt-free over time. Table 3.8 provides these parameters for different body parts and sexes involved in the study. Despite the female mature size (74 g) being smaller than the male's (123 g), the female's protein matured at a faster rate than the male's (0.017 vs. 0.010/d). The Gompertz equation (Table 3.8) predicted a heavier mature weight for water content in males (34 g vs. 32 g, respectively), with males maturing at a faster rate (0.036 vs. 0.039/day, respectively). At maturity, males and females exhibited similar body lipid weights (42 g and 39 g, respectively), along with comparable rates of maturing for these chemical components (0.0410 vs. 0.0471). Females have a lower mature size at maximum growth rate for body protein weight (843 vs. 1497 g/kg) than males, but they matured at a faster rate (0.0172 vs. 0.0103/d) than the males.

3.3.5 Allometric relationships in chemical components of the body

The pelt-free body exhibited a robust allometric relationship between body water and protein content, with an R^2 value of 0.964, considering various ages and both sexes. The equation representing this relationship is *ln* body water, g = 3.1714 ± 0.0592 + 0.6310 ± 0.0112 * *ln* body protein, following the format of *ln* Y = a + b *ln* X (Equation 1). Similarly, the same equation format was utilized to depict the allometric relationship between body lipids and protein in the pelt-free for both males and females: ln body lipid, g = -0.7089 ± 0.0945 + 1.0041 ± 0.018 * *ln* body protein, showing a strong allometric relationship of 0.963 between the two components.

Furthermore, ash content in the pelt-free body displayed a high allometric relationship with body protein (R2 = 0.979), described by the equation *ln* ash, g = -1.5281 ± 0.0730 + 1.0145 ± 0.0138 * *ln* body protein. Despite ash weight being numerically lower than other chemical components in the body, its allometric relationship with *ln* body protein revealed a shift over time. The regression

coefficient for ash was higher (steeper) than that of lipids (1.0145 vs 1.0041), while the constant term for the ash component was lower than that of lipid components (-1.5281 vs. -0.7089, respectively).

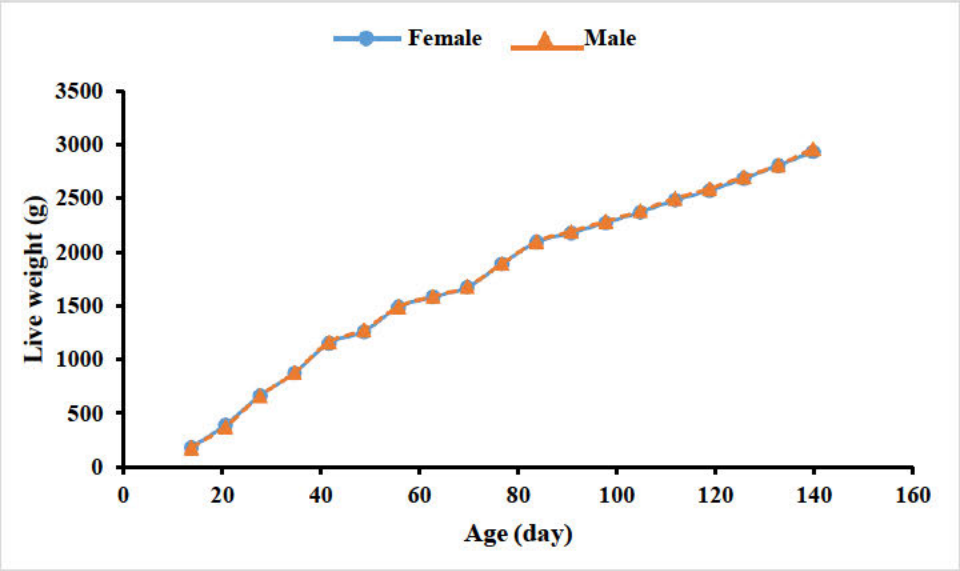

Figure 3.1. The growth curves of males and females NZW rabbits

Table 3.6: Mean pelt-free body protein, lipid, water, and ash content (g/kg) of male and female New Zealand White rabbits at different ages.

	Protein		LipId d		Water		Ash	
Age	F	M	F	M	F	M	F	M
14	104	102	58	49	810	828	28	22
21	124	123	44	56	808	799	23	22
28	161	169	65	68	733	719	41	44
35	180	193	93	90	687	675	41	42
42	184	189	102	89	673	672	42	50
56	202	196	156	149	603	599	44	56
70	211	200	105	110	636	643	48	46
84	224	207	88	130	648	628	40	36
112	258	194	105	93	574	661	63	52
140	292	299	112	126	523	493	73	82
Mean	**194**	**187**	**93**	**96**	**670**	**672**	**44**	**45**
SEM	2.54		4.50		11.38		1.81	
P-value	Age	***	***		***		***	
	Sex	ns	ns		ns		ns	
	Age*sex	***	***		***		***	

P<0.001: significant; SEM: standard error of mean; ns: not significant; F: female; M: male

Table 3.7: Parameters of the Gompertz growth curve (mature weight, rate of maturation and age at maximum growth rate)± SE, describing the growth of body components in the pelt-free body of males (M) and females (F) New Zealand White rabbits.

	Age at maximur growth rate(t*, d)		Rate of nmaturing, /d		Mature weight, (g/ kg)		
Item	Mean	s.e.	Mean	s.e.	Mean	s.e.	R^2
Pelt-free							
Males	2387	90.8	0.0278	0.0024	42.71	2.02	0.95
Females	2229	49.9	0.0309	0.0018	39.93	1.13	0.96
Pelt							
Males	522.5	36.5	0.0214	0.0026	52.19	4.29	0.93
Females	456.4	17.3	0.0249	0.0019	44.80	2.11	0.93
Head							
Males	325.6	19.4	0.0209	0.0025	41.45	3.55	0.93
Females	311.8	12.5	0.0209	0.0017	39.65	2.35	0.93
Forelimbs							
Males	296.7	18.7	0.2425	0.0032	43.10	3.53	0.91
Females	273.0	10.5	0.2626	0.0023	39.46	2.04	0.91
Hindlimbs							
Males	521.1	31.1	0.0282	0.0039	41.08	3.12	0.88
Female	497.0	17.1	0.0313	0.0028	38.83	1.73	0.99
Organs							
Males	131.3	1.97	0.0671	0.0044	28.32	0.624	0.97
Females	128.7	1.48	0.0673	0.0034	27.81	0.479	0.96
Ribs							
Males	365.7	16.5	0.0339	0.0038	44.63	2.26	0.92
Females	333.6	9.2	0.0398	0.0031	41.48	1.32	0.92
Saddle							
Males	653.7	45.0	0.0231	0.0028	55.03	4.07	0.93
Females	594.0	24.4	0.0259	0.0021	50.47	2.28	0.93

Gompertz equation of the form A + C*EXP(-EXP(-B*(X-M)))

Table 3.8: Gompertz parameters describing the growth of the body chemical components (protein, water, lipid and ash) in the pelt-free body of male and female New Zealand White rabbits.

Parameter	Age at maximum growth rate (t*, d)		Rate of maturing, /d		Mature weight, g/ kg		
	Mean	s.e.	Mean	s.e.	Mean	s.e.	R^2
Body protein							
Male	1497	569	0.0103	0.0028	123.4	37.0	0.91
Female	843	73	0.0172	0.0018	73.54	6.17	0.93
Body water							
Male	1260	44.8	0.0356	0.0038	33.71	1.71	0.92
Female	1191	25.1	0.0391	0.0026	31.92	0.99	0.93
Body lipid							
Male	252.1	13.3	0.0410	0.0062	41.85	2.50	0.86
Female	226.8	7.78	0.0471	0.0052	38.78	1.56	0.85
Body ash							
Male	644	143	0.015	0.0030	168.8	4.46	0.90
Female	611	281	0.082	0.0019	172.6	4.97	0.91

Gompertz equation of the form A + C*EXP(-EXP(-B*(X-M)))

3.4 Discussion

It was crucial to make sure that the growth rates of the sexes and ages differed in order to accomplish this, particularly in terms of potential growth. To this end, the experiment was successful because there were notable variations in the ages of all body parts that were measured. All of the physical components that were measured showed weight variations throughout all age groups (days), supporting previous findings that these components seem to vary by sex (Kemp *et al*., 2005). The two sexes analyzed in the trial for growth and carcass analysis turned out to be nearly identical because they had comparable mature body weights, protein, water, and lipid contents, as well as remarkably similar maturation rates. In contrast to the findings reported by Dal Bosco *et al*. (2002) and Yalcin *et al*. (2001), the mean values for live weights obtained in this study were higher in males than in females. These variations could be caused by a number of variables, including feeding circumstances, weaning ages, environmental factors, and slaughtering ages (Fernandez and Fraga,1996), but they did not significantly affect the results of the current study. It has been noted that both sexes' live weight increases proportionately as they age. This is to be expected, as the animal grows, its body size and shape should also increase in tandem with age until maturity, at which point growth will gradually slow down and eventually cease (Onasanya *et al*., 2017). A proper description of potential growth will address the systematic changes in the physical composition of the body that occur during growth (Gous *et al*., 1999). The intended result was a wide range in the body growth rates and weights of the physical components of the animals in thesample, produced by the two sexes (male and female). In the current study, the sex of the rabbits did not seem to have any effect on the physical body components' growth patterns.

The body protein in the chemical composition of the carcass caused a significant difference in the response from both male and female NZW rabbits. Geneticists could therefore benefit from the innate growth and developmental differences between the sexes by raising male and female rabbits apart while providing them with a similar nutritional diet. A balanced, non- limiting nutritional regimen improved growth performance, according to the study's findings. Since nutrients can be adjusted for the faster growth and higher body weight of males, as demonstrated in this trial, raising the sexes separately may help to increase body weight

uniformity.

As a formal way of comparing the potential growth rates of the sexes at maturity, it is interesting to find out how much the relationships between the various body components and the body protein weight would differ between the male and female NZW rabbits by fitting Gompertz growth curves to these data for the sexes. Therefore, statistical comparisons could be made between the three Gompertz equation components rather than mean weekly weights. These details can be used to characterize the breed (Emmans, 1989). As in this study, females mature earlier than males and reach the age of maximum growth rate (t*). This is because the rate of maturation is inversely related to pelt-free body weights. Additionally, all males had higher matureweights than females in every body component measured at the end of the trial. This indicates thatmales matured at a faster rate than females, which led to their mature weight being higher earlier. It is expected that body water, lipid, and ash contents in NZW rabbits growing to their genetic potential will be allometrically related to body protein (Emmans and Fisher, 1986) and this was found to be true in this experiment. In order to determine allometric relationships between these chemical components and body protein, Riveira Torres *et al*. (2011) related the weights of body protein, water, lipid, and ash to pelt-free body weight. Simple power functions offer good descriptions of these relationships. When two variables share the same rate of maturation, they are said to be allometrically related (Emmans, 1986). In the chemicalcomposition of this study, the rates of maturation shared by the water, protein, and lipid contents were the same.

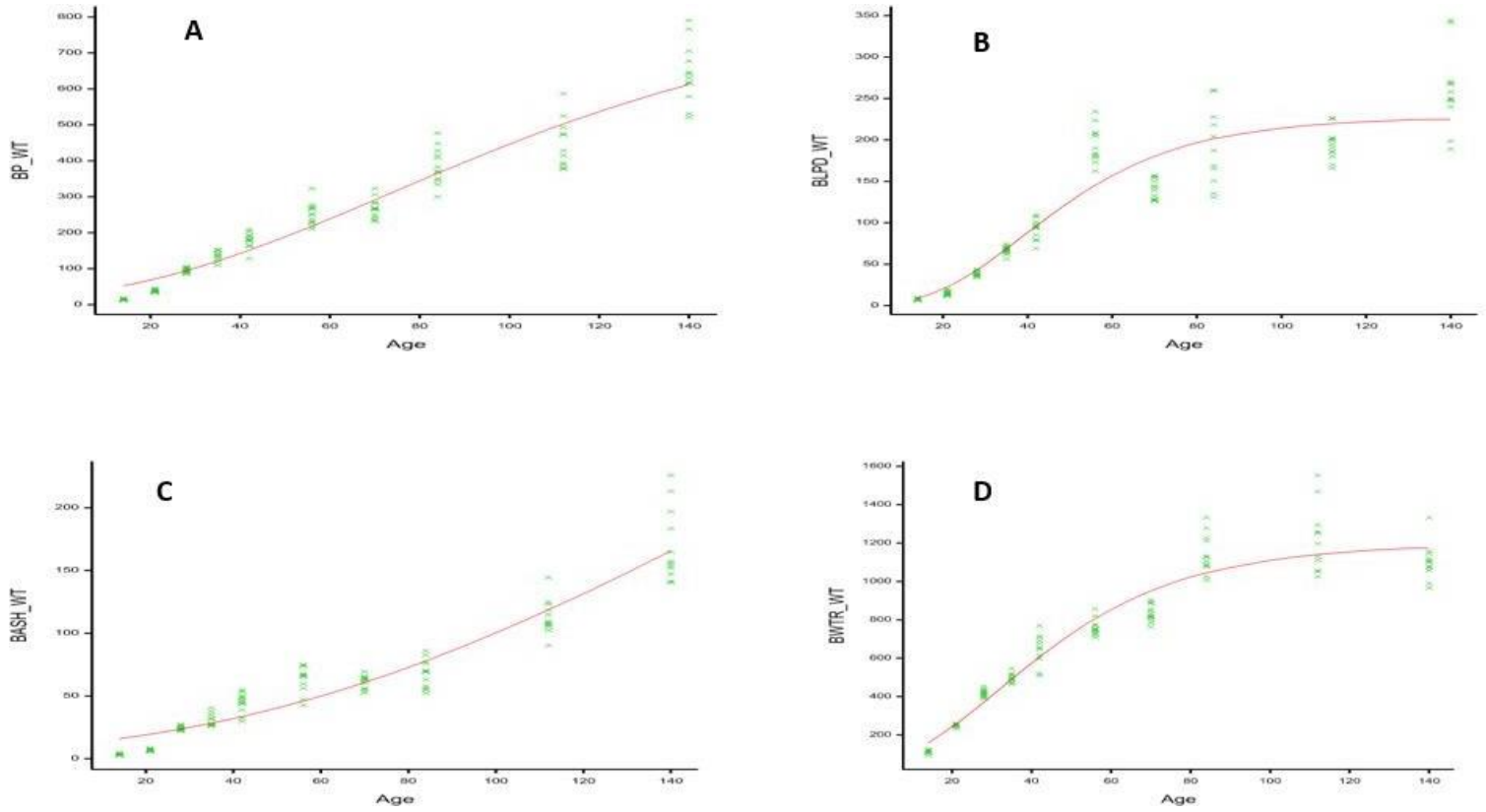

Figure 3.2: Chemical body components of A (body protein weight), B (body lipid weight), C (body ash weight) and D (body water weight)plotted against age.

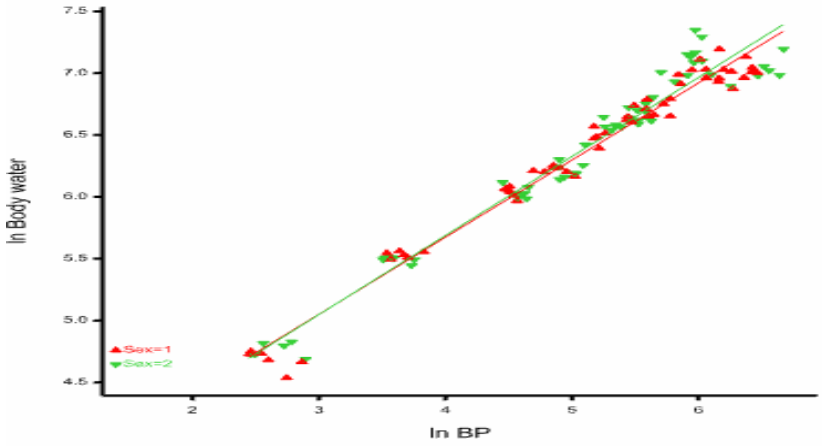

Figure 3.3: Allometric plot of body water weight (g/ kg) against body protein (g/ kg) for NZW male and female rabbits.

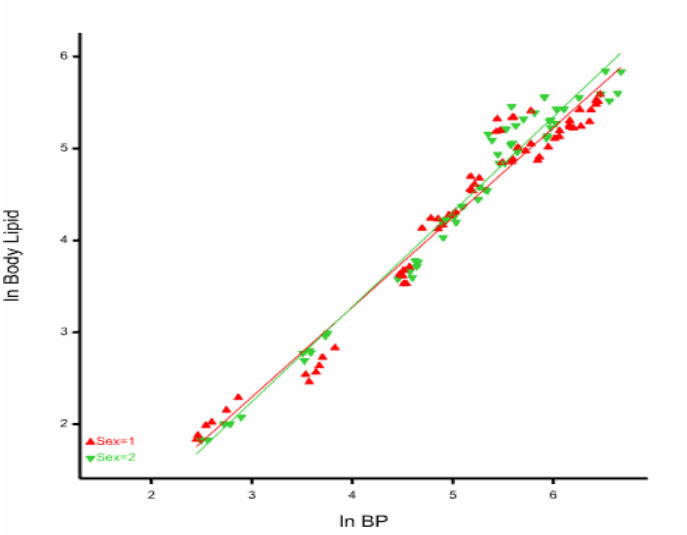

Figure 3.4: Allometric plot of body lipid weight (g/ kg) against body protein (g/ kg) for NZW male and female rabbits.

The water deposition in the NZW rabbits was much higher than the protein deposition, according to allometric coefficients characterizing the correlations between the water, lipid, and ash weights and protein weight in this study. The amount of water in the body dropped as the age of the rabbits increased, although the proportion of protein increased, as shown by the allometric coefficients. While lipid deposition is influenced by dietary and environmental factors, protein deposition is controlled by genetic factors (Dumas *et al*., 2010). The growing percentage of body lipid is usually responsible for the decreasing rate of water deposition in relation to body weight throughout growth (Gous, 2001). According to the current findings and those of Gous *et al*. (1999), variations in the fractionof tissues with varying water to protein ratios may be the cause of the decrease in water weight ascompared to protein weight. The allometric relationship between body protein and live weight in this study demonstrated an isogonic trend, with protein rising in proportion to the rise in live weight.

3.5. Conclusion

Based on the results that were obtained, it had been generally concluded that the proportional growth of body parts in NZW rabbits is not significantly affected by their sex when it comes to body protein content. From a young age, male rabbits weigh more than female rabbits, and this difference only gets bigger as the rabbits get older. Due to their smaller mature sizes than males, females mature more quickly than males, reaching the age at which their rate of growth reaches its maximum earlier. In a comparable way, the rabbits' body protein contents correlate with the weights of their physical body parts. As a key indicator of body and carcass composition, pelt-free body weight can be used to accurately estimate the chemical composition of NZW rabbits. The findings regarding the ash, lipid, water, and protein content of the pelt-free body were objective, making them useful for figuring out the chemical makeup of rabbits. With the help of this description of rabbit growth potential, it will be possible to precisely forecast rabbit growth models as well as the physical and chemical makeup of these rabbits' growth.

CHAPTER 4

Assessing the Growth of Body Components and Allometric Relationships of New Zealand White Rabbits

ABSTRACT

This study evaluated the different body component growth and allometric relationships of NZW rabbits. After measuring the weights of various body parts at different growth stages, each rabbit's components were minced simultaneously to determine the pelt-free body protein weight. A comparison between male and female New Zealand White rabbits focused on major body components and body protein. Allometric regressions were conducted, with ln body protein weight as the independent variable and ln component weights as dependent variables, using data from each sampled rabbit. The GenStat (2023) groups technique was employed to analyze data. The study identified significant allometric correlations between body components and body protein levels in rabbits, established through precise weight measurements. The analysis revealed that accurate predictions of different physical components' weights could be achieved by leveraging body protein weights, guided by the fitted allometric equations derived from the trial's data. Notably, the investigation demonstrated the effectiveness of an allometric relationship for both sexes, showing a robust correlation coefficient ($R^2 = 94.8$). Importantly, even when excluding head weight measurements at 14 days, the relationship's strength remained intact, emphasizing its reliability in predicting body component weights. The findings suggest that a single allometric equation could serve as a comprehensive tool for predicting body component weights in rabbits for each sex. The high R^2 value attests to the robustness of the relationship, reinforcing confidence in the model's predictive capabilities. The flexibility demonstrated by excluding specific measurements, like the head weight at 14 days, highlights the model's adaptability and reliability in practical applications. This study not only establishes the predictive power of the allometric equation but also emphasizes its versatility and reliability in accurately forecasting body component weights based on body protein levels in rabbits.

Keywords: Allometry, Body components, Physical parts, Regression, Rabbit, Sex.

4.1 INTRODUCTION

Under optimal growth conditions, body weight and body protein measurements at different growth stages facilitate the estimation of body composition using allometric functions. Simultaneously, Gompertz growth functions enable the examination of chemical constituent evolution over time, yielding operational values to describe a rabbit population. Emmans (1981b) provides models for predicting body protein increase influenced by genetics, diet, and environment. These models may be broadly applied to project proportional development of body parts, based on the scaling principle proposed by Emmans (1987) for components with similar growth rates.

The core of the model relies on body protein weight, simplifying it while maintaining its precision in predicting changes in body composition. Body protein content serves as a measure for other body constituents and their corresponding growth rates, offering insights into the current state or condition of the animal (Taylor, 1980). Utilizing the allometric correlations existing between body protein and various body components (Moughan *et al*., 1990) allows the assessment of these connections across ages and sexes using the component weights and protein contents of each rabbit (Emmans and Fisher, 1986). Understanding these allometric relationships becomes crucial for modeling effects arising from differences in genotypes, sexes, or variations due to nutritional or environmental changes.

To establish the allometric relationships between major body components and body proteins at different growth stages, it is essential to determine their weights for each genotype (Gous *et al*., 1996). Allometric equations, often formulated as y = axb, provide a proportional adjustment for various morphological and physiological parameters relative to body size (Schmidt-Nielsen, 1984; Emmans, 1987). The allometric coefficients associated with different carcass components dictate the extent to which these components vary in proportion (Govaerts *et al*., 2000). In modelling, there are advantages to building the body structure according to the weights of its constituent parts. One disadvantage, though, is that body composition data from slaughter studies are more expensive and less common to get than live weight data. Moreover, it becomes appropriate to think about this live weight data as a first step towards creating a growth model because accurate weight measurements can be acquired several times for a particular animal (Lewis *et al.*, 2002). This study aimed to determine the allometric relationships between the body's major anatomical segments and the protein composition of the body in New Zealand White rabbits.

4.2 MATERIALS AND METHODS

4.2.1 Study Site

As described in 3.2.1.

4.2.2 Animals and Experimental Design

As described in 3.2.2

4.2.3 Animal Housing and Management

As described in 3.2.3

4.2.4 Slaughtering Procedures

As described in 3.2.4

4.2.4.1 Dissecting and measuring of parts

Following the removal of the skin from the carcass while it was suspended on the cutting hanger, the rabbits were taken down from the hanger and positioned on their backs. A cut was created running from the tail end to the abdominal region, revealing the peritoneum lining the inside of the abdominal cavity. The peritoneum was incised, allowing for the extraction of the abdominal organs. The abdominal organs comprise the following: the large and small intestines, stomach, liver, two kidneys, pancreas, spleen, the urinary tract, and the heart. Following the extraction and weighing of the contents of the abdominal tract, the carcass was dissected into fore and hindlimbs, ribs, and saddle. Measurements and documentation were performed for all body components, including the head.

4.2.5 Carcass Composition Parameters and Chemical Analyses

As described in 3.2.5.1, 3.2.5.2, 3.2.5.3 and 3.2.5.4

4.2.6 Statistical Analysis

The weight and the logarithm (*ln*) of each bodily and chemical component's weight were

computed. Subsequently, the proportional connections between these constituents (Y) and the weight of body protein (X) were established through the employment of the following equation,

$ln\ Y = ln\ a + b\ ln\ X$

The logarithmic plot's slope, represented by the exponent b, is determined through linear regression. The GenStat (2023) groups technique was employed to analyze the distinctions between the constant terms (a) and slopes (b) of the regressions. The primary objective of the study was to establish the allometric correlations between the major body parts and body protein in New Zealand White rabbits.

4.3 Results

Instead of assessing the impact of dietary protein content on growth rate, the trial aimed to generate a diverse range of body component weights during the growth period to analyze the allometric relationships between the physical features of NZW rabbits and their body protein contents. When fitting allometric equations and associating the weights of rabbits' head, forelimbs, hindlimbs, ribs, and saddle with body protein content, there was no observable variation in the regression concerning age and sexes (Table 4.2). Regarding the body protein weight of carcass components, the constant terms and regression coefficients applied to both sexes were similar, indicating no significant difference between male and female rabbits ($p>0.001$).

Allometric equations for body component and body protein weight data were independently computed for each sex within the sampled rabbit population. These equations were then compared using simple linear regression in Genstat, with the corresponding coefficients detailed in Tables 4.4, 4.5 and 4.7. When no apparent variations in the constant term or regression coefficients were noted for both sexes, a common value was employed. Specifically, the saddle weight, irrespective of body protein content, was characterized by a single constant term (1.0193) and regression coefficient (0.8276) (Table 4.7). For hind limbs in males (Table 4.5), the constant term varied between (1.3971±0.0715) and (1.1924±0.0724), while for forelimbs (Table 4.4), it remained consistent at (1.0193). The corresponding regression coefficients were 0.7663±0.0137 and 0.6913±0.0137, respectively.

4.3.1. Head weight

The allometric coefficients for the influence of sex that relate head component weight to body protein weight are shown in Table 2. From the observation of this trial, the head weight of a 14-day-old was below the regression line (Fig.1). In another regression analysis, the two sexes had a common regression, but the R^2 value showed a tiny increase from 94.7 to 94.8. The regression showing a correlation between head weight and body protein were linear as body protein content increased. There was a significant deviation from the reference for female heads to body protein in both the regression coefficients ($P<0.001$) and the constant term ($P<0.001$).

4.3.2. Fore limb weight

Instead of using separate regression to fit the data, common constant terms, slopes for the two sexes, and body protein weight did (Table 4.2); Table 4.4 illustrates the relationship between body protein weight and forelimb weight.

4.3.3. Hind limb weight

As there was no effect of sex on the allometric regression between the two variables (Table 4.2), the relationship between hind limb weight and body protein weight could be explained by a significant difference between the sexes in the constant term, in the same way that the slope and constant terms for sex did not differ.

4.3.4. Rib weight

The rib weight and body protein weight data obtained from each sampled rabbit were utilized to derive the allometric equations for each sex, even though there was no distinction in body protein weight and rib weight between the sexes during the growth period (Table 6). As indicated in Table 2, it was observed that defining rib weight in relation to body protein levels in both sexes required a single constant term (0.8084) and a single regression coefficient (0.7916). Notably, the constant term and regression coefficient for rib weight did not exhibit any significant differences.

4.3.5. Saddle weight

A notable correlation was observed between the male sex and the allometric coefficients for saddle

meat production. The regression coefficients were 0.8276 ± 0.0124, and the constant term for saddle weight exhibited variability, ranging between 1.0193 ± 0.0278. This variation stemmed from the consistent increase in saddle weight in tandem with the body protein content during the growth phase. Substantial differences in constant terms were evident due to the primary influence of sex on the allometric relationship between saddle weight and body protein weight (Table 4.7).

4.3.6. Body lipid content

In the body lipid content of the sampled male and female rabbits, the males had a mean weight that was greater than females (96 vs. 93 g lipid/kg of body weight). Additionally, thebody's lipid and protein contents were positively correlated ($P<0.001$) for all age groups.

Table 4.1: Chemical composition of commercial diet fed to the rabbits

Item	Chemical composition (g/ kg)
Protein	140
Fat	25
Fibre	170
Moisture	120
Calcium	18
Phosphorus	7

Table 4.2: Allometric coefficients (constant term and regression coefficients) relating the *ln* of some physical parts of male and female rabbits to the *ln* of body protein weight

	Constant term		Regressior Coefficients		
Component	Mean	s.e.	Mean	s.e.	R^2
Pelt	1.7797	0.0926	0.6563	0.0175	0.922
Head	2.3432	0.0244	0.5021	0.0109	0.947
Forelimbs	1.1924	0.0724	0.6913	0.0137	0.956
Hindlimbs	1.3971	0.0715	0.7663	0.0137	0.964
Rib	0.8084	0.108	0.7916	0.0204	0.927
Saddle	1.0193	0.0278	0.8276	0.0124	0.974

Allometric coefficients: constant term and regression coefficients

Parameters of body component interactions and body protein compared with the reference level, sex, F.

Table 4.3: Estimates of parameters for head

Parameter	estimate	SE	t (116)	t pr.
Constant	2.3311	0.0563	41.43	<.001
ln_BP	0.5024	0.0109	46.19	<.001
Sex, M	0.0246	0.0244	1.00	0.317
ln_BP. Sex M	0.0357	0.0216	1.65	0.101

BP: body protein weight

Table 4.4: Estimates of parameters for fore limbs

Parameter	estimate	SE	t (116)	t pr.
Constant	1.1787	0.0706	16.69	<.001
ln_BP	0.6913	0.0136	50.67	<.001
Sex, M	0.0281	0.0307	0.92	0.361
ln_BP. Sex M	0.0312	0.0273	1.14	0.255

BP : body protein weight

Table 4.5: Estimate parameters for hind limbs

Parameter	estimate	SE	t (116)	t pr.
Constant	1.3876	0.0697	19.92	<.001
ln_BP	0.7662	0.0135	56.94	<.001
Sex, M	0.0194	0.0303	0.64	0.524
ln_BP. Sex M	-0.0065	0.0271	-0.24	0.811

BP: body protein weight

Table 4.6: Estimates parameters for ribs

Parameter	estimate	SE	t (116)	t pr.
Constant	0.7860	0.1050	7.46	<.001
ln_BP	0.7915	0.0203	38.90	<.001
Sex, M	0.0398	0.0458	0.87	0.387
ln_BP. Sex M	0.0106	0.0409	0.26	0.796

BP: body protein weight

Table 4.7: Estimates parameters for saddle

Parameter	estimate	SE	t (116)	t pr.
Constant	0.9948	0.0647	15.38	<.001
ln_BP	0.8275	0.0125	66.23	<.001
Sex, M	0.0500	0.0278	1.80	0.075
ln_BP. Sex M	-0.0156	0.0248	-0.63	0.531

BP: body protein weight

Table 4.8: Estimates parameters for pelts

Parameter	estimate	SE	t (116)	t pr.
Constant	1.7797	0.0927	19.29	<.001
ln_BP	0.6563	0.0157	37.58	<.001
Sex, M	-0.0057	0.0393	-0.15	0.884
ln_BP .Sex M	0.0445	0.0348	1.28	0.204

The logarithmic allometric equations of body components against body protein using the equation,

ln Y = *ln* a + b *ln* X

ln pelt weight: 1.7797 (±0.0926) + 0.6563 (±0.0153)* ln body protein weight

ln head weight: 2.343 (±0.0244) + 0.5021 (±0.0109)* ln body protein weight

ln FL weight: 1.1924 (±0.0724) + 0.6913 (±0.0137)* ln body protein weight

ln HL weight: 1.3971 (±0.0715) + 0.7663 (±0.0137)* ln body protein weight

ln rib weight: 0.8084 (±0.0108) + 0.7916 (±0.0204)* ln body protein weight

ln saddle weight: 1.0193 (±0.0278) + 0.8276(±0.0124)* ln body protein weight

4.4. Discussion

Substantial changes in component weights are commonly observed across strains, sexes, and feed protein levels, as noted in previous studiesby poultry researchers (Le Bihan-Duval *et al*., 1999; Berri *et al*., 2001; Kemp *et al*., 2005). Whilethere is limited variation in the allometric relationships between different body parts and body protein across strains, sexes, and feed protein levels, Danisman and Gous (2008) suggested that these variations likely stem from the comparisons being made at distinct body protein weights. The amount of lipid deposited in different parts might have varied, influenced partly by the provided feed protein level and the maximum lipid capacity for each tissue. This could have accounted for some of the variations observed in the allometric relationship. This experiment only provides information on the overall chemical composition of the rabbits' bodies. Detailed data regarding the amounts of water, protein, fat, and ash in each specific body component are not available. With a protein concentration of 140 g/kg and a fat content of 25 g/kg, Table 4.1 illustrates the chemical makeup of the commercial diet employed in this investigation. Although Hakansson *et al*. (1978) examined the quantity of lipid deposited in all edible meat on meals with varied metabolizable energy contents, this is not very useful because, for example, it is more likely that lipids would be deposited in some areas than others.

Consequently, the allometric slope observed in this study is linear, as the early-measured allometric coefficients between the rabbits' body parts and body protein fall below the slope. The relationship between the forelimbs and hindlimbs with the body protein weight notably show deviations from the regression line, particularly in the early stages, suggesting potential challenges in nutrient accessibility before weaning. The goodness of fit in this study ranks highest for the saddle (0.974), followed by hind limbs (0.964) and ribs (0.927).

The choice of body protein content as the independent variable, rather than body weight, was based on similar reasoning. It is more preferable to measure and regress the protein weight in each part against the body protein weight rather than incorporating the lipid content of these parts in the derivation of allometric equations.

If the lipid content in each part could be predicted on feeds with varying protein contents, the weights of the body parts could be adjusted without creating a separate allometric equation for every level of dietary protein fed to broilers (Danisman and Gous,2011). This contrasts with the findings of Danisman and Gous (2013), where the body lipid content was altered by feeding different dietary protein contents, leading to unidentical allometric relationships.

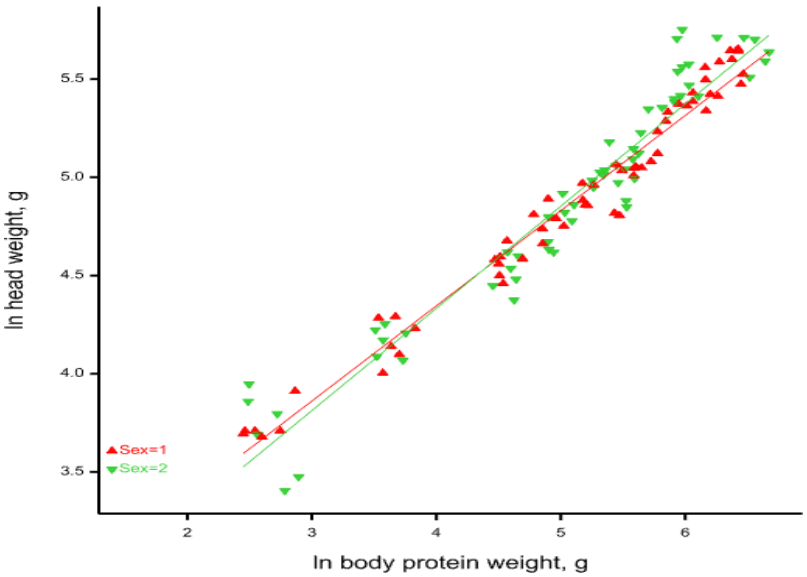

Figure 4.1: Allometric plot of *ln* head weight against *ln* body protein weight

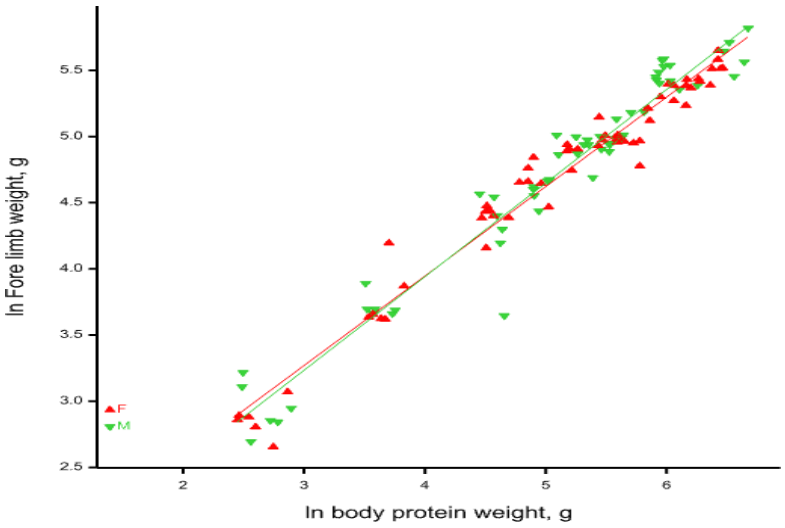

Figure 4.2: Allometric plot of *ln* fore limb against *ln* body protein weight.

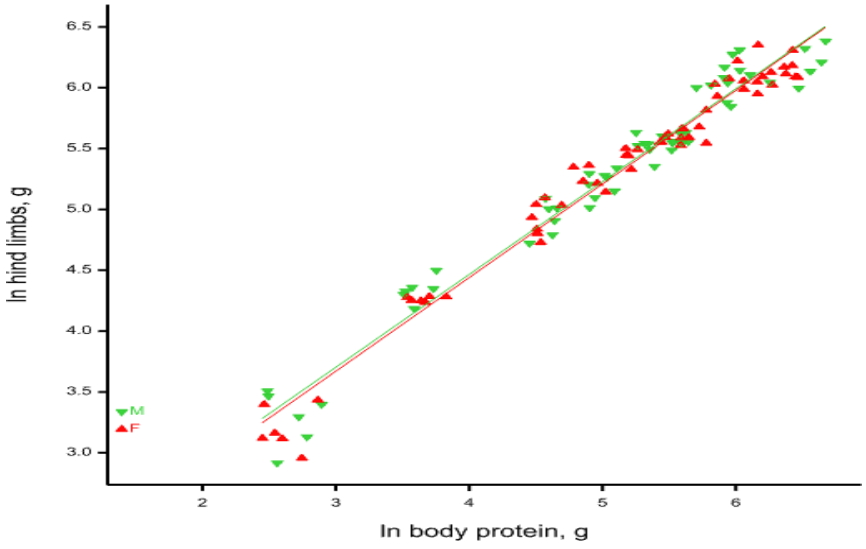

Figure 4.3: Allometric plot of *ln* hind limbs against *ln* body protein weight.

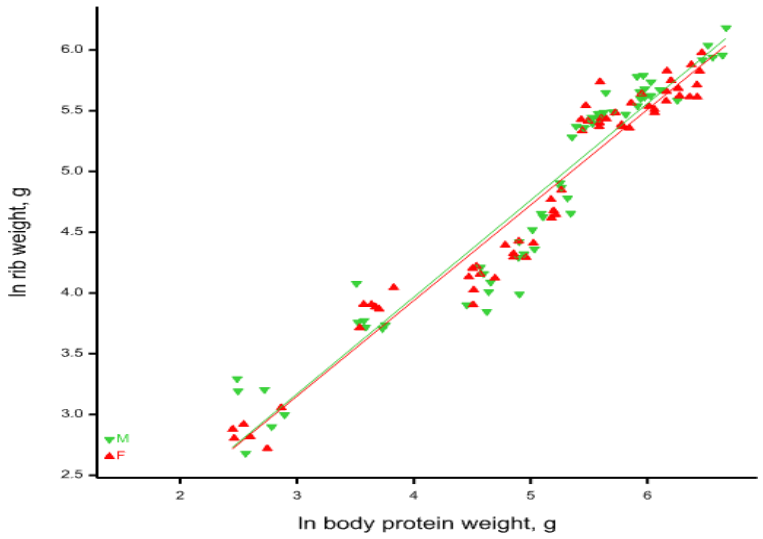

Figure 4.4: Allometric plot of *ln* rib weight against *ln* body protein weight.

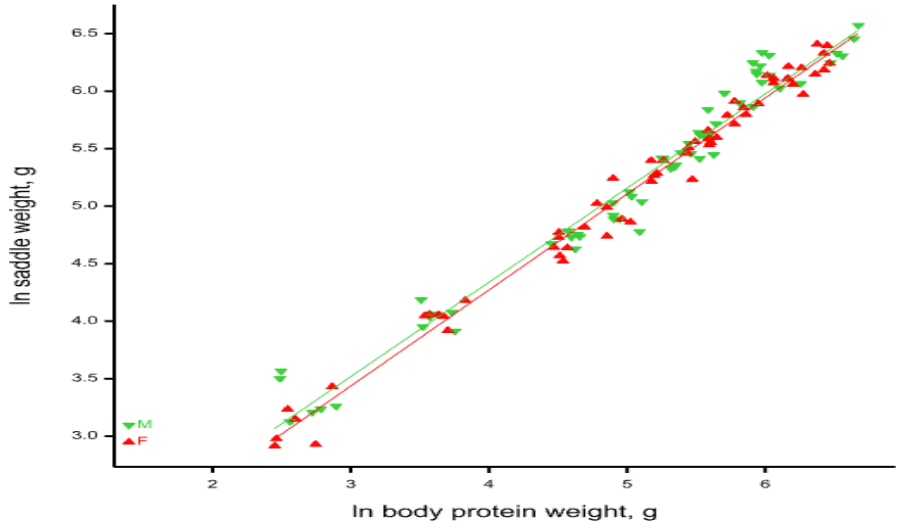

Figure 4.5: **Allometric plot of *ln* saddle weight against *ln* body protein weight**

4.5 Conclusion

The body protein content of rabbits, as determined in this study, enables precise predictions of the weights of the measured body components. Utilizing the allometric correlations established between these body parts and body protein weight, the trial data facilitates adjustments to the weights of the rabbit's major body components. Furthermore, there exists a positive correlation between the rabbit's body protein level and the weights of its various body parts. The allometric relationships between different body parts and body protein, though similar between sexes, exhibited statistical differences in component weights.

CHAPTER 5

Predicting the potential Growth and Chemical Composition in the body of Chinchilla Rabbits

ABSTRACT

A research study was conducted to investigate the potential growth and chemical variations in the body composition of Chinchilla rabbits over a 126-day growth period. The study involved a cohort of 220 Chinchilla rabbits, evenly distributed between males and females. One hundred rabbits (50 males and 50 females) were dedicated to assessing potential growth, and an additional 120 rabbits, comprising 60 males and 60 females, were used for carcass examination. Slaughtering occurred at specific time intervals (14, 21, 28, 35, 42, 56, 70, 84, 116, and 140 days of age), with proximate analyses conducted on the entire empty body carcass. The results were expressed as a percentage of pelt-free for various slaughter ages. The Gompertz growth curve was applied to live weights, individual body components, and the weights of individual chemical components in the rabbits. The relationship between age, sex, and body weight was well-described with a good fit (coefficient of determination) (R^2 = 0.97) for modeling growth in Chinchilla rabbits. The estimated growth parameters m, b, and c were 44.1, 0.0247, and 56.3, respectively. Protein and lipid quantities in the body increased as the rabbits matured, while no apparent pattern was observed in ash content. Additionally, the concentration of body water dropped. The fitted Gompertz parameters for the different chemical components are as follows: for lipid, m = 55.84, b = 0.0225, and c = 225.9 (R^2 = 0.85); for protein, m = 61.88, b = 0.0247, and c = 550.1 (R^2 = 0.93); for ash, m = 59.89, b = 0.0236, and c = 137.7 (R^2 = 0.84); and for water, m = 51.41, b = 0.0265, and c = 1530.8 (R^2 = 0.95). Like other animals, body lipids and proteins are tissues that mature later, while body water is a tissue that matures relatively early. With the weight of body protein as a starting point, the allometric equations fitted to the trial's data allow precise estimation of the weights of the other physical components. These findings are crucial for characterizing growing rabbits.

Keywords: Age, Chinchilla, Gompertz, Growth, Rabbits, Sex.

5.1 INTRODUCTION

Rabbits exhibit significant growth potential, and the importance of enhancing their development cannot be overstated. This is primarily because they make a valuable contribution to the supply of essential animal protein in developing nations. Understanding the genetic and growth significance holds immense importance in the genetic enhancement of farm animals (Akanno and Ibe, 2006; Okoro *et al*., 2010). Analyzing the growth potential of animals is a crucial element in predicting meat production, as it directly influences the market worth of these animals (Ikeobi and Faleti, 1996). Breeds such as Chinchilla, New Zealand White, and Dutch continue to be the most widely reared breeds, and these breeds are distinguished from one another by peculiar traits. The Chinchilla rabbit is a well-known breed, primarily bred for commercial meat production purposes. The Chinchilla rabbit, as its name implies, was first bred in France during the early 1900s and received its name due to the resemblance of its fur to that of the South American rodent known as the Chinchilla. It is a huge breed with a compact, medium-built body. It possesses a concise neck and a relatively wide head, accompanied by short, upright ears. Its coat is characterized by its incredibly soft and silky texture, consisting of dense, medium-length fur. The primary purpose of breeding this rabbit breed was originally for both meat and fur production. However, in contemporary times, it is predominantly raised for meat production, as the rabbit fur industry declined significantly in the late 1940s.The Chinchilla is a rabbit of modest size, typically ranging from 2.5 to 3 kilograms (equivalent to 5.5 to 7 pounds) in weight.

A growth function can be employed to illustrate the presence of protein in the body, establishing a connection between the growth of water, ash, lipid, and protein. This linkage can be utilized to determine the overall rate of body growth, following the approach outlined by Emmans (1989). Similar to weight, the growth pattern of body protein can be elucidated. Two methods can be employed to predict the growth of other chemical components of the body: firstly, by utilizing believed allometric relationships between different body parts (Emmans and Fisher, 1986; Emmans, 1989), and secondly, by directly estimating their growth parameters using nonlinear approaches.

Examining growth curves obtained from individual growth patterns is one method for predicting and evaluating how animal bodies will evolve. According to Arango and Van Vleck (2002), the

main models used to describe growth rely on differential equations that attempt to be biologically interpretable. Different nonlinear equations are used in the field of animal production to represent the progression of animal growth over time. The Gompertz growth function has been used to illustrate how an animal's ability for growth fluctuates in relation to size while dealing with young animals (Emmans and Kyriazakis, 1999). Both the potential rate of growth and the desired level of fatness in the animal are solely determined by the animal's species and its level of maturity, representing inherent characteristics.

It is possible to hypothesize that animals have an innate capacity for protein growth rate, which they aspire to and can achieve with adequate nutrition and a favorable environment. It becomes possible to predict this future growth rate with a thorough genetic description. The animal's nutritional and environmental requirements for achieving this aim can then be determined. The animal will not be able to grow to its full potential when the dietary and environmental inputs are insufficient; the degree to which it is confined can be anticipated using a set of principles (Ferguson *et al*., 1994). The purpose of this study was to gather information on the growth of a few key body parts in male and female Chinchilla rabbits under non-limiting conditions and to demonstrate how the rabbits' potential growth can be described in terms of overall live weight and chemical composition from days 14 (2 weeks) to days 140 (20 weeks) of age.

The objective, materials and methods, numbers of animals and experimental design were the same as in an earlier exercise (see chapter 3), except that Chinchilla rabbits are used.

5.2 MATERIALS AND METHODS

5.2.1 Study Site

As described in 3. 2.1

5.2.2 Animals and Experimental Design

In all, 220 *Chinchilla gigantas* rabbits, evenly distributed between males and females (110 males and 110 females), were used in this investigation for a duration of 14 to 140 days. 120 rabbits (60 males and 60 females) were employed for the samplingprocess and 100 (50 males and 50 females) were used to assess potential growth. Twelve rabbits, six males and six females, were randomly selected at each of the following time points: 14, 21, 28, 35, 42, 56, 70, 84, 112

and 140 days for the purpose of carcass analysis. The100 rabbits for potential growth were weighed from day 14 to day 140. Male and female rabbits were raised separately in separate cages.

5.2.3 Animal Housing Management

As described in 3.2.3

5.2.4 Slaughtering Procedures

As described in 3.2.4

5.2.5Carcass Composition Parameters and Chemical Analyses

As described in 3.2.5.1

5.2.6 Statistical Analysis

The weights of individual rabbits and the analysis of variance of their means were examined using GenStat 23rd edition (VSN International 2023). The Gompertz growth curve was utilized to model changes in the live weight of male and female Chinchilla rabbits during the experiment's duration employing GenStat International (version 2023). An investigation was conducted to examine the allometric correlations between the live weight and bodily components.

5.3 Results

5.3.1. Potential Growth Analysis for Chinchilla Rabbits

Table 5.1 shows the average growth rate of male and female Chinchilla rabbits at different ages of sampling. The growth rate for both males and females show a comparable growth pattern along identical direction. There was no apparent trend of growth in the male and female rabbits between day 14 and day 35. Starting from day 42, the growth rate of the males exceeded that of the females until day 140. The average body weights of males and females at 140 days of age were 1560 g/kg and 1557 g/kg, respectively. The study involved tracking the body weight of individuals from day 14 to day 140, indicating a consistent and steady growth pattern in both males and females. The

correlation between ages was statistically significant (P<0.001), although there was no significant correlation between sexes (P<0.009) and age*sex (P<0.170). Table 5.2 indicates that when the Gompertz equation was applied to the growth data for males and females, it projected that the mature weight of females would be 2 kg greater than that of males (56.3 vs. 54.5 kg). Compared to females, males had a notably greater rate of maturity (B) (0.0255 vs. 0.0247/d), but they also had a lower weight at maturity (54.5 vs. 56.3 g). Male rabbits achieved this age at 43 days, as contrast to 44 days for female rabbits, which corresponds to the period when the rabbits observed their highest growth rate. The Gompertz growth curve demonstrated that the Chinchilla rabbits' goodness of fit (R^2) is equivalent for both males and females (R^2 = 0.097). When the live weights of female and male chinchilla rabbits were plotted against age (in days), it was observed that their growth patterns were quite similar (Fig. 1).

5.3.2 Growth Analysis

5.3.2.1 Pelt-free and Pelt growth weight

The study of carcass analysis utilized averaged data sets to analyze growth trends, specifically focusing on the weight of various body parts. The average weight of each bodily component was computed for each sex and age group. Table 5.3 displays the impact of age and sex on the weights of fur with and without the pelt. The pelt-free weight was not significantly affected by age and the interaction between age and sex (P>0.001). There was a significant difference (P<0.001) in the increase of fur-free and fur-weight between males and females. There was no obvious trend in the weight gain of the pelt-free weight in both males and females from day 14 to day 35. The weight of the animals without their fur increased in direct proportion to their age and sex. The average weight of the males (1007 g) was 15 g greater than that of the females (992 g). The interaction between age and age*sex had a substantial effect on pelt weights (P<0.001) (Table 5.3). Male individuals had greater pelt weights compared to females from day 14 to day 42. However, no noticeable pattern was observed from day 56 to day 140.There was a very small variation in the average weight of the pelt between male and female animals, with males weighing 168 g and females weighing 167 g. However, when looking at the weight at d-140, it was found that males had a pelt weight of 348 g, which was 25 g more than the females' weight of 323 g. The adult weight of males without pelt was 55 grammes per kilogram, but that of females was 58 grammes

per kilogram. The males exhibited a considerably higher level of maturity (B) compared to the females (0.02590 vs. 0.02423), with a statistically significant difference (P<0.001). The females' mature weight (45 g/kg) was lower than that of the males (51 g/kg) because the females' pelt weight had a slower rate of development (0.02025) compared to the males (0.02400).

Table 5.1: Mean live weight (g) of male and female Chinchilla rabbits from day 14 to days 140.

Age (Days)	Females	Males	Mean
14	125	125	125
21	191	188	189
28	441	442	442
35	498	494	496
42	865	868	867
49	1124	1126	1125
56	1379	1380	1380
63	1481	1482	1481
70	1523	1527	1525
77	1594	1595	1594
84	1682	1688	1685
91	1847	1853	1850
98	2018	2024	2021
105	2200	2206	2203
112	2384	2390	2387
119	2428	2429	2428
126	2517	2519	2518
133	2598	2599	2598
140	2696	2697	2697
Mean	**1557**	**1560**	**1558**

Table 5.2: Gompertz parameters describing the potential growth of the Chinchilla rabbits

Parameter	Female		Male	
	Mean	s.e.	Mean	s.e.
Age at maximum growth rate, (t*, d), M	44.14	3.24	43.14	3.01
Rate of maturing, (g/ d), B	0.0247	0.0018	0.0255	0.0018
Mature weight (g/ kg), C	56.3	123	54.5	113
R^2	0.97		0.97	

s.e: significant error

5.3.3. Weight of carcass components by sex and age (g).

Table 5.3: Mean live, pelt-free and pelt weights (g) of female and male Chinchilla rabbits at 10 sampling ages.

	Live			**Pelt-free**			**Pelt**		
Age (days)	F	M	Mean	F	M	Mean	F	M	Mean
14	125	120	122	99	93	96	25	27	26
21	174	187	180	139	150	144	34	37	36
28	441	434	438	373	364	368	68	71	69
35	471	500	485	394	423	408	77	77	77
42	877	894	885	720	727	724	157	167	162
56	1335	1379	1357	1110	1153	1131	225	209	217
70	1476	1479	1477	1230	1270	1250	238	225	232
84	1591	1622	1606	1353	1385	1369	246	236	237
112	2380	2396	2388	2224	2224	2224	278	286	283
140	2692	2676	2684	2281	2307	2294	323	348	336
Mean	**1156**	**1169**	**1162**	**992**	**1007**	**1001**	**167**	**168**	**168**
	Age	Sex	Age*sex	Age	Sex	Age*Sex	Age	Sex	Age*Sex
P Value	***	ns	ns	***	ns	ns	***	Ns	***
SEM	11.68	5.23	16.52	10.95	4.89	15.48	3.86	1.72	5.46
RMS	81 .2			719			89.52		

SEM: standard error of mean; RMS: residual mean square; F: female; M: male; ns: not significant

Table 5.4: Mean head, fore and hind limbs weights (g) of female and male Chinchilla rabbits at 10 sampling ages.

	Head			Fore			Hind		
Age (days)	F	M	Mean	F	M	Mean	F	M	Mean
14	28	25	27	11	10	11	11	11	11
21	35	35	35	13	14	14	16	18	17
28	65	66	65	44	43	44	72	66	69
35	82	79	81	52	58	55	91	98	95
42	123	125	124	82	89	85	133	132	132
56	151	169	160	127	134	130	227	240	233
70	168	170	169	145	146	145	259	265	262
84	171	178	175	160	161	161	278	274	276
112	221	226	223	194	202	263	388	416	446
140	235	242	238	246	263	265	447	459	464
Mean	**128**	**131**	**130**	**107**	**112**	**110**	**192**	**198**	**195**
	Age	Sex	Age*Sex	Age	Sex	Age*Sex	Age	Sex	Age*Sex
P Value	***	ns	Ns	***	***	ns	***	ns	ns
SEM	3.43	1.54	4.85	3.03	1.36	4.29	4.15	1.86	5.87
RMS	71			55			103		

SEM: standard error of mean; RMS: residual mean square; F: female; M: male; NS: not significant

Table 5.5: Mean rib and saddle weights (g) of female and male Chinchilla rabbits at 10 sampling ages.

	Rib			Saddle		
Age (days)	F	M	Mean	F	M	Mean
14	11	11	11	11	11	11
21	17	21	19	16	19	18
28	37	42	40	47	54	51
35	60	60	60	62	62	62
42	134	128	131	126	127	126
56	174	181	177	222	230	226
70	191	200	195	262	274	268
84	229	240	234	276	292	284
112	283	294	289	398	418	408
140	363	366	364	454	495	474
Mean	**150**	**154**	**152**	**187**	**198**	**193**
	Age	Sex	Age*Sex	Age	Sex	Age*Sex
P Value	***	ns	ns	***	***	***
SEM	3.83	1.71	5.4	3.84	1.72	5.44
RMS	88.07			88.62		

SEM: standard error of mean; RMS: residual mean square; F: female; M: male; ns: not significant.

5.3.4. Carcass Composition

5.3.4.1. Heads, fore limbs, and hind limbs growth weights

The result of the growth analysis of the average individual population of the head, forelimb and hindlimbs of the Chinchilla rabbits are shown in Table 5.4. There was a linear increase in the head, FL, and HL of the male and female Chinchilla rabbits measured. The age was highly significant ($P<0.001$) across both sexes in the head while the sex and age*sex were not significant ($P>0.001$). From d-14 to d-35, there was no trend in the growth across both sexes, but from d-42, the head weight of the male rabbits weighs more than the females with a mean value of 131 g against the 128 g of the female. There was no significant difference ($P>0.001$) in the age*sex across both

sexes of the FL, however, there were significant relationship (P<0.001) in the age and sex of both sexes. Although, there was no statistical differences across the sexes as the age increases, therefore there is linear trend of increase in the males from d-35 to d-140 in the head and FL of the body components. The mean weight of the hind limbs showed that the males weighed more than the females (198 g *vs* 192 g) and the sex and age*sex did not significantly differ (P>0.001) across the ages, likewise, there was no trend of increase across both sexes at all the sampling ages. The rate of maturation of the head in females is lower (0.03213) than that of the males (0.03969) with the females having a higher mature head weight than the males (36 g/kg *vs* 34 g/kg), Table 5.7. The mature size (56 g/kg) and the rate of maturity (0.025 /d) respectively of the FL in both sexes are similar. The goodness of fit (R^2) of the HL are the same (0.97) for both sexes with the female having a higher mature weight than the male (56 *vs* 54 g/kg, respectively) and the rate of maturing, higher in the male than in the female (0.028 *vs* 0.026 /d, respectively), Table 5.7.

5.3.4.2. Ribs and saddle growth weights

Table 5.5 presents the weights of rib and saddle body components for both sexes at various sampling ages. Male rib weights were higher at 154 g compared to females at 150 g, showing a significant relationship (P<0.001) across all ages. However, there was no significant correlation (P>0.001) between sex and age*sex. Throughout the reported ages (d-14 to d-140), malesexhibited positive increase in saddle weight, with a mean total weight of 198 g, while females hada mean weight of 187 g. there was a significant relationship (P<0.01) across ages, sexes, and the interaction between age*sex. The mature weight of female ribs (80 g/kg) exceeded that of males (78 g/kg), while the maturity rate was lower in females (0.0197) compared to males (0.0203), as indicated in Table 5.7. Additionally, the mature weight of females' saddle was 5 g/kg heavier thanmales (61 vs 66 g/kg), and males, with their lower mature weight, matured faster than females (0.027 vs 0.024).

5.3.4.3 Chemical composition of the empty body (pelt-free)

Table 5.6 provides insights into the chemical composition of rabbits' empty bodies from d-14 to d-140. Notably, there was a significant increase (P<0.001) in protein weight as both sexes aged, with mean weights at d-14 of 117 g/kg for males and 128 g/kg for females, increasing to 276 g/kg

and 282 g/kg, respectively, at d-140. The male exhibited a slightly higher mean protein weight compared to the female (200 vs 199 g/kg). Age was identified as the sole factor ($P<0.001$) influencing protein content outcomes.

A linear decline in water content from d-14 to d-140 was observed, with a total mean weight of 656 g/kg for males and 660 g/kg for females. A significant relationship ($P<0.001$) existed between age and the interaction of age and sex in water content weight (Fig. 5.2).

Lipid weight showed a consistent increase in both male and female Chinchilla rabbits throughout the growth period, with an identical mean weight of 113 g/kg. Body ash content exhibited no distinguishable trend during the growth period in both sexes (Fig 5.2). The Gompertz growth curve parameters, obtained from the increasing weight of protein content in the empty body, revealed that females matured at a faster rate than males (0.0256 vs 0.0237 /d) with mature weights of 61 g/kg and 63 g/kg, respectively. Additionally, predictions from the Gompertz curves indicated that at maturity, the female body water content would be heavier than the male (52 vs 51 g/kg), and due to their mature weights, males matured faster than females (0.0262 vs 0.0268 /d). For lipid body contents in females, the rate of maturity was higher than in males (0.0225 vs 0.0224 /d), although they both reached the same mature weight size of 56 g/kg.

Table 5.6: Mean empty body protein, lipid, water, and ash content (g/kg) of male and female Chinchilla rabbits at different ages.

	Protein		Lipid		Water		Ash	
Age	F	M	F	M	F	M	F	M
14	128	117	45	53	801	801	27	29
21	174	181	76	73	714	711	36	28
28	177	186	80	78	710	702	25	25
35	185	191	110	105	691	686	42	48
42	191	191	117	123	668	667	45	44
56	191	195	128	124	647	645	38	30
70	206	210	134	128	629	627	46	40
84	216	215	139	141	613	606	32	40
112	236	242	140	145	599	580	57	53
140	282	276	163	162	531	535	66	58
Mean	**199**	**200**	**113**	**113**	**660**	**656**	**41**	**40**
SEM	3.87		3.5		11.58		2.27	
P-value Age	***		***		***		***	
Sex	ns		ns		ns		ns	
Age*sex	ns		ns		***		***	

P<0.001: significant; SEM: standard error of mean; ns: not significant; F: female; M: male:

Table 5.7: Parameters of the Gompertz growth curve (mature weight, rate of maturation and age at maximum growth rate) ± SE, describing the growth of body components in the empty body of males (M) and females (F) Chinchilla rabbits.

	Age at maximum growth rate (t*,d)		Rate of maturity, /d		Mature weight, (g/kg)		
Item	Mean	s.e.	Mean	s.e.	Mean	s.e.	R^2
Pelt-free							
Male	2591	94.8	0.0259	0.0018	55.07	2.05	0.97
Female	2696	112	0.0242	0.0018	58.12	2.41	0.97
Pelt							
Male	427.5	23.6	0.0240	0.0025	50.60	3.18	0.94
Female	388.6	14.5	0.0303	0.0026	45.21	1.93	0.95
Head							
Male	229.9	5.29	0.0397	0.0028	34.07	1.08	0.96
Female	240.2	6.24	0.0321	0.0023	36.29	1.28	0.96
Forelimbs							
Males	308.2	14.3	0.0252	0.0022	55.51	2.63	0.96
Females	304.3	12.3	0.0255	0.0019	56.28	2.28	0.97
Hindlimbs							
Males	510.1	20.1	0.0278	0.0022	54.00	2.13	0.97
Females	524.5	19.5	0.0263	0.0019	56.17	2.07	0.97
Organs							
Males	139.4	2.79	0.0387	0.0022	38.53	0.96	0.98
Females	139.2	2.74	0.0389	0.0022	38.52	0.94	0.98
Rib							
Males	718.3	63.4	0.0203	0.0023	77.57	5.57	0.96
Females	736.7	76.5	0.0197	0.0025	80.08	6.64	0.95
Saddle							
Males	594.9	23.7	0.0269	0.0020	60.69	2.18	0.97
Females	652.3	35.5	0.0244	0.0022	66.20	3.11	0.97

Gompertz equation of the form A + C*EXP(-EXP(-B*(X-M)))

Table 5.8: Gompertz parameters describing the growth of the body chemical components (protein, water, lipid, and ash) in the empty body of male and female Chinchilla rabbits

	Age at max. growth rate (t*, d)		Rate of maturity, /d		Mature weight (g/kg)		
Parameters	Mean	s.e.	Mean	s.e.	Mean	s.e.	R^2
Body protein							
Male	564.2	46.3	0.0237	0.0032	62.87	4.81	0.92
Female	536.0	34.5	0.0256	0.0029	60.88	3.61	0.94
Body water							
Male	1455.3	61.4	0.0262	0.0031	50.65	2.19	0.94
Female	1606.3	65.8	0.0268	0.0022	52.17	2.25	0.96
Body lipid							
Male	256.4	12.6	0.0224	0.0051	55.59	1.48	0.85
Female	255.4	11.9	0.0225	0.0039	56.08	1.52	0.85
Body ash							
Male	156.9	22.8	0.0218	0.0049	64.63	8.93	0.82
Female	118.5	11.4	0.0254	0.0022	55.15	5.45	0.85

Gompertz equation of the form A + C*EXP(-EXP(-B*(X-M))).

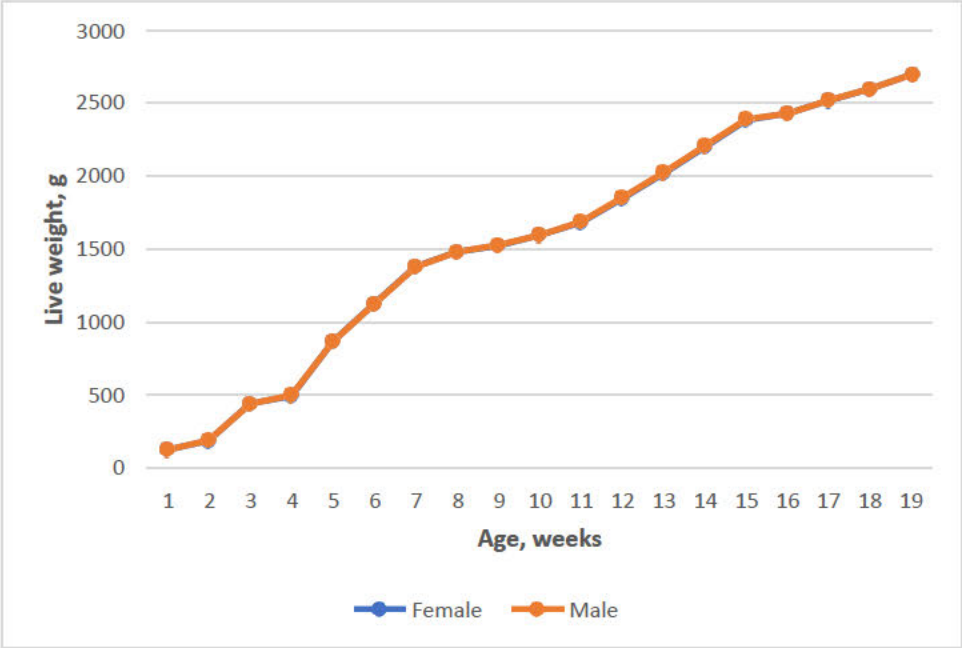

Figure 5.1: The growth curves of males and females Chinchilla rabbits

5.3.4.4. Allometric growth of the chemical body

The estimated values for the parameter of the Gompertz equation for the four chemical components are presented in Table 5.8. The male Chinchilla rabbits exhibited a higher estimated mature weight overall, while the differences were only statistically significant for water and lipid content in the females ($P<0.001$). Both males and females exhibited a substantial difference ($P<0.001$) in mature body protein and ash weight, with males having greater values. However, there was no significant difference in lipid weight between the two sexes. For both sexes over the ages measured, body water and body lipid content of the empty body showed a strong allometric relationships (0.93 and 0.95), respectively. The relationship between *ln* body water and *ln* body protein weight and between *ln* of body lipid and *ln* protein weight are illustrated in Figures 5.3 and 5.4 for the two sexes of the Chinchilla *gigantas* rabbit. It is evident in these figures (5.3 and 5.4) that the weight of *ln* body protein fell below the regression line at early stage of life but later conform to the allometric relationship developed as the weights progresses. Using the equation below, the *ln* body chemical components could bedescribed as:

$ln\ Y = a + b\ ln\ X$

ln body water, g = 2.353 (±0.0475) + 0.7633 (0.0092)**ln body protein*(0.983)

ln body lipid, g = -1.176 (±0.0682) +1.1177 (±0.013)**ln body protein*(0.984)

ln body ash, g = -1.266 (±0.0109) + 0.8719 (±0.0212)**ln body protein* (0.934)

There is a strong allometric relationship that existed between ln body water and ln body lipid (0.983 and 0.984), and allometrically lower in the ln body ash (0.934) of the Chinchilla rabbits respectively. The constant term of the ln body water is higher than that of the ln body lipid (2.353 vs -1.176) while the regression coefficient of the ln body lipid is higher than that of the ln body water (1.1177 vs 0.7633).

5.4. Discussion

The study aimed to explore developmental disparities between male and female Chinchilla rabbits and assessed the growth allometry of their chemical components. Across various age groups, weightsof different body components differed between genders, showing a gradual increase with age. However, sex did not significantly influence animal growth. These findings align with Gous *et al.* (1999) results, emphasizing systematic changes in the body's chemical and physical composition during growth, necessitating a comprehensive analysis.

Body components such as pelt-free, FL, HL, saddle, head, and organs (excluding pelt and ribs) matured at the same rate as body protein. This allowed predicting the growth rate of these components by studying their allometric relationship with body protein weight (Emmans and Fisher, 1986). The rate of maturity coefficients was 0.025/d in female rabbits and 0.026/d in male rabbits, consistent with Emmans' (1989) findings for female and male turkeys. Extrapolation of data using the Gompertz curve indicated that female rabbits reach a mature body weight of 56 g/kg, while males reach 55 g/kg. Table 5.7 illustrated larger variability in parameter estimations among females, except for pelt. Although the rate of maturity varied between sexes, data suggested a correlation between higher mature weight and slower rate of maturity.

For Chinchilla rabbit carcass chemical composition, females at 140 days had a body lipid content of 163 g/kg, slightly higher than males. This differed from Gous *et al*.'s (2019) findings for Hybrid Converter (HYB) turkeys. Protein content showed females reaching a maximum mature weight of 282 g/kg on day 140, while males had 276 g/kg, indicating males' superior protein utilization. Protein maturity rates were 0.0237 for males and 0.0256 for females. As age increased, body protein content in rabbits rose progressively, consistent with McDonald *et al*. (2002). Females had a higher mature body water weight (52 g/kg) than males (47 g/kg), while males exhibited a faster rate of maturity (0.0312 /d *vs*. 0.0268 /d). Allometric correlations between chemical components

suggested body protein as a suitable variable, displaying linearity with R^2 values of 0.984 and 0.972 for males and females, respectively. The study emphasized the similarity in carcass growth and chemical composition between male and female rabbits, showcasing equivalent levels of mature weight and component content.

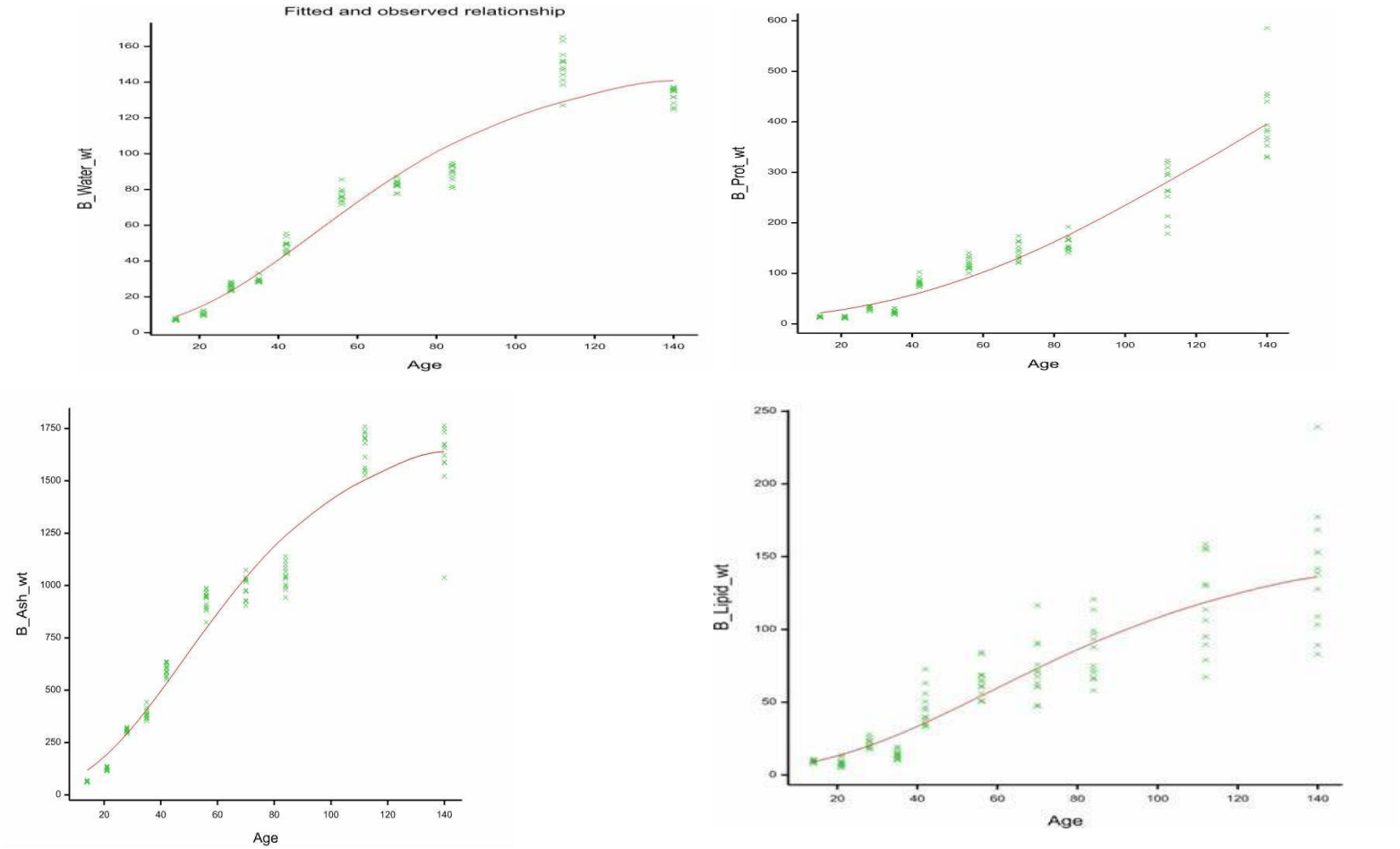

Figure 5.2: Gompertz growth curves fitted to chemical body components (water, protein, ash, and lipid) of Chinchilla rabbits plotted against age.

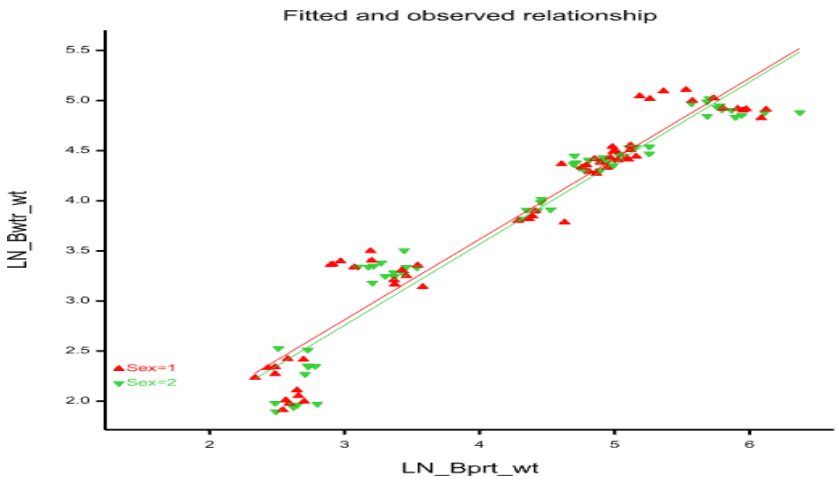

Figure 5.3: Allometric plot of body water weight (g/kg) against body protein (g/kg) for Chinchilla male and female rabbits.

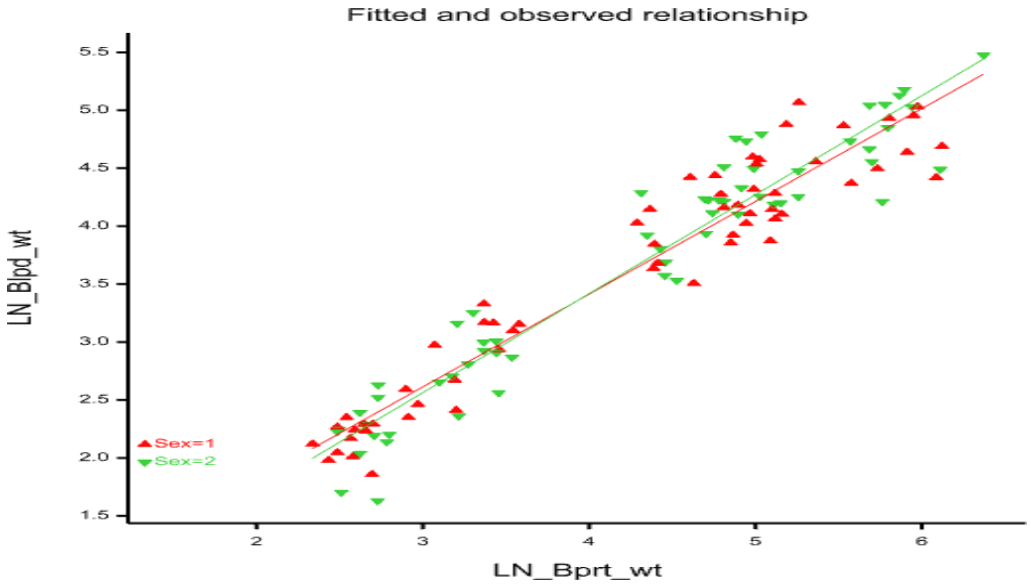

Figure 5.4: Allometric plot of body lipid weight (g/kg) against body protein (g/kg) for Chinchilla male and female rabbits.

5.5 Conclusion

The results represented here could be regarded as representing the potential growth rate of Chinchilla rabbits. The weights of the physical components of the body are correlated with the body protein content of the rabbits. In most cases, a single equation can be used to describe the growth ofthese components based on the body protein content at any given moment. The maturation of proteins and lipids was observed to occur comparatively late, while the maturation of body water was observed to occur early. This confirms that the chemical constituents of the rabbitsexhibit comparable patterns of increase to those observed in other species of rabbits or animals. The use of allometric relations with body protein to estimate the ash, water, and lipid content of rabbits is valid due to the presence of a linear relationship. To summarize, the Gompertz function is an appropriate tool for characterizing the potential growth in settings when there are no limitations. It uses a limited number of criteria and accommodatesa wide range of degrees of maturity. Further investigations will be conducted to validate the precision of the chemical components on each specific body component of the Chinchilla rabbits.

CHAPTER 6

Allometric Relationships Between Body Components and Body Protein of Chinchilla Rabbits

ABSTRACT

This research study aimed to investigate the correlation between major body components and body protein in both male and female Chinchilla rabbits. Measurements of head, forelimbs, hindlimbs, ribs, saddle, internal organs, and pelts were taken at different growth stages. Subsequently, all components, excluding the pelt, were minced together to determine the body protein weight for each sampled rabbit. Allometric relationships between body components and body protein were established, considering the weights of each component and the protein content of individual rabbits. Sex-specific allometric regressions were compared using linear regression techniques. The study revealed that a single allometric equation could accurately predict the weights of all assessed body components for both male and female rabbits. All measured physical components exhibited satisfactory allometric relationships, with the saddle showing the highest coefficient of determination ($R^2 = 0.957$), followed bythe ribs ($R^2 = 0.948$). These findings suggest that a common relationship between males andfemales could effectively predict the weight of each carcass part. The allometric regression model applied in this research facilitates precise predictions of various physical component weights based on body protein weight.

Keywords: Allometric regression, body protein, chinchilla rabbits, physical parts, sex

6.1. INTRODUCTION

Research on how a rabbit's body composition changes as it grows has been limited, and there have been fewer experiments conducted to gather data that would allow us to forecast how different genotypes will grow and how their bodies and chemical makeup will vary in different environmental conditions. There is currently a general understanding that the first step in predicting growth entails measuring the rate at which protein is deposited. From there, allometric equations can be used to calculate the growth of other body components including water, fat, and ash (Emmans, 1981a). Furthermore, it is thought that regardless of genotype or environmental factors, the amino acid composition of body proteins is constant (Hruby, 1994). However, empirical evidence suggests that the amino acid content of body proteins can be influenced by both genotype and nutrition (Fatufe *et al*., 2004). According to this theory, it is possible to undertake efforts to set useful characteristics for describing a particular rabbit population when growth conditions are favorable. This can be done by taking body weight measurements at different growth stages, estimating body composition using allometric functions based on these data, and studying the evolution of chemical components through time, using Gompertz growth functions.

Gous (1990) and Emmans (1999) proposed a comprehensive approach, suggesting that instead of focusing solely on overall body weight or body protein weight, an examination of various body parts at different growth stages is more informative. Allometric correlations are established when a simple power function relating the weight of one component can elucidate the weight of another. By estimating the allometric relationship between protein, pelts, lipid, water, and ash, it becomes possible to predict the values of other body components, provided we have knowledge of the body's protein weight. The aim of this study was to employ an allometric approach to determine the relationships between key body components and body protein in Chinchilla rabbits over a specified time frame.

6.2. MATERIALS AND METHODS

6.2.1 Study Site

As described in 3.2.1

6.2.2 Animals and Experimental Design

As described in 3.2.2

6.2.3 Animal Housing and Management

As described in 3.2.3

6.2.4 Slaughtering Procedures

As described in 3.2.4

6.2.5Carcass Composition Parameters and Chemical Analyses

As described in 3.2.5

6.2.6 Statistical Analysis

The objective of the study was to identify the allometric correlations between major body components and body protein in Chinchilla rabbits. This involved calculating the weights and natural logarithms (*ln*) of the weights for each physical and chemical component. Proportional relationships were then established between these components (Y) and the body protein weight (X) using the equation: $ln\ Y = ln\ a + b\ ln\ X$. In a logarithmic plot, the exponent b represents the slope of the linear regression. The GenStat 23rd edition (VSN International, 2023) groups technique was employed to assess differences between the constant terms (a) and slopes (b) of these regressions.

6.3. RESULTS

The mean weights of different body components of male and female Chinchilla rabbits from day 14 to day 140 are shown in Table 5.3, 5.4, and 5.5 respectively. The parameter estimates for the allometric relationships between body components and body protein are presented in Table 6.1. The table indicates that there were no significant differences in the constant terms and regression coefficients between male and female Chinchilla rabbits in relation to the body protein weights of the carcass components.

The methods used to calculate the weights of all body components were identical for both sexes and consistent across different body protein weights. Statistically significant interactions were observed for all the measured componentcomponents, as indicated in Table 6.2 to 6.7. In order to establish the allometric equation, the weight of the body component and the weight of the protein were considered for each rabbit sample. The equations were then compared using simple linear regression with groups.The head and ribs exhibit greater constant terms of 1.380 and 1.180, respectively, when compared to other measured body components. The constant term of hindlimbs (-480) and saddle are not statistically significant. The constant term for the forelimbs of males was found to be within the range of 0.552±118, with a regression coefficient of 1.016±0.0239, which were highly significant ($p<0.001$) respectively.

6.3.1 Pelt weight

The same constant terms and slopes are regressed to fit in the data of the pelt weight, and this is illustrated in Table 6.1. Table 6.2 itemize the relationship between the pelt weight and the body protein weight.

6.3.2. Head weight

The allometric coefficient relating head component weight to body protein weight for the effect of sex is given in Table 6.1, the relationship illustrated in Fig. 6.2 fell below the regression line at the early and latter age with a R^2 value of 0.93. There was a common regression and constant term to represent this equation as shown in Table 6.3. There was a linear regression showing a correlation between head weight and body protein weight.

6.3.3. Forelimbs weight

The relationship between the forelimbs and body protein weight is shown on Table 6.1 for the sex, M. The same constant terms and slopes for the sexes fitted the data below (Table 6.4). When these interactions are tested, the regression coefficient (slopes) for Chinchilla male rabbits (1.016) differed significantly ($P<0.001$) from the reference combination.

6.3.4. Hindlimbs weight

The relationship between the hindlimbs and body protein weight is illustrated in Table 6.5 for the grouped Chinchilla rabbits used in this trial. Similar constant terms and slopes were achieved for each sex (Table 6.1). When the interactions were tested, there were significant difference ($P<0.001$) from the reference combination.

6.3.5. Ribs weight

The main effect of sex had no effect on the allometric regression between the rib weight and body protein weight (Table 6.6), whereas there were small but significant differences between the sexes in the constant term used to describe this relationship. Although a common slope was appropriate for the main effect of sex, resulting in parallel lines (Fig. 6.4) describing the relationship between the rib weights and body protein weight.

6.3.6. Saddle weight

The regression for male saddle weight differed significantly ($P<0.001$) between the combination (Table 6.7), the constant term less steep (-1.1070) and the slope being higher (1.2158). Fig. 6.1 to 6.5 illustrate the allometric graph for each of the body component against body protein weight.

Table 6.1: Allometric coefficients (constant terms and regression coefficient) relating the *ln* of some physical parts of Chinchilla rabbits to the *ln* body protein.

	Constant term		Regression Coefficient		
Body components	Mean	s.e	Mean	s.e	R^2
Pelt	0.8091	0.0859	0.8442	0.0171	0.954
Head	1.3676	0.0888	0.6815	0.0177	0.926
Forelimbs	0.5501	0.0118	1.0157	0.0239	0.937
Hindlimbs	-480.9	22.7	141.98	4.51	0.892
Rib	-1.0171	0.127	1.18	0.0252	0.948
Saddle	-1.0973	0.119	1.2158	0.0238	0.957

Parameters of body component interactions and body protein compared with the reference level, sex, F.

Table 6.2: Estimates of parameters for pelt

Parameter	estimate	S.E	t (116)	t pr.
Constant	0.8101	0.0838	9.67	<0.001
ln-BP	0.8442	0.0171	49.45	<0.001
Sex, M	-0.0021	0.0357	-0.06	0.953
*ln*_BP.Sex M	-0.0280	0.0343	-0.81	0.417

Table 6.3: Estimates of parameters for head

Parameter	Estimate	S.E	t (116)	t pr.
Constant	1.3803	0.0888	15.55	<0.001
*ln*_BP	0.6815	0.0177	38.60	<0.001
Sex, M	-0.0127	0.0369	-0.34	0.732
*ln*_BP.Sex M	0.0363	0.0354	1.02	0.308

Table 6.4: Estimates of parameters for forelimbs

Parameter	estimate	S.E.	t (116)	t pr.
Constant	0.552	0.118	-4.70	<0.001
*ln*_BP	1.0157	0.0239	42.43	<0.001
Sex, M	0.0029	0.0501	0.06	0.954
*ln*_BP. Sex M	0.0122	0.0483	0.25	0.801

Table 6.5: Estimates of parameters for hindlimbs

Parameter	estimate	S.E.	t (116)	t pr.
Constant	-480.4	22.7	-21.19	<0.001
*ln*_BP	141.98	4.53	31.37	<0.001
Sex, M	-0.50	9.42	-0.05	0.958
*ln*_BP.Sex M	-0.42	9.09	-0.05	0.963

Table 6.6: Estimates of parameters for ribs

Parameter	estimate	S. E.	t (116)	t pr.
Constant	-1.042	0.127	-8.22	<0.001
*ln*_BP	1.1800	0.0252	46.81	<0.001
Sex, M	0.0249	0.0527	0.47	0.637
*ln*_BP.Sex M	-0.0271	0.0507	-0.53	0.594

Table 6.7: Estimates of parameters for saddle

Parameter	estimate	S.E.	t (116)	t pr.
Constant	-1.1070	0.0119	-9.27	<0.001
*ln*_BP	1.2158	0.0238	50.98	<0.001
Sex, M	0.0097	0.0497	0.19	0.846
*ln*_BP.Sex M	-0.0154	0.0479	- 0.32	0.748

The logarithmic allometric equations of body components against body protein are represented using the equation,

ln Y = *ln* a + b *ln* X

ln pelt weight: 0.8111(±0.0859) + 0.8442(±0.0171)**ln* body protein weight

ln head weight: 1.3742(±0.0867) + 0.6815(±0.0177)**ln* body protein weight

ln FL weight: -0.553(±0.120) + 1.0157(±0.0240)**ln* body protein weight

ln HL weight: -480.6(±22.1) + 141.98 (±4.51)**ln* body protein weight

ln rib weight: -1.030 (±0.124) + 1.1798 (±0.0253)**ln* body protein weight

ln saddle weight: -1.103 (±0.117) + 1.2158 (±0.0238)*ln body protein weigh

6.4. Discussion

The primary objective of this experiment was not to assess the performance of individual body components but rather to establish the allometric relationships between the weights of body components and body protein. Noteworthy differences were identified in the allometric equations describing the relationship between the components and body protein weight. These variations could be attributed to specific practices during the slaughtering process, considering the substantial number of animals involved (Danisman and Gous, 2011). The yield of components might fluctuate based on the sampling method used in such experiments. Despite being statistically significant, the observed differences were relatively small compared to variations seen when comparing individuals of different ages. These differences became inconsequential when considering the modeling of body component weights in response to changes in feeding or environmental conditions that impact body protein weight (Emmans and Fisher, 1986). The trial demonstrated that predicting body component weights based on body protein weight remained consistent and unaffected by feeding and environmental conditions (Fisher and Gous, 2009). Additionally, the allometric correlations were found to be unchanged under these circumstances.

As a result, the treatments in the experiment yielded successful outcomes, with significant differences observed in all evaluated variables. Notably, sex and body protein weight showed significant differences in all examined physical components. To simulate the effects of different inputs on the growth of a rabbit's physical parts, a practical approach is to predict the growth of body protein without pelt and utilize the existing allometric relationships between physical parts and body protein. This approach facilitates the prediction of part weights at various growth stages. The experiment's findings support the validity of using separate allometric equations for each sex, as demonstrated by the cases where a general allometric regression encompassed all observations throughout the entire growth phase (Danisman and Gous, 2011).

The measurement of lipid accumulation in individual body components was not conducted in this study. However, it would be valuable to have such data, as it would enable adjustments to be made for each body part based on the extent of excessive lipid deposition in the entire body. The examples with varying regression equations can often be attributed to the variable lipid deposition in different body areas, which depends on the genotype and the level of dietary protein intake (Emmans and Fisher, 1986).

A fascinating finding from the analysis of Figures 6.1 to 6.5 was that all the body components measured at the early stage were situated below the regression line that was fitted to the data. Gous *et al*. (1996) made a similar observation, noting that the breast muscles of day-old broiler chicks were underdeveloped compared to the amount of protein in their bodies. The cause of this phenomenon remains unknown, underscoring the necessity for more investigation into the regulation of this crucial tissue's development and its susceptibility to environmental and nutritional factors. The findings from the study indicate that the saddle has the highest goodness of fit (R^2) with a value of 0.957, followed by the rib with a value of 0.948, and the forelimbs with a value of 0.937, respectively. This study presents a linear allometric slope.

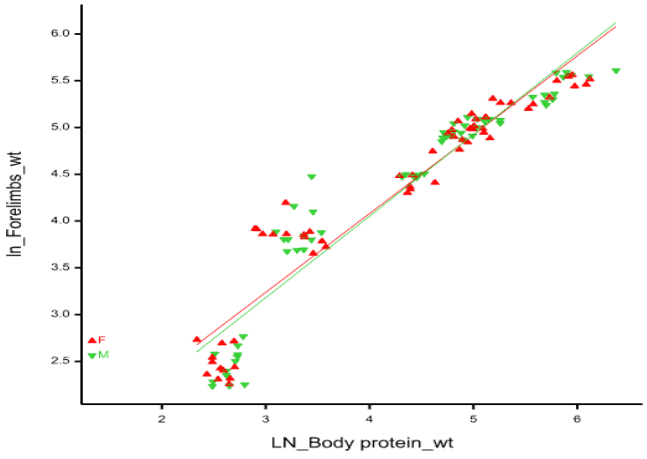

Figure 6.1: Allometric plot of ln forelimb weight against ln body protein weight

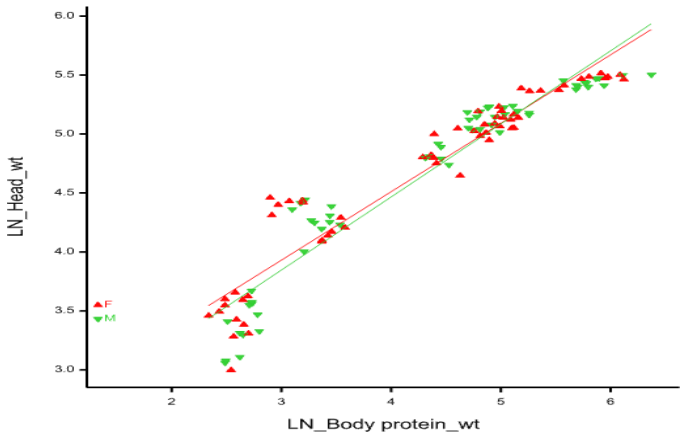

Figure 6.2: Allometric plot of ln head weight against ln body protein weight.

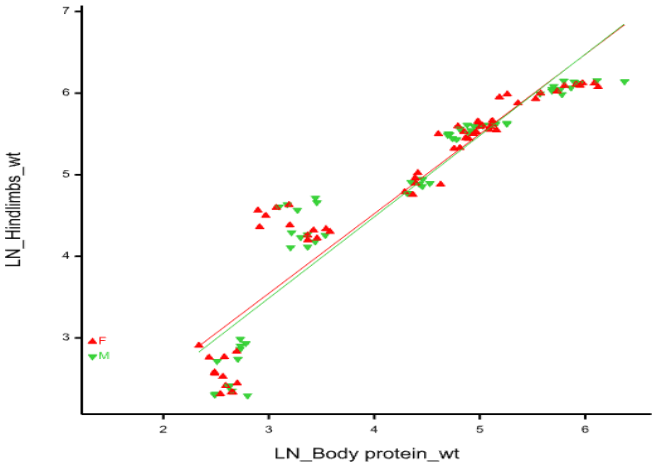

Figure 6.3: Allometric plot of ln hindlimbs weight against ln body protein weight.

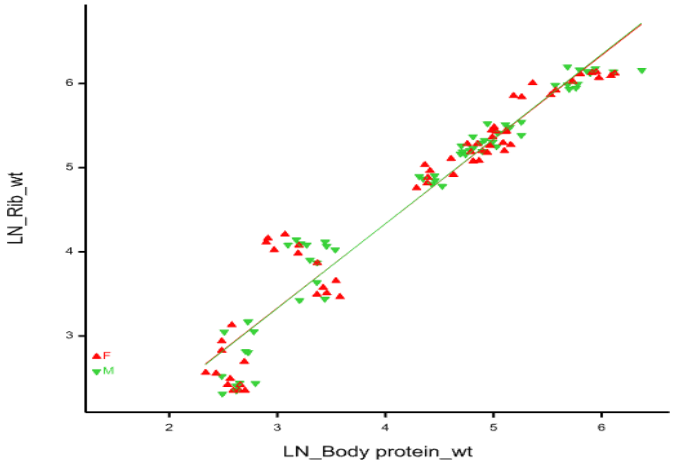

Figure 6.4: Allometric plot of ln ribs weight against ln body protein weight.

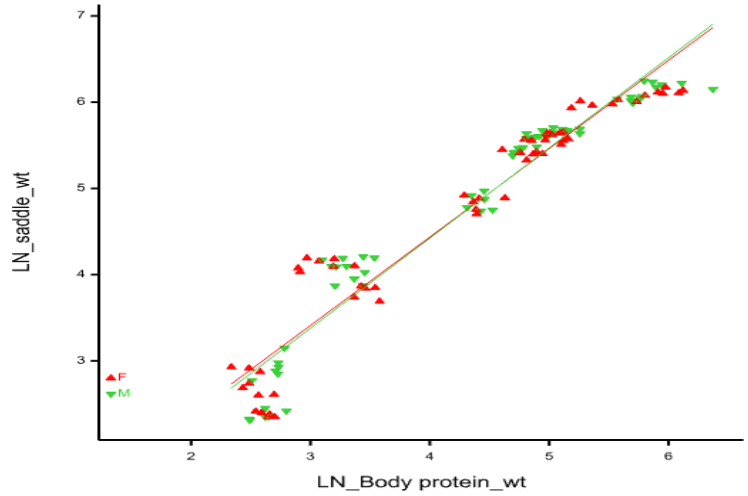

Figure 6.5: Allometric plot of ln saddle weight against ln body protein weight.

6.5 Conclusion

In summary, the data collected in this study can be employed to adjust the weights of significant physical body components in rabbits, as highlighted by the existing allometric correlations between these components and body protein weights. An analysis of the weights of these body components through allometric regression with respect to body protein weight reveals that the observed differences are not statistically significant when examined at the same level of body protein weight. To enhance the precision of predicting the weights of various body components, considering the influence of sex and body protein weight, it is essential to evaluate the upper and lower limits of the chemical components, especially lipids, present in each physical body component.

CHAPTER 7

General discussions, conclusions, and recommendations

7.1 General discussion

In the area of animal science research, a critical concern revolves around forecasting growth rates and body composition (Emmans and Fisher, 1986; Ferguson and Gous, 1993). This study aims to explore the growth rates, chemical composition, and allometric relationships of carcasses from specific body parts in both male and female NZW and Chinchilla rabbits. Establishing distinct variations in growth rates among different sexes and age groups is crucial for understanding the growth potential. Knowledge of changes in mass and chemical composition of physical components is pivotal in assessing the potential growth of rabbits. The NZW rabbit study revealed practically identical growth and carcass characteristics between male and female rabbits, attributed to their equivalent mature body weights, protein, water, and fat contents, along with similar rates of maturation. Also, the Chinchilla rabbit trial showed variations in the weights of several body components between male and female rabbits of different ages. Although the weights of all evaluated body components increased gradually with age, the growth was not significantly influenced by the sex of the animals. The results of the two rabbit breeds aligns with previous findings suggesting systematic changes in the chemical and physical components of the body during growth (Gous *et al*., 1999). Therefore, any comprehensive analysis of potential growth must consider these changes.

Numerous factors, including weaning ages, environmental conditions, and slaughtering ages, can influence animal growth (Fernandez and Fraza, 1996). The live weight of both male and female rabbits in both strains increased proportionally with age, indicating a direct correlation between age and body size which was similar to what was reported by Danisman and Gous (2008). The continuous growth of pelts through successive stages led to an overall increase in pelt weight over the growth period. The allometric correlation between body weight and pelt weight is established due to the straightforward and continuous growth process of pelts from birth to maturity. Unlike feather weight, pelt weight consistently increases during growth. Allometric relationships between physical andchemical

components and body protein were not affected by strain or sex, emphasizing the importance of body lipid and body protein weights in animal growth models (Gous et al, 2018). The analysis of carcass growth in both strains demonstrated similarities in mature weights and chemical composition, including protein, lipid, water, and ash content (Sakomura *et al*., 2011). The rates of maturity for various components in both strains were influenced by factors such as sex and strain, highlighting the complex dynamics of growth in rabbits. The allometric correlations presented in this study, utilizing body protein as a variable, provide insights into the relationships between different chemical components.

The findings of this experiment offer valuable data for adjusting the weights ofsignificant physical body components in rabbits based on allometric correlations with body protein weights. Despite observed differences in component weights, these distinctions become statistically insignificant when examined at the same level of body protein weight. To enhance predictive accuracy for various body components, considering sex and body protein weight, it is essential to evaluate the upper and lower limits of chemical components, particularly lipids, present in each physical body component.

7.2. Conclusions and recommendations

The insights provided into the potential growth of rabbits in this study will enhance the precision of rabbit growth models, allowing for more accurate predictions of body and pelt growth, as well as the chemical and physical composition of these rabbits throughout their development. The proportional growth of body parts in both rabbit strains appears to be unaffected significantly by the sex of the rabbits, particularly in relation to body protein weight.

In both breed of rabbits, the males exhibit a slightly higher mean weights compared to females, with these differences amplifying as the rabbits mature.

The pelt-free body weight, a crucial indicator of body and carcass composition, proves to be a reliable measure for estimating the chemical composition of different rabbit strains.

The findings suggest that sex has minimal or negligible influence on the growth of specific body components when considering body protein weight.

The observed allometric relationships between body components and deposition rates show a strong correlation between protein and body weight throughout various life stages of rabbits.

The late maturation of protein and lipids, coupled with the early maturation of body water, aligns with patterns observed in other rabbit species and animals, confirming similarities in the chemical components' growth trajectories.

For future research considerations:

- Encouraging the use of Gompertz growth curves in rabbit and animal modeling is recommended.
- Further investigations into the partitioning of lipid and protein in different body parts across various strains, sexes, and feed protein contents would contribute to refining models to account for these allometric differences.
- Additional studies should be conducted to validate the accuracy of chemical components in predicting the characteristics of individual body components in rabbits.

REFERENCES

AFRC (1991). Nutritive requirements of ruminant animals and energy. Technical committee on responses to nutrients, Report No. 5. *Nutr. Abstr Rev. Series B, 60: 729 – 804*.

AKANNO, E. C. & IBE, S. N. (2006). Prediction of body weight of the domestic rabbit at different stages of growth using linear body measurements. *Nigerian Journal of Animal Production, 33(1): 3 – 8.*

AOAC INTERNATIONAL (2003). Official Methods of Analysis. (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Washington, USA.

ARANGO, J. & VAN VLECK, L. D. (2002). Size of beef cows: early ideas, new developments. *Gen Mol Res 1: 51 – 63*.

ARC (Agricultural Research Council) (1965). 'The nutrient requirements of farm livestock No 2 Ruminants'. (Agricultural Research Council London: London).

ATTIAH, Y. A., BURKE, W. H., YAMANI, K. A. & JENSEN, L. S. (1995). Daily energy allotments and performance of broiler breeders. 2. Females. *Poultry Science, 74: 261 – 270.*

AVIAGEN. (2010). Broiler Performance Objectives. Accessed Sep. 2010. Http://www.aviagenturkeys.us/uploads/2010/11/19/*ati_commercial_feeding_recommendation*.

BASTIANELLI, D. and SAUVANT, D. (1997). Modelling the mechanisms of pig growth. *Livestock Production Science, 51: 97 – 107.*

BATHAEI, S. & LEROY, P. (1996). Growth and Mature weight of Mehraban Iranian fat- tail sheep. *Small Rumin. Res. 22: 155- 162.*

BELLAIRS, R. & OSMOND, M. (2005). The atlas of chick development. Academic Press, London.

BERHE, E. T. and GOUS R. M. (2008). Effect of dietary protein content on allometric relationships

between carcass portions and body protein in Cobb and Ross broilers. World's Poultry Science Association, South African Branch. Proceedings of the 24th Scientific Day. University of Pretoria 28 – 49.

BERRI, C., WACRENIER, N., MILLET, N. & LE BIHAN-DUVAL, E. (2001). Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines. *Poultry Science 80: 833 –838.*

BLAXTER, K. L. (1962). "Energy metabolism of ruminants". (Hutchinson: London).

BRODY, S. (1945). Bioenergetics and Growth with Special Reference to the Efficiency Complex in Domestic Animals. Hafner Publishing Company, New York, NY, USA.

CAVANI, C., BIANCHI, M., LAZZARONI, C., LUZI, F., MINELLI, G., PETRACCI, M. (2000). Influence of type of rearing, slaughter age and sex on fattening rabbit: II. Meat quality. In: Proceeding of the 7 Ed., Vol. A: 567 – 572.

COBB. (2010). Cobb 500 Broiler Performance and nutrition Supplement. Accessed Sep. 2010. Http://www. cobb-vantress.com.

COSTA, A. S. H., PAULO, C., RUI, J. B. B., JOSE, P. C. L., JORGE, S. S., CARLOS, M. G. A., JOSE, A. M. P. (2013). Carcass fat partitioning and meat quality of Alentejana and Barossa young bulls fed high or low maize silage diets. *Meat Science 93: 405 – 512*.

DAL BOSCO, A., CASTELLINI, C., & MUGNAI, C. (2002). Rearing rabbits on wire net floor or straw litter: behaviour, growth, and meat qualitative traits. *Livest. Prod. Sci. 75: 149 – 156.*

DALLE ZOTTE, A. (2002). Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. *Livestock Production Science, 75(1), 11–32.*

DANISMAN, R. & GOUS, R. M. (2008). Predicting the physical parts of broilers. Proceedings of XXVII world's poultry congress, Brisbane, Australia.

DANISMAN, R. & GOUS, R. M. (2011). Effects of dietary protein on the allometric relationships between some carcass portions and body protein in three broiler strains. *South Afr. J. Anim. Sci. 2011: 41(3): 194 – 208.*

DANISMAN, R. & GOUS, R. M. (2013). Effect of dietary protein on performance of four broiler strains and on the allometric relationships between carcass portions and body protein. *South African Journal of Animal Science 43: 25 – 37.*

DAY, T. & TAYLOR, P. D. (1997). Von Bertalanffy's growth equation should not be used to model age and size at maturity. *American Naturalist 149: 381 – 393.*

DEAN, W. M. (2016). Small animal care and management 4th edition.

DE LANGE, C. F. M. (2003). A system approach to optimizing phosphorus and nitrogen utilizationin the growing pig. Proceedings of 25th Western Nutrition Conference, Saskatoon, Pp. 226 –246.

DOZIER, W. A. (2003). Nutritional Considerations for broiler breeders. *Poultry Digest Online Volume, 4, Number 2.*

DUMAS, A., LANGE, C. F., FRANCE, J., & BUREAU, D. P. (2007). Quantitative description of body composition and rates of nutrient deposition in rainbow trout (Oncorhynchus mykiss). *Aquaculture 273: 165 – 181*.

DUMAS, A., FRANCE, J. & BUREAU, D. (2010). Modelling growth and body composition in fish nutrition: where have we been and where are we going? *Aquaculture Research 41: 161 –181.*

EITS, R. M., KWAKKEL, R. P. & VERSTEGEN, M. W. A. (2002). Nutrition affects fat-free body composition in broiler chickens. *Journal of nutrition 132: 2222 – 2228.*

EMMANS, G. C. (1981a). A model of the growth and feed intake of ad libitum fed animals, particularly poultry. Pages 103 – 110 in: Computers in animal production. Animal Production,

Occasional Publication No 5. G. M. Hillyer., C. T. Whittemore. And R. G. Gunn, ed. British Society of Animal Production, Penicuk, Midlothian, U. K.

EMMANS, G. C.(1981b). A model of the growth and feed intake of ad libitum fed animals, particularly protein. in: Computers in animal production. Animal Production, Occasional Publication No 5. G. M. Hillyer., C. T. Whittemore. And R. G. Gunn, ed. British Society of Animal Production, Penicuk, Midlothian, U. K.

EMMANS, G. C. (1986). Selection by hens of a diet from a pair of feeds. Anim. Prod.

EMMANS, G. C. (1987). Growth, body composition and feed intake. *World's Poultry Science Journal 43:208 – 227.*

EMMAN, G. C. (1989). The growth of turkeys. In: Recent Advances in Turkey Science. (Eds) NIXEY, C. & GREY, T. C., Butterworths, London. Pp 135 – 166.

EMMANS, G. C. (1991). Animal growth and feed intake. A collection of papers. Scottish Agricultural College, Edinburg.

EMMANS, G. C. (1995). Problems in modelling the growth of poultry. *World's Poult. Sci. J. 51: 77 – 89.*

EMMANS, G. C. (2022). The potential post-hatching growth of domestic birds is sufficiently described by the Gompertz function. *British Poultry Science 63: 701 – 719.*

EMMANS, G. C. & KYRIAZAKIS, I. (1995). A general method for predicting the weight of water in the empty bodies of pigs. *Animal Science 61: 103 – 108.*

EMMANS, G. C. & OLDMAN, J. D. (1988). Modelling of growth and nutrition in different species. Pages 13 – 21 in: Modelling of Livestock Production Systems. Karver, S., and Arendonk, J. A. M. ed. Kluwer Academic Publishers, Dordrecht, The Netherlands.

EMMANS, G. C. (1997). A method to predict the food intake of domestic animals from birth to maturity as a function of time. *J. Theoretical Biol. 186: 189 – 200.*

EMMANS, G. C. (1999). Nutrition and behaviour group symposium on 'future perspectives in nutrition and behaviour research'. Proceedings of the nutrition society(1999), 60, 115 – 125.

EMMANS, G. C. (2002). The potential post-hatching growth of domestic birds is sufficiently described by the Gompertz function. *British Poultry Science, vol. 63(5): 701 – 719.*

EMMANS, G. C. AND FISHER, C. (1986). Problems of Nutritional Theory. In: Nutritional Requirements and Nutritional Theory. Eds. Fisher, C. and Boorman, K. N., Butterworths, London p 9 – 39.

EMMANS, G. C. AND KYRIAZAKIS, I. (1999). Growth and body composition. In A quantitative biology of the pig (ed. 1. Kyriazakis), pp. 181 – 197. CAB International, Wallingford.

EMMANS, G. C. AND KYRIAZAKIS, I. (2000). Consequences of genetic change in farm animals on food intake and feeding behaviour. Proceeding of Nutrition Society, 60: 115 – 125.

FATUFE, A. A., TIMMLER, R., RODEHUTSCORD, M. (2004). Response to lysine intake in composition of body weight gain and efficiency of lysine utilization of growing male chickens from two genotypes. *Poultry Science, 83: 1314 – 1324.*

FERGUSON, N. S. (2006). Basic concepts describing animal growth and feed intake. In: Mechanistic modelling in pig and poultry production. Ed. Gous, R. M., Moris, T. R., and Fisher, C., CAB International, Oxfordshire, pp. 22 – 54.

FERGUSON, N. S., & GOUS, R. M. (1993). Evaluation of pig genotypes. I. Theoretical aspects of measuring genetic parameters. *Anim. Prod. 56: 233 – 243.*

FERGUSON, N. S., GOUS, R. M., & EMMANS, G. C. (1994). Preferred components for the construction of a new simulation model of growth, feed intake and nutrient requirements of growing pigs. *South African Journal of Animal Science, Vol. 24 (1), pp 10 – 17.*

FERGUSON, N. S. & GOUS, R. M. (1997). The influence of heat production on voluntary food intake in growing pigs given protein – deficient diets. *Animal Sci. 64: 365 – 378.*

FERNANDEZ, C. & FRAGA, M. (1996). The effect of dietary fat inclusion on growth, carcass characteristics, and chemical composition of rabbits. *Journal of Animal Science, pp 136 – 145*.

FERNANDA, D. M., RICARDO, P. R., CARLOS, L. O., & EMIKO, K. R. (2015). Growth curve by Gompertz linear regression model in females and males in Tambaqui (Colossomamacropomum). *Anais da Academia Brasileira de Ciencius 24(3): 54 – 58.*

FISHER, C. (1983). Nutrition and growth: experimental methods. Proceedings IV European Poultry Nutrition Symposium, pp. 1 – 16.

FISHER, C. (2013). An overview of models. Proc. Symp. Nutr. Mod. Pig Poult., Jaboticabal, Brazil.

FISHER, (2014). "An overview of poultry models". In Nutritional Modelling for pigs and poultry, edited by N. K. Sakomura, R. M. Gous, I. Kyriazakis, and I. Hauschild, 1- 21. Wallingford, Oxon: CABI.

FISHER, C & GOUS, R. M. (2009). "Protein and amino acid responses". In Biology of Breeding Poultry, British Poultry Science Symposium no 29, edited by P. Hocking, 331-360. London, CABI

FOWLER, V. R., FULLER, M. R., CLOSE, W. H. & WHITTEMORE, C. T. (1980). Energy requirements for the growing pig. In: Energy Metabolism. Butterworths, London. P 151 – 156.

GENSTAT (2023). GenStat Statistical software, Release 6.1. Lawes Agricultural Trust, Rothamsted, UK.

GILLE, U. (2004). Analysis of growth. Http://www.Uni-leipzig.de/ vetana/ growth. html. Last updated 30: 03: 2004, accessed 30: 07: 2008.

GOLIOMYTIS, M., PANOPOULOU, E., & ROGDAKIS, E. (2003). Growth curves for body weight and major component parts, feed consumption, and mortality of male broiler chickens raised to maturity. *Poult. Sci. 82: 1061 – 1068.*

GOMPERTZ (1825). On the nature of the function expressive of the law of human mortality, and on a new method of determining the value of life contingencies. Phil Trans Roy Soc., 115: 513 – 585.

GOUS, R. M. (1990). Nutritional effects on the growth and fatness of broilers. *Br. Poult. Sci. 31: 495 – 505.*

GOUS, R. M. (1998). Making progress in the nutrition of broilers. *Poultry Science 77: 111 – 117.*

GOUS, R. M. (2001). Modelling energy and amino acid requirements in order to optimize the feeding of commercial broilers. 2nd International Symposium on Avian Nutrition. Concordia,Brazil.

GOUS, R. M. (2002). Optimizing broiler performance with the use of simulation models. In: 4th International Poultry Symposium. NuTech Explicit Nutrition, Southern Africa (Pty) Ltd.

GOUS, R. M., EMMANS, G. C. & FISHER, C. (1991). The response of broilers to feeds differingin protein content following a period of fattening. *Poultry Science 71: 151.*

GOUS, R. M., EMMANS, G. C., BRADBENT, L. A & FISHER, C. (1990). Nutritional effects on the growth and fatness of broilers. *British Poultry Science 31: 495 – 505.*

GOUS, R. M., PYM, R. A. E., MANNION, P. F., & WU, J. X. (1996). An evaluation of the parameters of the Gompertz growth equation that describe the growth of eight strains of broiler. Proceedings of the Australian Poultry Science Symposium, 1996. University of Sydney, pp. 174 – 177.

GOUS, R. M., MORAN, E. T., STILBORN, H. R. & BRADFORD, G. D. (1999). Evaluation of the parameters needed to describe the overall growth, the chemical growth, and the growth

of feathers and breast muscles of broilers. *Poult. Sci. 78: 812 – 821.*

GOUS, R. M., FISHER, C., TUMOVA, E., MACHANDER, V., CHODOVA, D., VLCKOVA, J., UHLIROVA, L & KETTA, M (2018). "The growth of Turkeys. 2. Body Components and Allometric Relationships". *British Poultry Science, 60:5, 548-553.*

GOVAERTS, T., ROOM, G., BUYSE, J., LIPPENS, M., De GROOTE, G., DECUYPERE, E. (2000). Early and temporary quantitative food restriction of broiler chickens. 2. Effects on allometric growth and growth hormone secretion. *Br Poult Sci. 41(3): 355 – 362.*

HAKANSSON, J., ERIKSSON, S. & SVENSSON, S. A. (1978). Influence of feed energy level on chemical composition of tissues and on the energy and protein utilization by broiler chicks. Swedish University of Agricultural Science, Department of Animal Husbandary, Report 59, Uppsala.

HANCOCK, C. E., BRADFORD, G. D., EMMANS, G. C. & GOUS, R. M. (1995). The evaluation of the growth parameters of six strains of commercial broiler chickens. *Br. Poult. Sci. 36: 247 – 264.*

HRUBY, M. (1994). Growth modelling as a tool for predicting amino acid requirements of broilers. *Journal of Applied Poultry Research, 3: 403 – 415.*

HRUBY, M., HAMRA, M. L. & COON, C. (1996). Non- linear and linear functions in body protein growth. *Journal of Applied Poultry Research 5: 109- 115.*

HUXLEY, J. S. (1932). Problems of relative growth. Methuen and Co., Ltd., London.

IBÁÑEZ-ESCRICHE, N. & BLASCO, A. (2011). Modifying growth curve parameters by multitrait genomic selection. *Journal of Animal Science, Vol 89 (3), Pp. 661–668.*

IGE, A. O., ODUNSI, A. A., AKINLADE, J. A. & OYEDAPO, L. O. (2006). Gliricidia leaf meal

in layer's diet: effect on performance, nutrient digestibility, and economy production. *J. Anim. Vet. Adv., 5 (6): 483 – 486.*

IJI, P. A., VAN DER WALT, J. G., BRAND, T. S., BOOMKER, E.A. & BOOYSE, D. (2003). Development of the digestive tract in the Ostrich (Struthio camelus). Arch. *Anim. Nutr. 57, 217 – 228.*

IKEOBI, C. O. N. & FALETI, O. A. (1996). Factors affecting live weight of goats and sheep on two locations within Ogun State, Nigeria. *Nigerian Journal of Animal Production, 23(1): 12 – 15.*

KEMM, E. H., SIEBRITS, F. K., RAS, M. N & BADENHORST, H. A. (1991). Feed intake, live mass gain, body composition and protein deposition in pigs fed three protein levels. *South African Journal of Animal Science 21: 127.*

KEMP, C., FISHER, C., & KENNY, M. (2005). Genotype- nutrition interactions in broilers; response to balanced protein in two commercial strains. Proceedings of the 15th European symposium on poultry nutrition, Balatonfured, Hungary, pp. 54 – 56.

KNAP, P.W. (2000). Variation in maintenance requirements of growing pigs in relation to body composition. A stimulation studies. PhD Thesis, University of Wageningen, Holland.

KNÍZETOVÁ, H., HYÁNEK, J., KNIZE, B., and ROUBÍCEK, J (1991). Analysis of growth curves of fowl. I. Chickens. *Br. Poult. Sci. 32:1039–1053.*

KYRIAZAKIS, I. & EMMANS, G. C. (1991). Diets selection in pigs: Dietary choices made by growing pigs following a period of underfeeding with protein. *Animal Production 52: 337 – 346.*

KYRIAZAKIS, I. & EMMANS, G. C. (1992). The growth of mammals following a period of nutritional limitation. *Journal of Theoretical Biology 156: 485 – 498.*

KYRIAZAKIS, I. & EMMANS, G. C. (1992a). The effects of varying protein and energy intakeson the growth and body composition of pigs. 1. The effects of energy intake at constant, high protein intake. *British Journal of Nutrition 68: 603.*

KYRIAZAKIS, I. & EMMANS, G. C. (1992b). The effects of varying protein and energy intakeson the growth and body composition of pigs. 1. The effects of varying both energy and protein intake. *British Journal of Nutrition 68: 603.*

KYRIAZAKIS, I. & EMMANS, G. C. (1994). The voluntary feed intake of pigs given feeds basedon wheat bran, dried citrus pulp, and grass meal in relation to measurements of feed bulk. *British Journal of Nutrition 73: 191 – 207.*

LAWRENCE, T. L. J. & FOWLER, V. R. (1997). Growth of farm animals. CAB International, Wallingford.

Le BIHAN- DUVAL, E., MILLET, N. & REMINGNON, H. (1999). Broiler meat quality, effectof selection for increased carcass quality and estimates of genetic parameters. *Poultry Science78: 822 – 826.*

LESTER, N. P., SHUTER, B. J. & ABRAMS, P. A. (2004). Interpreting the Von Bertalanffy model of somatic growth in fishes: the cost of reproduction. Proceedings of the Royal Societyof London Series B 271: 1625 – 1631.

LEWIS, R. M., EMMANS, G. C. & SIMM, G. (2002). A description of the growth of sheep andits genetic analysis. Faculty Papers and Publications in Animal Science, 827.

LOEWER, O. J., TURNER, L. W., GAY, N., MUNTIFERING, R. & BROWN, C. J. (1980). Using the concept of physiological age to predict the efficiency of growth in beef animals. *Agricultural systems 24 (4): 269 – 289.*

MACDONALD, P., EDWARDS, R. A., GREENHALGH, J. F. D. & MORGAN, C. A. (2002). Animal nutrition, 6th ed. Pearson, Prentice Hall.

MAHAN, D. C & SHIELDS, R. G. (1998). Essential and non-essential amino-acid composition of pigs from birth to 145 kg of body weight, and comparison to other studies. *Journal of Animal science, 76: 513 – 521.*

MALHADO, C., CARNEIRO, P., AFFONSO, P., SOUZA, A. & SARMENTO, J. (2009). Growth curves in Dorper Sheep crossed with the local Brazilian breeds, Morada nova, Rabo Largo and Santa Ines. Small Rumin. Res. 84: 16- 21.

MARCATO, S., SAKOMURA, N. K., MUNARO, B., FERNANDES, J. B., KAWAUCHI, I. & BONATO, M. (2008). Growth and body nutrient deposition of two broiler's commercial genetic lines. *Braz. J. Poult. Sci. 10: 117 – 123.*

MARTIN, P. A., BRADFORD, G. D. & GOUS, R. M. (1994). A formal method of determining the dietary amino acid requirements of laying – type pullets during their growing period. *British Poultry Science 35: 709 – 724.*

MOUGHAN, P. J., SMITH, W. C & PEARSON, G. (1987). Description and validation of a model simulating growth in the pig (20 – 90 kg liveweight). *New Zealand Journal of Agricultural Research, 30: 481.*

MOUGHAN, P. J. & VERSTEGEN, M. W. A. (1988). The modelling of growth in the pig. *Netherlands Journal of Agricultural Science 36: 145 – 166.*

MURAWSKA, D., KOZLOWSKI, K., TOMASZEWSKA, K., BRZOZOWSKI, W., ZAWACKA, M., MICHALIK, D. (2015). Age-related changes in the tissue composition of carcass parts and in the distribution of lean meat, fat with skin and bones in turkey carcasses. *European Poult. Sci.79 (9): 1 – 4.*

NELSON, D. L. & COX, M. M. (2000). Lehninger Principles of Biochemistry. 3rd edn. Worth Publishers, New York, NY, USA.

NRC (1994). Committee on Animal Nutrition. Subcommittee on poultry nutrition. Nutrient requirements of poultry, 9. Ed. (National Academy of Sciences, Washington, DC).

NRC (1996). Nutrient Requirements of Beef Cattle, Seventh Revised Edition. Committee on Animal Nutrition, National Research Council. The National Academic Press, Washington, DC, USA.

NRC (1998). Nutrient requirements of Swine, Tenth Revised Edition. Committee on Animal Nutrition, National Research Council. The National Academic Press, Washington, DC, USA.

OKORO, V. M. O., EZEOKEKE, C. T., OGUNDU, U. E. &CHUKWUDUM, C. (2010). Phenotypic correlation of body weight and linear body measurement in Chinchilla rabbits (Oryctolagus cuniculus). *Journal of Agricultural Biotechnology and Sustainability Development, 2(2): 27 – 29.*

OLDMAN, J. D. & EMMANS, G. C. (1990). Animal performance as the criterion food feed evaluation. In: Feedstuffs evaluation. Ed: Wiseman, J and Cole, D. J. A. Butterworths, London, pp 77 – 90.

ONASANYA, G. O., THIRUVENKADAN, A. K., SREEKUMAR, C., TIRUMURUGAAN, G.K., MSALYA, G. M., SANNI, M. T., DECAMPOS, J. S., AMUSAN, A. S., OLOWOFESO, O., FAFIOLU, A. O., OKPEKU, M., YAKUBU, A. & IKEOBI, C. O. (2017). Single Nucleotide polymorphism-based characterization of HSP 90AIA gene in some Nigerian cattle breeds. *Dutse Journal of Agriculture and food security (DUJAFS), vol. 6 (2): 126 – 140.*

OWENS, F. N., DUBESKI, P. & HANSON, C. (1993). Factors that alter the growth and development of ruminants. *Journal of Anim. Sci. 71: 3138 – 3150.*

PARK. J. (1982). A theory of growth in Animals. Springer – Verlag, Berlin, Germany.

POMAR, C., HARRIS, D. L. & MINVIELLE, F. (1991). Computer simulation model of swine production systems: I. Modelling the growth of young pigs. *Journal of Animal Science 62: 109.*

REDDEN, R. R., SURBER, L. M.N., GROVE, A. V. & KOTT, R. W. (2013). Growth efficiency of ewe lambs classified into residual feed intake groups and pen fed a restricted amount of feed.

Small Rumin. Res. 114: 214- 219.

RIVEIRA-TORRES, NOBLET, J. & VAN MIGLEN, J. (2011). "Changes in chemical composition in male turkeys during growth". *Poultry Science 90: 68 – 74.*

ROBERTSON, T. B. (1923). The chemical basis of growth and senescence. Monographs of Experimental Biology, J. B. Lippincott Co., Philadelphia.

WALTER, W. L., WILDE, C. J., & JACKSON, J. R. (1996). Animal models for study of milk secretion. *Journals of Mammalian Glands Biol. Neoplasia 1: 123 – 134.*

SAKOMURA, N. K., LONGO, F., ROUDON, E. O., RABELLO, C. B. V., & FERRAUDO, A. S. (2005). Modelling Energy utilization and growth parameter description for broiler chickens. *Poult. Sci. 84: 1363 – 1369.*

SAKOMURA, N. K., GOUS, R. M., MARCATO, S. M. & FERNANDES, J. B. K. (2011). A description of the growth of the major body components of 2 broiler chicken strains. *Poultry Science 90: 2888-2896.*

SCHMIDT-NIELSEN, K. (1984). Scaling: Why is animal size so important?

SCHMIDT-NIELSEN, K. (1991).Scaling: Why is animal size so important? New York: Cambridge University Press.

SCHULZE, S. J., CLOETE, S. W. P. & OLIVER, J. J. (2013). Returns on investment in sheep and goat breeding in South Africa. *Livest. Sci. 130: 70 – 82.*

SPRATT, R. S. & LEESON, S. (1987). Broiler breeder performance and energy. *Poultry Science, 68: 683 – 693.*

SPRATT, R. S., BAYLEY, H. S., McBRIDE, B. W. & LEESON, S. (1990). Energy metabolism of broiler breeder hens. 1. The partition of dietary energy intake. *Poultry Science, 65: 1339 – 1347.*

TAYLOR, ST. C. S. & YOUNG, G. B. (1986). Equilibrium weight in relation to food intake and genotype in twin cattle. *Animal Production 10: 392 – 412.*

TAYLOR, ST. C. S. (1965). Genetic studies on twin cattle. In: 9th International Congress of Animal Production, Edinburg, Pp 3 – 8.

TAYLOR, ST. C. S. (1980). Animal Production, 30: 167 – 175.

TROCINO, A., XICCATO, G., SARTORI, A. & QUEAQUE, P.I. (2002). Feeding plans at different protein levels: effects on growth performance, meat quality and nitrogen excretion in rabbits. In Proc.7th World Rabbit Congress, A. Blasco (Ed.), Valencia Univ. Publ., Spain, 100: 467 – 474.

TUMOVA, E & CHODOVA, D. (2018). Performance and changes in body composition of broiler chickens depending on feeding regime and sex. *Czech J Anim Sci.63(12): 518-525.*

TYLUTKI, T. P., FOX, D. G. & ANRIQUE, R. G. (1994). Predicting net energy and protein requirements for growth of implanted and nonimplanted heifers and steers and implanted bulls varying in body size. *Journal of Animal Science 72(7): 1806 – 1813.*

VON BERTALANFFY, L. (1957). Quantitative laws for Metabolism and growth. *Quarterly Reviews of Biology 32: 217 – 232.*

VSN INTERNATIONAL (2023). GENSTAT. Release 18.1. Rothamsted Experimental Station.

WELLOCK, I. J., EMMANS, G. C. & KYRIAZAKIS, (2003). Describing and predicting potential growth in the pig. *J. Animal. Sci. 78: 379- 388.*

WHITTEMORE, C. T. & FAWCETT, R. H. (1976). Theoretical aspects of a flexible model to stimulate protein and lipid growths in pigs. *Animal Production 22: 87 – 96.*

WHITTEMORE, C. T. (1986). Causes of variation in the body composition of growing pigs.

Proceedings of nutrition society.

WHITTEMORE, C. T. (1993). Development of recommended energy and protein allowances for growing pigs. *Agricultural systems 11: 159 – 186.*

YALCIN, S., ONBASILAR, E.E. & ONBASILAR, I. (2001). Effect of sex on carcass and meat characteristics of New Zealand White rabbits aged 11vweeks. *Asian-Australasian Journal of Animal Sciences 19(8), 1212 – 1216.*

ZOONS, J., BUYSE, J. & DECUYPERE. E. (1991). Mathematical models in broilers raising. *Worlds' Poultry Science 47: 243 – 255.*