Evaluating the price discount between imported and locally produced soybean meal – A case of *in vivo* trials on broiler growth performance

By

U Barnard

A dissertation submitted in partial fulfilment of the requirements for the degree

MCom Agricultural Economics

In the

Department of Agricultural Economics, Extension and Rural Development

Faculty of Economics and Management Science

University of Pretoria

South Africa

August 2018

DECLARATION

I, U Barnard, declare that the dissertation, which I hereby submit for the degree MCom Agricultural Economics at the University of Pretoria, is my own work and has not been submitted for a degree at this or any other tertiary institution.

______________________________ August 2018

Signature Date

ACKNOWLEDGEMENTS

The assistance and cooperation of various institutions and individuals made this study possible. Therefore, I wish to thank everybody who contributed towards the study in some way or the other. Some I would like to mention by name:

I would first like the opportunity to thank my supervisor Mr Deon Scheepers of the Department of Agricultural Economics, Extension and Rural Development within the Faculty of Natural and Agricultural Sciences at the University of Pretoria. Mr Scheepers continuously provided me with support, steering me in the right direction whilst still allowing this thesis to be my own work. Thank you furthermore for encouraging and providing the environment for industry collaboration.

Besides my supervisor I would also like to thank my co-supervisors, Dr Christine Janse van Rensburg and Dr Marlene Louw, for their intuitive comments and insightful questions.

I would also like to thank the experts whom I consulted frequently during the research project and trial. Without their passionate input this research study would not have been successfully conducted.

I would like to express my gratitude for the financial assistance received for this study. *Please note: The opinions expressed and conclusions drawn in this study are those of the author and are not necessarily to be recognised to the sponsor*.

Lastly, I must express my very deep gratitude to my spouse, parents, family and friends, for supporting me without failure and providing me with continuous encouragement throughout my years of study as well as through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Evaluating the price discount between imported and locally produced soybean meal – A case of *in vivo* trials on broiler growth performance

By

U Barnard

Degree: MCom Agricultural Economics

Department: Agricultural Economics, Extension and Rural Development

Supervisor: Mr Deon Scheepers

Co-supervisors: Dr Christine Janse van Rensburg and Dr Marlene Louw

ABSTRACT

Soybean meal remains the most essential and favoured protein source in the production of animal feed. When analysing the South African soybean industry there seems to be a general perception that South African produced soybean meal is inferior, with reference to protein quality, to that of imported South American soybean meal. The perception dictates that animals which are fed on feed containing local soybean meal show suboptimal growth in relation to animals fed on feed containing imported soybean meal. This perception is reflected by an observed discounted price received by the local product.

When considering the daily Argentine (imported) as well as South African (locally produced) price of soybean meal for the period January 2010 to June 2017, it is evident that price discounts received by the local product sometimes reach as much as R950 per ton, approximately 13%

of the local price. Considering the average price discount per ton received by locally produced soybean meal during the 2014/2015, 2015/2016, 2016/2017 and 2017/2018 production seasons the local industry forfeited R229.9 million, R209.4 million, R430.6 million and R459.3 million respectively. This is a total of more than R1.3 billion over four production seasons. Thus, in order to promote the use of local soybean meal as a source of protein in animal feed, this study challenged the negative market perception towards local soybean meal.

The protein quality of soybean meal is dependent on the digestibility of the protein content and the reduction of anti-nutritional factors present in raw soybeans. Protein quality in soybean meal is determined when the crushed flakes are exposed to heat treatment. Insufficient or over-heating of the crushed flakes will result in poor quality soybean meal as insufficient heating will fail to destroy anti-nutritional factors and over-heating will reduce protein digestibility and the availability of amino acids. Feed formulators need reliable methods to differentiate between good quality soybean meal and under- or over-processed soybean meal.

In South Africa, feed manufacturers rely only on indirect analysis, i.e. *in vitro* analysis, to determine protein quality of soybean meal as direct analysis of soybean protein quality, i.e. *in vivo* analysis, is challenging in routine operations. Various studies have drawn the validity of these *in vitro* methods of quality analysis into question as test results between laboratories differ significantly. At the end of the day *in vivo* monogastric animal growth performance testing is the most relevant test for soybean meal quality. Since no published *in vivo* studies, performed in South Africa, substantiating inferior protein quality claims could be found, the discounted price received by locally produced soybean meal, based on inferior quality claims, is questionable. Therefore, a complete and independently verified market discount or premium, on the back of an *in vivo* growth performance study, is necessary to promote the South African soybean meal industry.

This findings of this study has shown that the perception that South African produced soybean meal should trade at a discount relative to imported Argentine soybean meal is unsubstantiated. Results from the *in vivo* broiler growth performance study has shown a South African (RSA) night-shift soybean meal diet to be the most favourable soybean meal for broiler production during the *in vivo* broiler growth performance trial, based on: mortality rates; feed conversion; production efficiency as well as economic feasibility, when compared to an Argentine, RSA day-shift and RSA under-processed soybean meal diet.

Therefore, based on the findings of this study industry participants may be inclined to replace imported protein sources by that of local protein sources. An increase in the demand for local soybean meal products will shift the demand curve outward, ultimately increasing local soybean meal market prices. Higher market prices and thus greater profitability could in the end lead to an expansion in soybean meal production. This in turn could ultimately improve South Africa's self-sufficiency in protein for animal production for human consumption and as a result improve the country's trade balance in the future.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ALW	Average Live Weight
ANOVA	Analysis of Variance
AOAC	Association of Analytical Communities
ARP	Analysis, Prediction and Response
BFAP	Bureau for Food and Agricultural Policy
CP	Crude Protein
CSDG	Corn, Soybean Meal and Dried Grains
DAFF	Department of Agriculture, Forestry and Fisheries
DDGS	Distilled Dried Grain with Solubles
DM	Dry Matter
EU	European Union
FCR	Feed Conversion Ratio
GC	Ground Corn
GLM	General Linear Model
ITAC	International Trade Administration Commission of South Africa
KOH	Potassium Hydroxide
MT	Metric Ton
NAS	Natural and Agricultural Sciences
NCEC	National Crop Estimates Committee
N.D.	No Date
NSI	Nitrogen Solubility Index
PDI	Protein Dispersibility Index

PEF	Production Efficiency Factor
PRF	Protein Research Foundation
PS	Protein Solubility
RSA	Republic of South Africa
SACU	Southern African Customs Union
SAS	Statistical Analysis System
SB	Soybean
SBM	Soybean Meal
SBO	Soybean Oil
SAPA	South African Poultry Association
UI	Urease Index
UP	University of Pretoria
WTO	World Trade Organisation

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER 1 INTRODUCTION

1.1 CONTEXT

Large price discounts and premiums are common in the South African market of locally produced soybean meal (Figure 1.1 and Figure 1.2). Historically, price premiums received by the local product would arise when the aggregate demand for imported soybean meal outweighed the aggregate supply of the imported product. This could be as a result of, amongst other, production shortages in the exporting country or from difficulties experienced when importing soybean meal into South Africa. In such cases users of soybean meal have no other choice but to buy the South African produced product even if it means having to pay a premium for the local product. Such premiums received by the local product are usually short-term in nature.

Price discounts for South African produced soybean meal on the other hand seem to be based on the perception associated with a lower protein quality of the local product. The perception dictates that animals (i.e. poultry, pigs, etc.) which are fed on feed containing local soybean meal show suboptimal growth in relation to animals fed on feed containing imported soybean meal. This perception ultimately manifests in a price discount received by the local product.

Figure 1.1 shows the daily Argentine (imported) as well as South African (locally produced) price of soybean meal for the period January 2010 to June 2017, as quoted by Seaboard. Figure 1.2 on the other hand illustrates the calculated price premiums and discounts received by the locally produced product during the same period, i.e. a positive value indicating a price premium and a negative value indicating a price discount. Figure 1.2 shows that from January 2010 to January 2014 locally produced soybean meal frequently traded at a price premium to imported Argentine soybean meal. However, from January 2014 to May 2017 locally produced soybean meal traded at a continuous price discount to the imported product. Figure 1.2 also illustrates that price discounts received by the local product has historically reached as much as R950 per ton, approximately 13% of the local price. When considering the price data trend of Figure 1.2 it seems as if the price discounts received by locally produced soybean meal is likely here to stay, unless addressed urgently through studies like these.

Furthermore, only in rare instances there exists a suitable explanation for price discounts received by South African produced soybean meal, i.e. May to June 2014 and again in June 2016. During these months new market participants entered the market and aggressively pushed sales by discounting their product. This is supported by Kaszaz (2015) who said that "… the discounts received by the local product during May to June 2014 was as a result of incoming market participants lowering the local price of soybean meal as to gain market share and not as a result of the local product having a lower protein quality content…". For the other months considered price discounts received by the local product are most likely related to inferior protein quality claims.

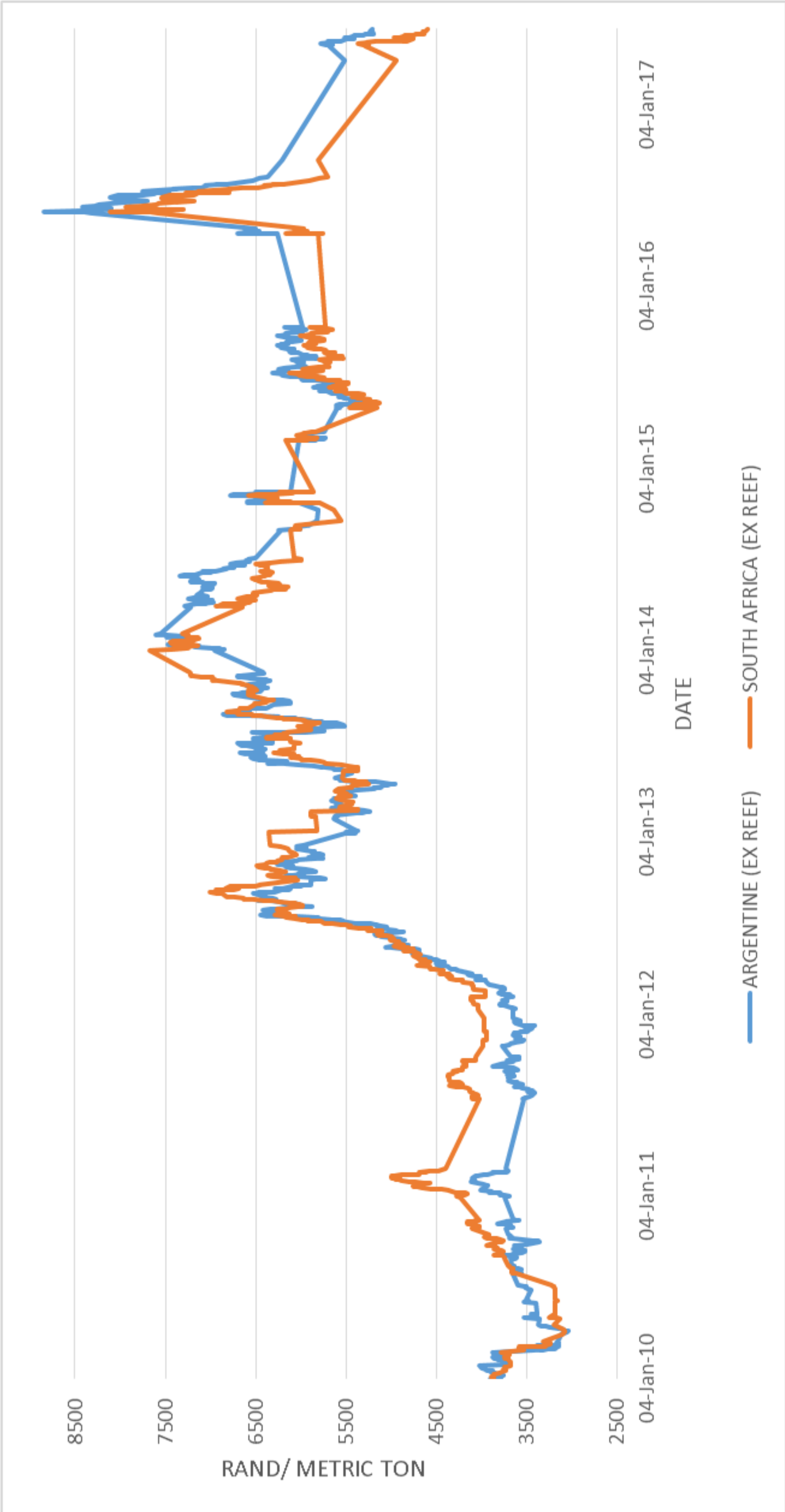

Figure 1.1 Daily Argentine and South African soybean meal prices: January 2010 to May 2017 (Rand/ MT)

Source: Seaboard (2017)

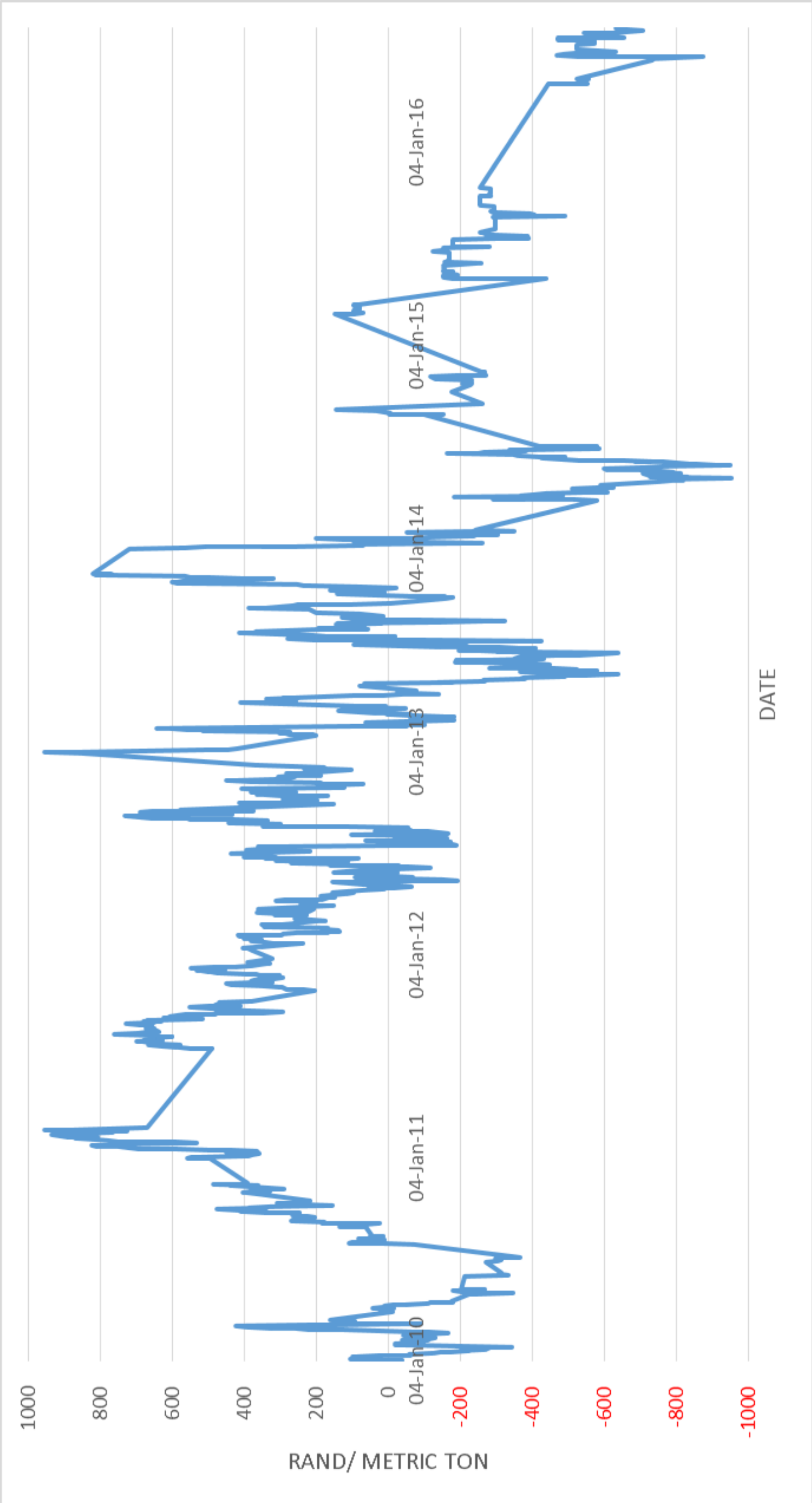

Figure 1.2 Daily soybean meal price premiums/ discounts January 2010 to May 2017 (Rand/ MT)[1]

Source: Own calculations based on Seaboard (2017)

[1] The daily soybean meal price premium/ discount received by the South African produced product has been calculated in terms of the local product, i.e. a value above zero portrays a premium and a value below zero portrays a discount.

According to the Bureau for Food and Agricultural Policy (BFAP) (2016) the historically discounted price received by the local product could be as a result of technical difficulties experienced by the local crushing industry which resulted in inconsistent protein content. Protein quality has a direct effect on the quality of feed and ultimately the growth performance of livestock that is fed on it. Feed manufacturers therefore need reliable methods to differentiate between good quality soybean meal and under- or over-processed soybean meal (Caprita *et al*., 2010[b]).

In recent years (2013 and 2014) the soybean meal industry has however made significant progress in addressing technical challenges when it comes to soybean processing and as utilisation rates and soybean availability improve price discounts received by local soybean meal should continuously be lessened. Therefore, the following question presents: To what factor(s) should a price discount received by the local product, if any, be attributed to?

1.2. BACKGROUND: THE SOUTH AFRICAN SOYBEAN MEAL VALUE CHAIN

The crushing of soybeans produces three products, namely: soybean meal (76%); soybean oil (18%); and soybean hulls (5%). The South African soybean complex consists out of three parts, i.e. soybeans, soybean meal and soybean oil (Jooste *et al.,* 2011). BFAP (2009) furthermore identifies the major role players in the soybean meal value chain to be soybean suppliers, soybean traders, soybean crushers and animal feed manufacturers. Jooste *et al.* (2011) adds that silo owners, wholesalers, retailers, distributors and end users also form a part of the soybean meal value chain (Figure 1.3).

The South African soybean supply is made up out of locally produced soybeans as well as imported soybeans. The importation of soybeans is done through international trading houses and trading is done electronically through the South African Futures Exchange (SAFEX). Agri-businesses (ex-cooperatives) can procure soybeans from international as well as national trading houses or directly from farmers. Local crushing plants can also procure soybeans from international as well as national trading houses, directly from the farmer or from agri-businesses. These crushers can then sell soybean meal to animal feed manufacturers or export their product. Animal feed manufacturers can also procure imported soybean meal through international trading houses (Figure 1.3).

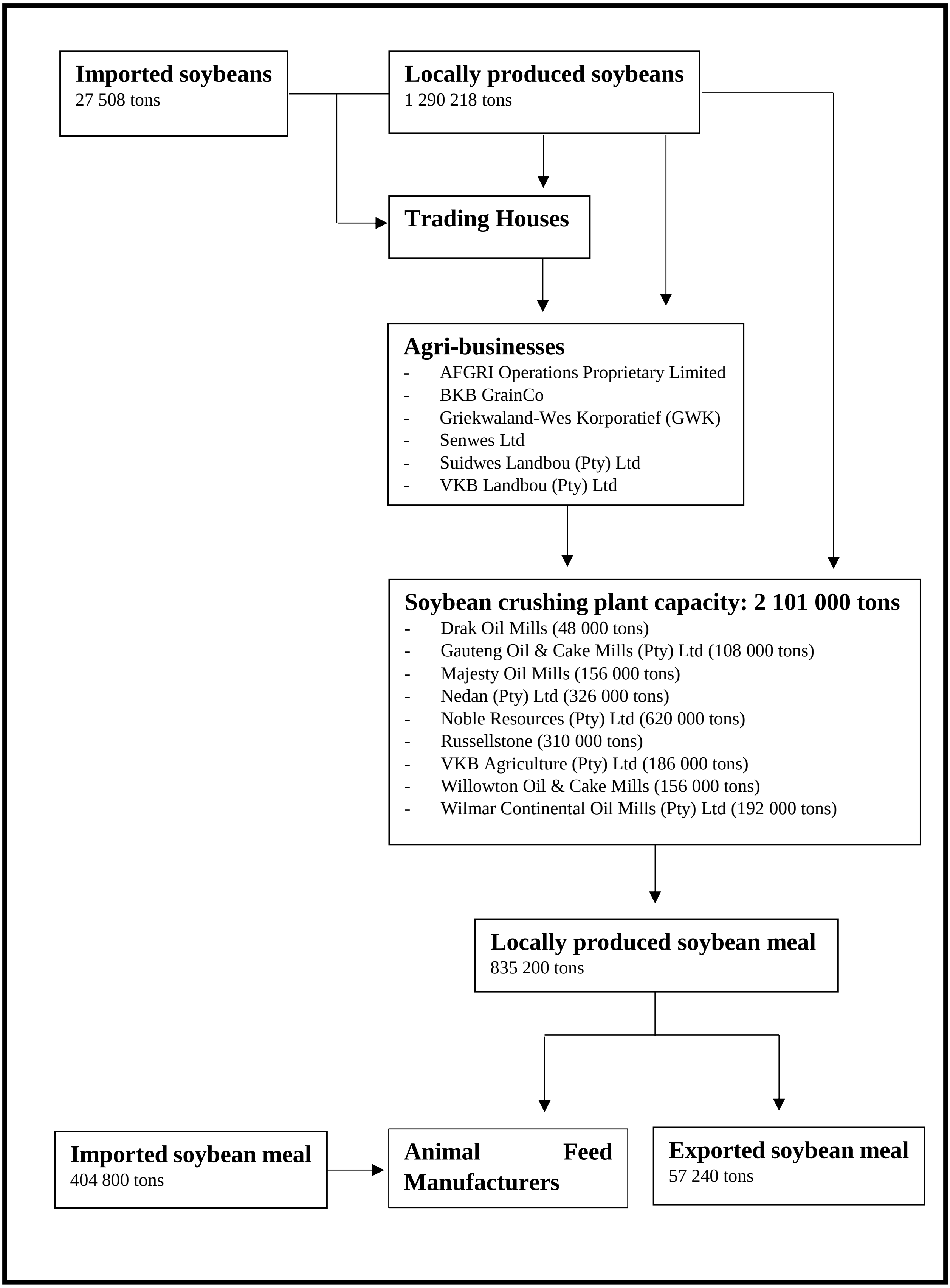

Figure 1.3 Quantified South African Soybean meal value chain (2017/2018) (MT)

Sources: Joubert (2016); PRF (2018); and SAGIS (2018[b])

In South Africa soybeans are furthermore utilised mainly for crushing purposes, i.e. soybean meal and soybean oil, comprising 84% of the total soybean demand in the 2017/2018 production season. During the same period full-fat soybeans for animal feed represented 14% of total soybean utilisation whereas human consumption represented only 2% (Figure 1.4) (SAGIS, 2018[b]).

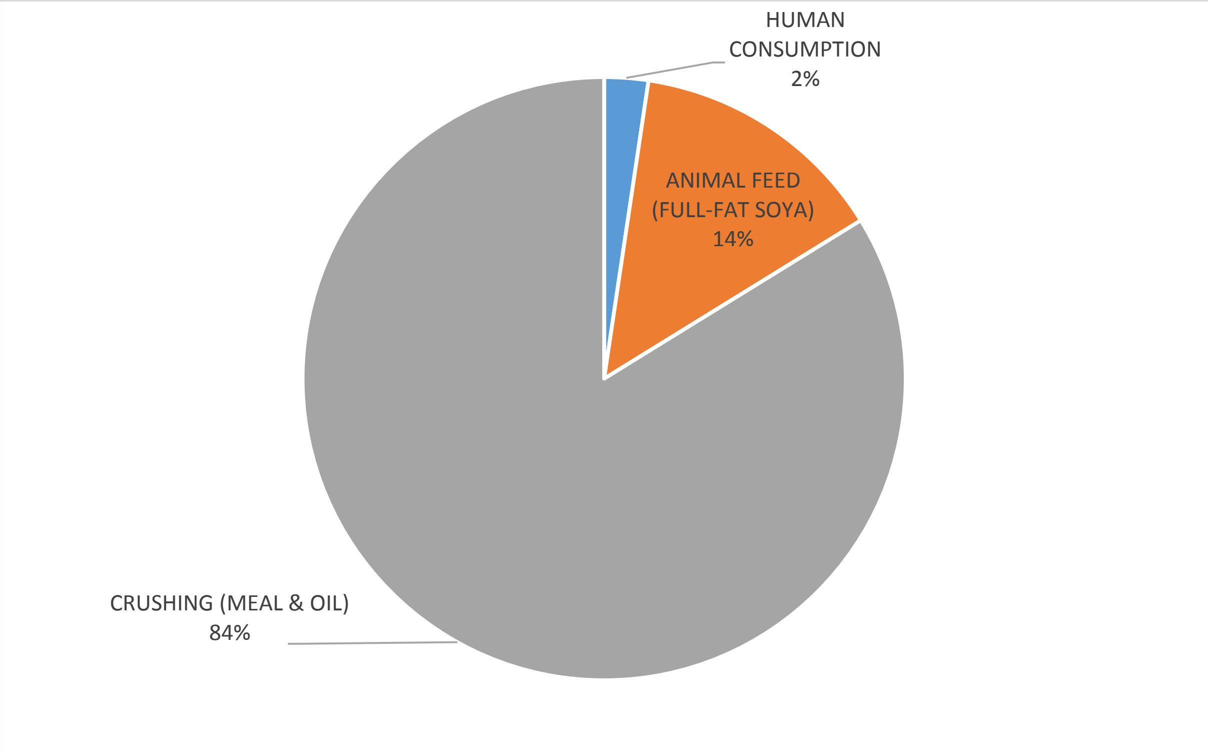

Figure 1.4 Local utilisation of soybeans 2017/2018 (%)

Source: SAGIS (2018[b])

1.2.1 Soybean Supply: Locally Produced and Imported Soybeans

Local soybean production has increased from 186 600 tons in the 1999/2000 production season to more than 1.29 million tons in 2017/2018 (Figure 1.3 and Figure 1.5). The National Crop Estimates Committee (NCEC) further estimates that more than 1.43 million tons of soybeans will be harvested in the 2018/2019 production season (SAGIS, 2018[b]). This increase in soybean production comes as a response to the recent (2013) expansion in local crushing capacity as the local soybean meal crushing industry invested R1 billion to increase the local crushing capacity to an estimated 2.1 million tons per annum (Joubert, 2013). According to BFAP

(2016), soybean production is expected to exceed 2.2 million tons by 2025, despite poor rainfall and warmer weather conditions.

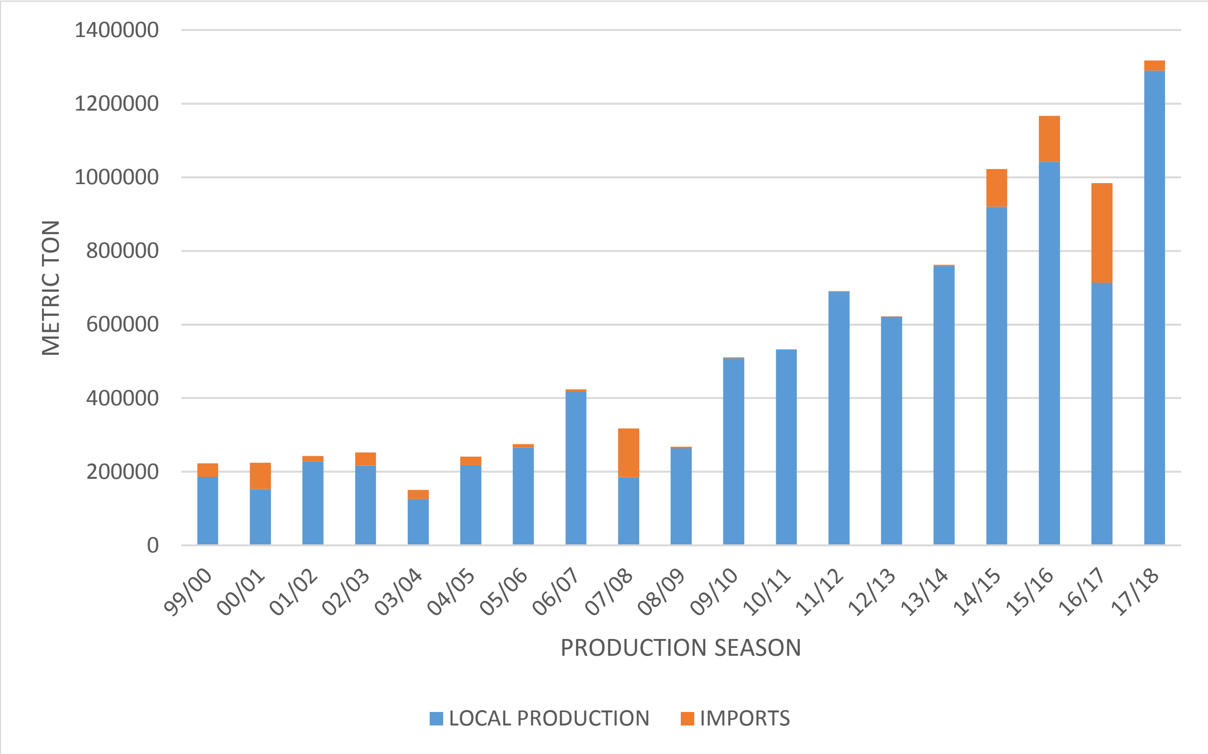

Figure 1.5 Soybean supply 1999/2000 to 2017/2018 (MT)

Source: SAGIS, 2018[b]

Even though local soybean production has increased significantly and is expected to increase even further in the future, the rapid expansion of the local soybean crushing capacity during 2013 has left South African soybean producers unable to supply sufficient amounts and hence domestic supply has been supplemented by imports of soybeans (nearly 28 000 tons during the 2017/2018 production season) (Figure 1.3 and Figure 1.5) (SAGIS, 2018[b]).

1.2.2 Soybean Meal Supply: Local Crushing Capacity and Imported Soybean Meal

Local soybean meal production has increased from 141 520 tons in the 2001/2002 production season to 835 200 tons in 2017/2018 (Figure 1.3 and Figure 1.6) (PRF, 2018). Considering dual crushing plants, local soybean crushing capacity is estimated to be more than 2.1 million tons (Joubert, 2016). According to BFAP (2017) far less than 80% (the international industry benchmark) of this crushing capacity was utilised in 2017. This shows that there is still significant room to increase local soybean meal production in the future. According to BFAP (2016) local soybean meal production is expected to exceed 1.6 million tons by 2025, continuously replacing imported soybean meal.

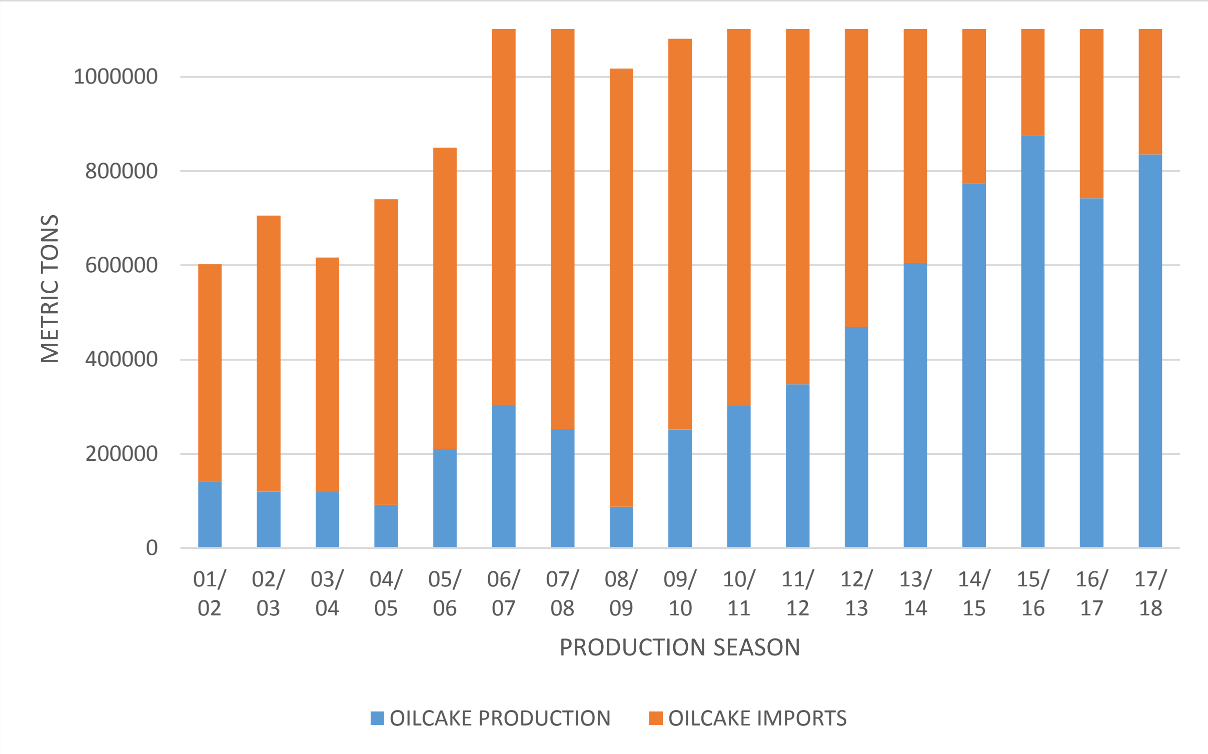

Figure 1.6 Soybean meal supply 2001/2002 to 2017/2018 (MT)

Source: PRF (2018)

Historically large soybean meal imports could be attributed to insufficient production, marginal profitability in the crushing industry as well as limited government support (Southern Africa Regional Soybean Roadmap Final Report, 2011). Since the rapid expansion in local soybean meal production, soybean meal imports have started to decrease as a direct result, with only 404 800 tons imported in the 2017/2018 production season (Figure 1.3 and Figure 1.6) (PRF, 2018). However, it is projected that domestic production would be insufficient to meet the total demand in the future and hence soybean meal prices would continue to move close to import parity (BFAP, 2016).

1.2.3 Soybean Meal Demand: Animal Feed Manufacturers and Exported Soybean Meal

Worldwide soybeans are crushed mainly to produce crude soybean oil and soybean meal. Soybean meal is used mainly as protein source in the production of animal feed where only a small portion is used for human consumption (Shurtleff and Aoyagi, 2007). The amino acids in soybean meal complement the amino acid pattern in maize and therefore soybean meal is used as a premium protein ingredient in the manufacturing of animal feed which supports optimum economic performance (Cromwell, 2012). In South Africa the domestic demand for soybean meal is primarily driven by the poultry industry since soybean meal is the most important dietary protein (Roosendal, 2010).

Soybean meal exports increased from 3 793 tons in the 2004/2005 production season to 57 240 tons in 2017/2018 (Figure 1.3) (SAGIS, 2018[a]). This significant increase, however, only took place in recent years (2013/2014) when local soybean meal production increased. During the 2017/2018 production season soybean meal was exported mainly to South Africa’s neighbouring countries, i.e. Botswana (37%); Swaziland (29%); Mozambique (15%); Namibia (8%); Angola (5%); Zimbabwe (4%) and Lesotho (2%) (Figure 1.7). Other countries where marginal export occurred to included: Congo; Nigeria and Zambia. It could therefore be anticipated that as the economies of South Africa’s neighbouring countries grow their demand for soybean meal, as protein source for the production of animal protein for human consumption, will also increase. This could serve as motivation for South Africa’s soybean crushing utilisation to increase, increasing soybean meal exports further.

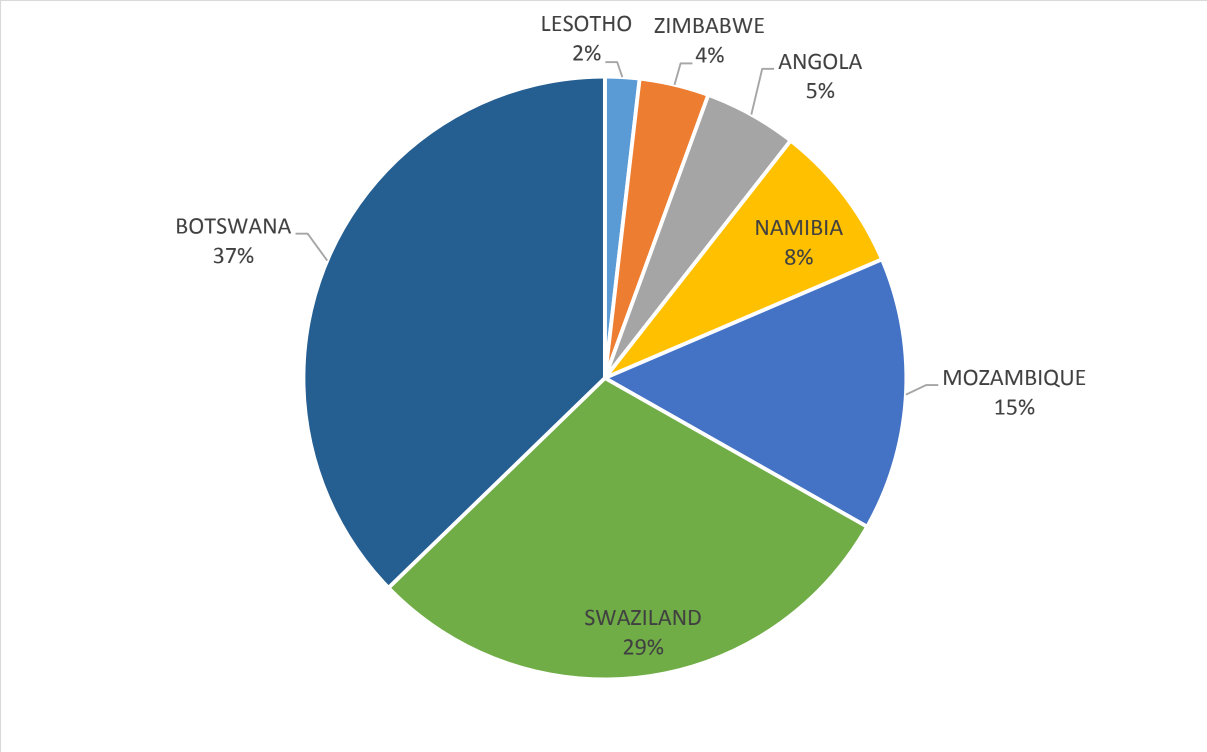

Figure 1.7 Soybean meal exports 2017/2018 (MT)

Source: SAGIS (2018[a])

1.2.4 Soybean Meal Crushing Profitability

Since South Africa is a net importer of soybean meal and soybean oil, domestic prices will move close to import parity. According to *the Quarterly soybean market Analysis and Outlook Bulletin 2 of 2014*, import parity prices reflect the prices soybean crushers and feed manufacturers pay if they were to buy imported soybean meal. Import parity prices are affected by: freight rates; insurance costs; financing costs; import tariffs; and the exchange rate (DAFF, 2014).

Whilst having their own supply and demand chains, the markets for soybeans, soybean meal and soybean oil are interdependent. As a result, South African soybean prices are influenced by: the international soybean price; the price of imported soybean oil; the price of imported soybean meal; as well as the cost of crushing the beans. This derived soybean price is used to determine the profit or loss from crushing soybeans, i.e. the crushing spread (Jooste *et al.*, 2011). Mitchell (2010) furthermore argues that market efficiency can be explored when one considers the crushing spread, as the fairly stable amount of soybean meal and oil produced from crushing soybeans allows for predictable value relationships between the relevant futures contracts. Differently stated, the crushing spread can be calculated as the difference between the combined value of soybean meal and soybean oil and the value of soybeans (Equation 1.1) (CME Group, 2015).

$$Crush\ spread = 0.80SBM + 0.18SBO - SB$$

Equation 1.1 The soybean crush spread[2]

Source: CME Group (2015)

Unfortunately, the economic profitability of producing soybean meal in South Africa is significantly higher than the market profitability of producing soybean meal. Economic profitability differs from market profitability as market profitability does not take into consideration the opportunity cost of crushing soybeans. Economic profit therefore measures the efficiency as well as the industry's comparative advantage. The fact that the economic profitability of producing soybean meal is significantly higher than the market profitability of producing soybean meal suggests that there are substantial distortions in the prices of production factors and outputs. (Jooste *et al.*, 2011)

1.3. THE RESEARCH PROBLEM

When one looks at the South African soybean industry there seems to be a general perception that products containing South African soybean meal are inferior to products containing soybean meal imported from Argentina and other South American countries. This perception implies that animals (i.e. poultry, pigs, etc.) which are fed on feed containing local soybean

---

[2] Where: SBM is the price of soybean meal per ton.
SBO is the price of soybean oil per ton.
SB is the price of soybeans per ton.
The coefficients convert the unit prices to a crush margin per one ton of soybeans.

meal show suboptimal growth in relation to animals fed on feed containing imported soybean meal.

Palić and Grove (2004) argue *in vivo* monogastric animal growth performance testing to be the most relevant test for soybean meal quality and nutrient determination. Unfortunately direct analysis (i.e. *in vivo* analysis) as well as biophysical analysis of soybean meal quality are challenging and impractical in routine operations. These trials are not only extremely costly and time consuming but *in vivo* animal testing also require vast ethical considerations. (Festing and Altman, 2002)

In South Africa feed formulators therefore, regrettably, only make use of indirect analysis (i.e. *in vitro* analysis) to assess soybean meal quality. Various research studies have however proved *in vitro* analysis of soybean meal quality to be a poor indicator of soybean meal quality (Palić and Grove, 2004; Caprita *et al.*, 2010[b]; Palić *et al.*, 2008 and Palić *et al.*, 2011). Although *in vitro* soybean meal quality test results within laboratories do not differ significantly, *in vitro* test results between laboratories differ significantly. Feed formulators furthermore need to consider various quality indicators jointly in order to make inference about the quality of the soybean meal. Consequently, the validity of relying only on *in vitro* soybean meal analysis to determine soybean meal quality is brought into question.

An estimated loss for the South African soybean meal industry, due to price discounts received by the local product, is calculated in Table 1.1 for the 2014/2015, 2015/2016, 2016/2017 and 2017/2018 production seasons (Equation 1.2). These production seasons were chosen since locally produced soybean meal traded at a continuous price discount to the imported product from January 2014 to May 2017 (Section 1.1).

$$Estimated\ loss = local\ soybean\ meal\ production\ \times average\ price\ discount$$

Equation 1.2 Estimated loss for the South African soybean meal industry[3]

[3] Where data for local soybean meal production (MT) was obtained from PRF (2017) and the average price discount (R/ MT) is the researcher's own calculations based on data obtained from Seaboard (2017).

Considering the average price discount per ton received by locally produced soybean meal during these production seasons the local industry forfeited R229.9 million, R209.4 million, R430.6 million and R459.3 million respectively (Table 1.1). This is a total of more than R1.3 billion over four production seasons.

Table 1.1 Estimated loss for the South African soybean meal industry (Rand)

Production season	**Local soybean oilcake production (MT)**	**Average price discount (R/ MT)**	**Estimated loss (Rand)**
2014/2015	604926	380	229 871 880
2015/2016	872 661	240	209 438 640
2016/2017	742 523	580	430 663 340
2017/2018	835 200	550	459 360 000

Source: Own calculations based on PRF (2017) and Seaboard (2017)

Thus, in order to promote the use of local soybean meal as a source of protein in animal feed mixtures and therefore ultimately promoting the industry, the current disputable market perception needs to be challenged. By scientifically quantifying the basis for a price discount or premium between local and imported soybean meal industry participants may be inclined to replace imported protein sources by that of local protein sources. An increase in the demand for local soybean meal products will shift the demand curve outward and ultimately increase local soybean meal market prices. Higher market prices and thus greater profitability could in the end lead to an expansion in soybean production. An expansion in the soybean industry could lead to a decrease in South Africa's dependence on imported protein sources for the production of animal protein for human consumption. This could, in turn, ultimately improve South Africa's trade balance in the future.

Finally, this study could potentially form a crucial part in various policy- and legislative recommendations. As indicated in the National Planning Commission's vision statement for 2030, Agriculture is to create 1 million job opportunities over the next fifteen years (National Planning Commission, 2009). Therefore, if local soybean meal consumption is stimulated the opportunities for employment creation (and ultimately poverty alleviation) up and down the soybean meal value stream could be enormous.

Another policy consideration could be to ensure South Africa's self-sufficiency in protein production. This is the Protein Research Foundation's (PRF) main objective: the replacement of imported protein sources with that of locally produced protein sources (Strydom, Briedenhann and De Jager, 2017). The advantages of improving South Africa's competitiveness in soybean meal production and consequently the country's self-sufficiency in protein production are infinite.

1.4. RESEARCH AIM AND OBJECTIVES

This study aligns with the vision and mission of various industry participants including soybean meal crushers, the PRF and Agricultural Business Management. These participants embrace the promotion of local protein consumption to satisfy the growing protein demand in the production of animal feeds (PRF, 2005).

From existing work (Panda, 2008), it is evident that the importance of a false perception surrounding a commodity cannot be underemphasised. A negative perception concerning the protein quality of local soybean meal do not only affect the profitability of the soybean meal industry but the entire soybean value chain. Therefore, the overarching aim of this study is to challenge price distortions in the South African soybean meal value chain by means of an *in vivo* broiler growth performance trial and relating it to a bottom line impact per production cycle. The research aim was accompanied by the following sub-objectives:

(1) Determining the significance of any growth performance differences, between broilers fed on diets containing locally produced soybean meal and broilers fed on diets containing imported soybean meal, through econometric analysis.

(2) Calculating the price discount or premium between South African produced soybean meal and imported soybean meal, by determining the economic feasibility of feeding broilers on diets containing South African produced soybean meal

1.5. HYPOTHESIS

Since the overarching aim of this study is to relate any growth performance differences between local and imported soybean meal to a bottom line impact, the main hypothesis to be tested states as follow:

H_0: The current discounted price, in percentage terms, received by local soybean meal producers is a true reflection of the soybean meal quality differences between the local product and imported soybean meal.

It follows that it is necessary to first scientifically estimate the significance of any growth performance differences between birds fed on feed containing local soybean meal to that of birds fed on feed containing imported soybean meal. Thus, the following hypothesis necessarily needs to be tested:

H_0: The growth performance of birds fed on feed containing local soybean meal do not differ significantly from broilers fed on feed containing imported soybean meal.

1.6. CHAPTER DEDICATION

Chapter 2 represents the Literature Review conducted for the purposes of this study. As soybean meal is considered the dominant protein source in South Africa and since the local broiler industry is the main consumer of soybean meal, the first part of Chapter 2 provides a short discussion on these local industries, emphasising their interdependence. Thereafter the Literature Review provides a short discussion on the importance of soybean meal as supplemental protein in animal feed, factors influencing soybean meal protein quality and ultimately the determination of protein quality in soybean meal. In South Africa, feed manufacturers rely only on *in vitro* analysis to determine protein quality of soybean meal. The Literature Review however explores research conducted on the validity of *in vitro* analysis of soybean meal protein quality. This is followed by short summaries of foregoing research where *in vivo* broiler growth performance trials were used to measure soybean meal quality, as this method is deemed the best indicator of soybean meal quality. This is followed by techniques to support the methods of economic and statistical analysis presented in this thesis.

The methodology of this project, as presented in Chapter 3, stems out of the literature obtained and presented in Chapter 2 of this thesis. The methodology therefore rested on the following four pillars:

(1) An *in vitro* analysis of soybean meal quality;
(2) An *in vivo* broiler growth performance trial testing soybean meal quality;
(3) A statistical analysis of growth performance differences; and
(4) An economic feasibility check on the back of the *in vivo* broiler growth performance trial.

Chapter 3 provides an in-depth explanation of each of these four pillars, starting with the research design and protocol, i.e. the *in vitro* and *in vivo* analysis of soybean meal quality. This is followed by in depth explanations of the efficiency calculations and the statistical analysis of broiler growth performance differences by means of the Mann-Whitney *U*-test. Lastly, the economic feasibility of the various soybean meal treatments was determined.

Data collected from the *in vivo* controlled experiment is presented in Chapter 4 of this thesis. Chapter 4 firstly compares results obtained from inter-laboratory *in vitro* analysis of soybean meal quality. Thereafter the *in vitro* test results of the various soybean meal feed mixtures used during the *in vivo* broiler growth performance trial is discussed. This included a general and nitrogen analysis as well as a urease activity check. Thereafter an in-depth discussion of the *in vivo* trial results follows, including: weekly average live bird body weight per treatment; mortality rate per treatment; and feed consumption per treatment. Efficiency calculations, based on the results of the *in vivo* controlled experiment, included feed conversion and production efficiency. The *in vivo* test results were furthermore accompanied by a statistical analysis testing for any significant broiler growth performance differences.

Chapter 5 of this thesis provides the conclusion as well as recommendations on the results of this research project.

Finally, before the reader moves on to the next chapters, it is important to take special note that although a price discount or premium between imported and locally produced soybean meal was evaluated on the back of an *in vivo* broiler growth performance trial, the basis of this study is essentially in economic terms.

CHAPTER 2 LITERATURE REVIEW

2.1INTRODUCTION

Soybean meal is considered the dominant protein source in South Africa as national soybean meal consumption constitutes the largest portion of total oilcake production in South Africa. The South African boiler industry is furthermore the main consumer of locally produced soybean meal (Strydom, Briedenhann and De Jager, 2017). Therefore, this chapter firstly provides a short discussion on South Africa's soybean meal and broilers industries.

Nutrient content is an extremely important aspect when considering animal nutrition (Srinivasan *et al*., 2013) as protein quality has a direct effect on the growth of animals which is fed on it (Korver *et al*., n.d.). As soybean meal is considered an exceptional source of protein in the diets of poultry (Cromwell, 2012) the second part of this chapter looks at the factors influencing protein quality and content.

In South Africa, feed manufacturers rely only on *in vitro* analysis to determine protein quality of soybean meal. The Literature Review however explores research conducted on the validity of *in vitro* analysis of soybean meal protein quality. This is followed by short discussions of foregoing research where *in vivo* broiler growth performance trials were used to measure soybean meal quality, as Palić and Grove (2004) determines this method to be the best indicator of soybean meal quality.

Due to the fact that the overarching aim of this study was accompanied by sub-objectives which require statistical tests of significance, this chapter also compares various methods for such tests.

Before the concluding remarks are made, the Literature Review also briefly explores factors influencing price distortions throughout markets.

2.2 A SHORT DISCUSSION ON THE SOUTH AFRICAN SOYBEAN MEAL AND BROILER INDUSTRIES

2.2.1 The Soybean Meal Industry: Past, Present and Predictions

During the 2017/2018 production season South Africa produced 67% of its local soybean meal demand, a significant increase from 20% in the 2007/2008 production season (Figure 2.1) (PRF, 2018). As discussed in Section 1.2.1, this significant increase came about during 2013/2014 when the local soybean crushing capacity expanded meaningfully, growing considerably in a relatively short period of time. Based on the Analysis, Prediction and Response (ARP) Model constructed by Strydom, Briedenhann and De Jager (2017), South Africa is predicted to produce close to 82% of its local soybean meal demand by 2020 and 87% of its local soybean meal demand by 2026.

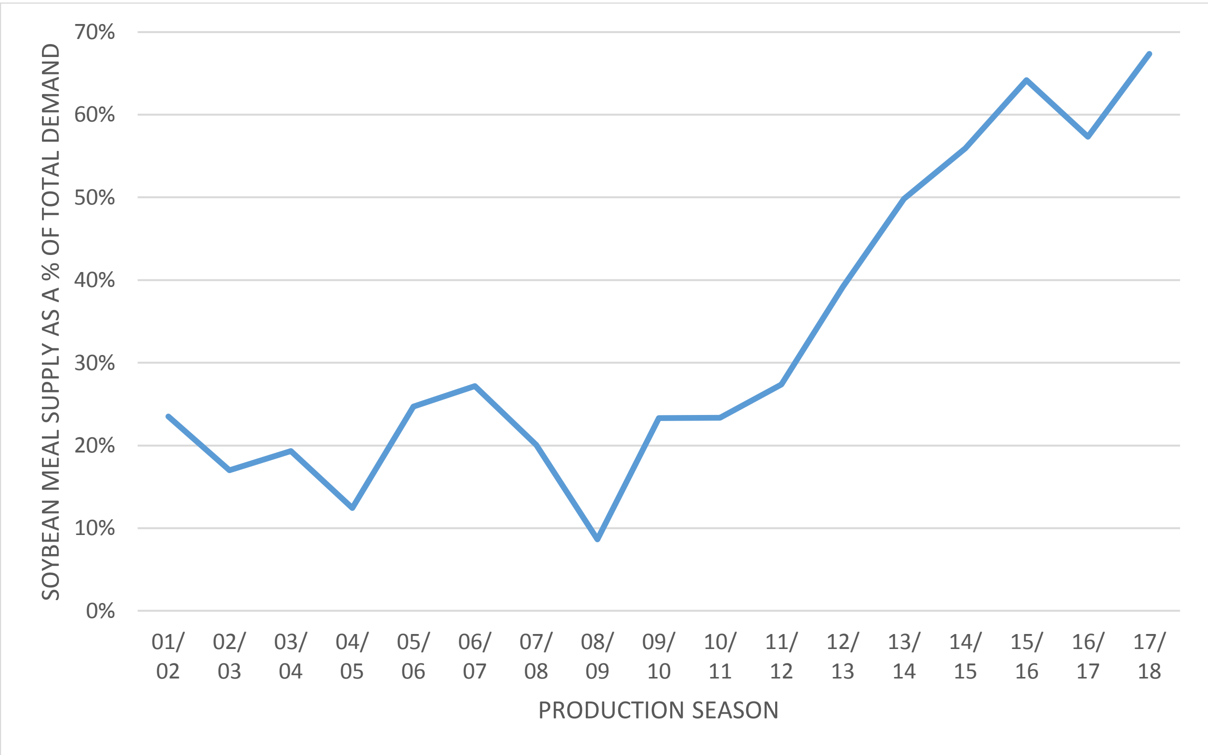

Figure 2.1 Local soybean meal supply as a percentage of total soybean meal demand (%)

Source: Own calculations based on PRF (2018)

The reef, an area once dependant on soybean meal imports, is now supplied by the locally produced product. Coastal regions however still utilise imported soybean meal as imported meal is more competitively priced when compared to soybean meal received from inland depots. RusstellStone (2017) estimates that this situation will change in the near future, i.e. the market share of locally produced soybean meal will expand as to include the whole of South Africa.

However, according to BFAP (2017), South African soybean meal crushers have unfortunately not been benefitting from an improved bean to meal ratio as what can be seen in other international soybean meal markets. The authors do however remark that since soybean meal and oil prices are predicted to remain close to import parity local crushers should be able to improve profitability if efficiency and utilisation rates can be improved. (BFAP, 2017)

National soybean meal consumption furthermore constitutes the largest portion of total oilcake production (63%), followed by: sunflower oilcake (19%); full-fat soya (8%); and canola oilcake (4%) (Figure 2.2). Consumption of full-fat cotton, cotton oilcake, full-fat canola and palm kernel constitutes the remaining 6% of total national meal consumption. Soybean meal is therefore considered the dominant protein source in South Africa.

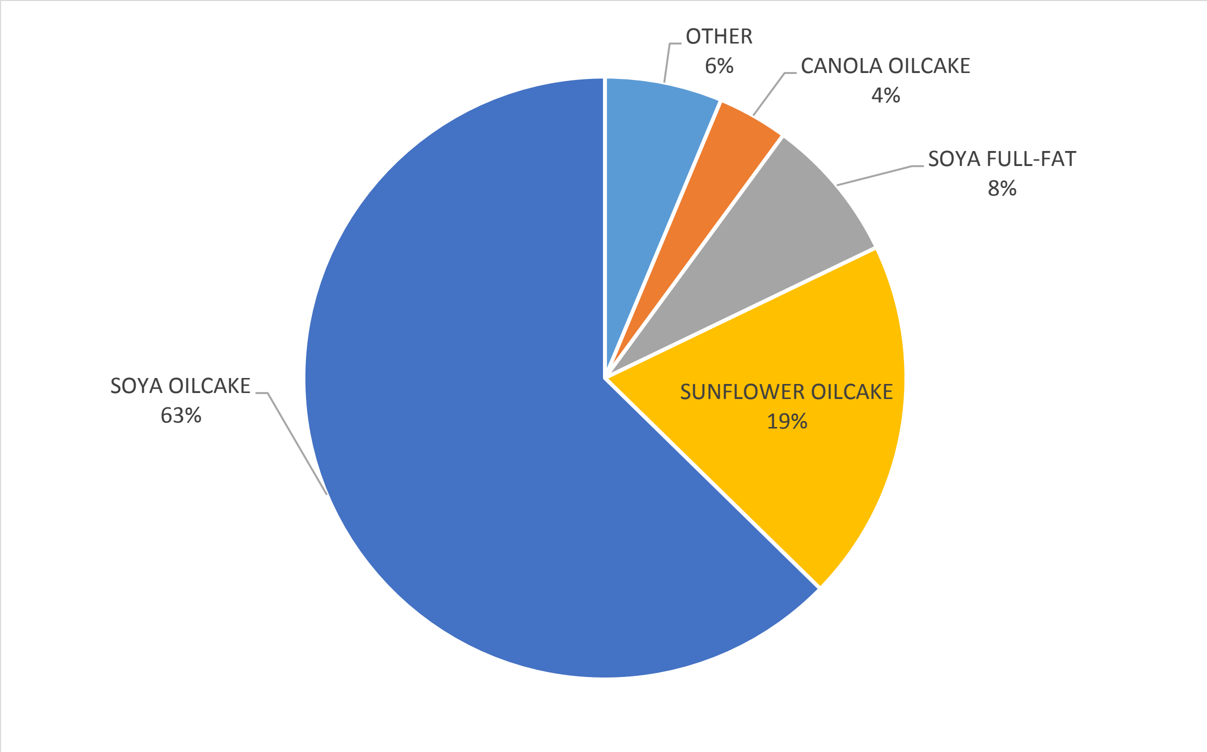

Figure 2.2 South African total oilcake usage 2017 (MT)

Source: Strydom, Briedenhann and De Jager (2017)

During 2017 soybean meal demand constituted 63% of total oilcake demand, a significant increased from 40% in 2010. It is furthermore estimated that soybean meal will continue to be the dominant local protein source in the future as predictions estimate that soybean meal demand will constitute 67% (1.425 million tons) of total oilcake demand by 2020 and 68% (1.454 million tons) of total oilcake demand by 2026 (Strydom, Briedenhann and De Jager, 2017).

2.2.2 The Broiler Industry: Past, Present and Predictions

The World Trade Organisation (WTO) defines *dumping* as the practice where an exporting country exports a product at a price lower than that country's domestic price for the product. This usually leads to a situation where the product is sold at a price lower than which it can be produced in the importing country (Wto.org, 2018). Producers in the importing country are then forced to decrease production costs and/ or to find more efficient ways of production.

The dumping of so-called brown-chicken meat (bone-in meat), mostly by Brazil and the European Union (EU), is common in the South African broiler industry. Figure 2.3 illustrates total frozen broiler imports from 2013 to 2017. During 2017 annual frozen broiler imports amounted to 523 428 tons, a meaningful increase of 32.32% since 2013. During this time nearly 61% of all frozen broiler imports originated from Brazil. (Nkuna, 2018)

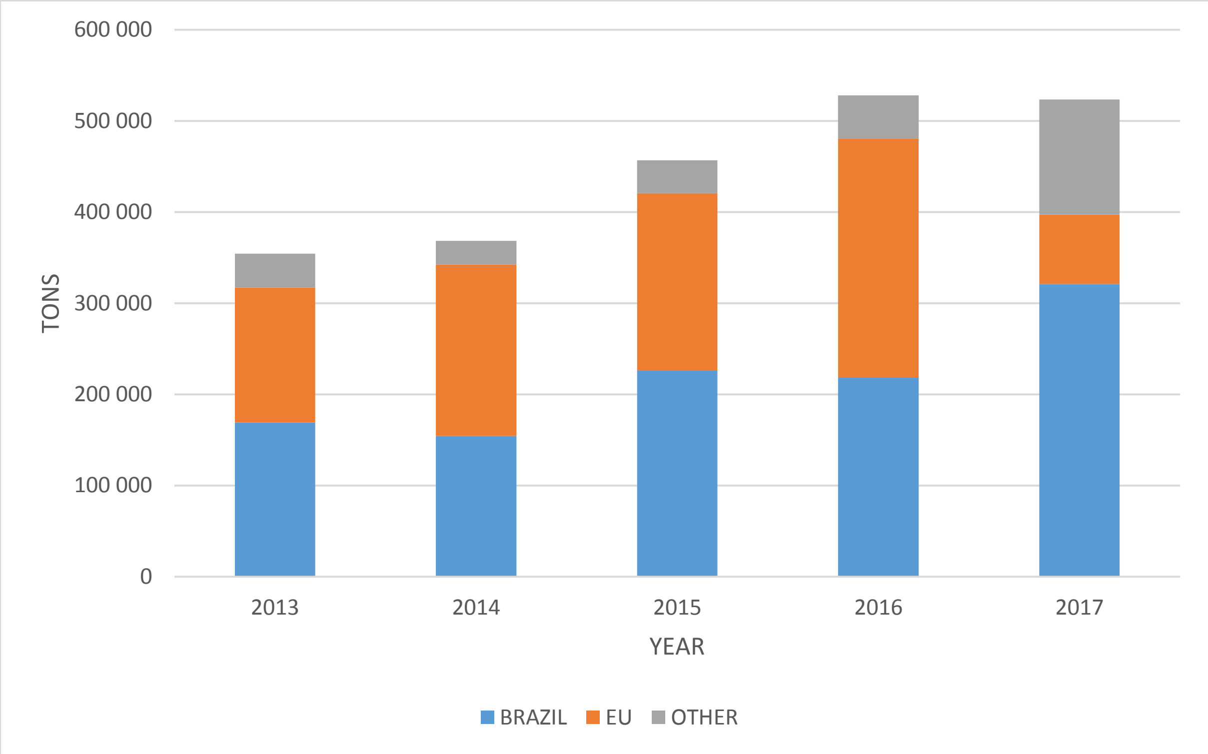

Figure 2.3 Annual frozen broiler imports 2013 to 2017 (MT)

Source: Nkuna (2016)

In October 2016 the South African Poultry Association (SAPA), RCL Foods and AFGRI Poultry appealed to the International Trade Administration Commission of South Africa (ITAC) to review the anti-dumping duties on bone-in chicken imports. The reason behind this appeal was to avoid the recurrence of material injury to the broiler industry caused by dumping practices. (Nkuna, 2018)

The South African poultry industry (primarily broilers and layers) is the main consumer of locally produced animal feed (39%) (Figure 2.4), as well as the main consumer of total oilcake

(83%) (Strydom, Briedenhann and De Jager, 2017). The authors further state that the growth and sustainability of the soybean meal industry will depend largely on the poultry industry's soybean meal requirements. These findings and predictions are in line with Dunn (2017).

According to Dunn (2017) broiler feeds represent, on a volume basis, nearly 27% of the total animal feed produced in South Africa on an annual basis. In monetary terms, broiler feed represents more than 60% of the total animal feed value of R29 billion, i.e. R17.6 billion annually. The author further states that these figures emphasise the size and value of the animal feeds industry as well as the importance of the broiler industry. It is therefore estimated that if the broiler industry were to collapse, 720 000 tons of soybean meal will be lost in the animal feed value chain. This loss in demand represents 83% of the current (2017/2018) soybean meal supply. (Dunn, 2017)

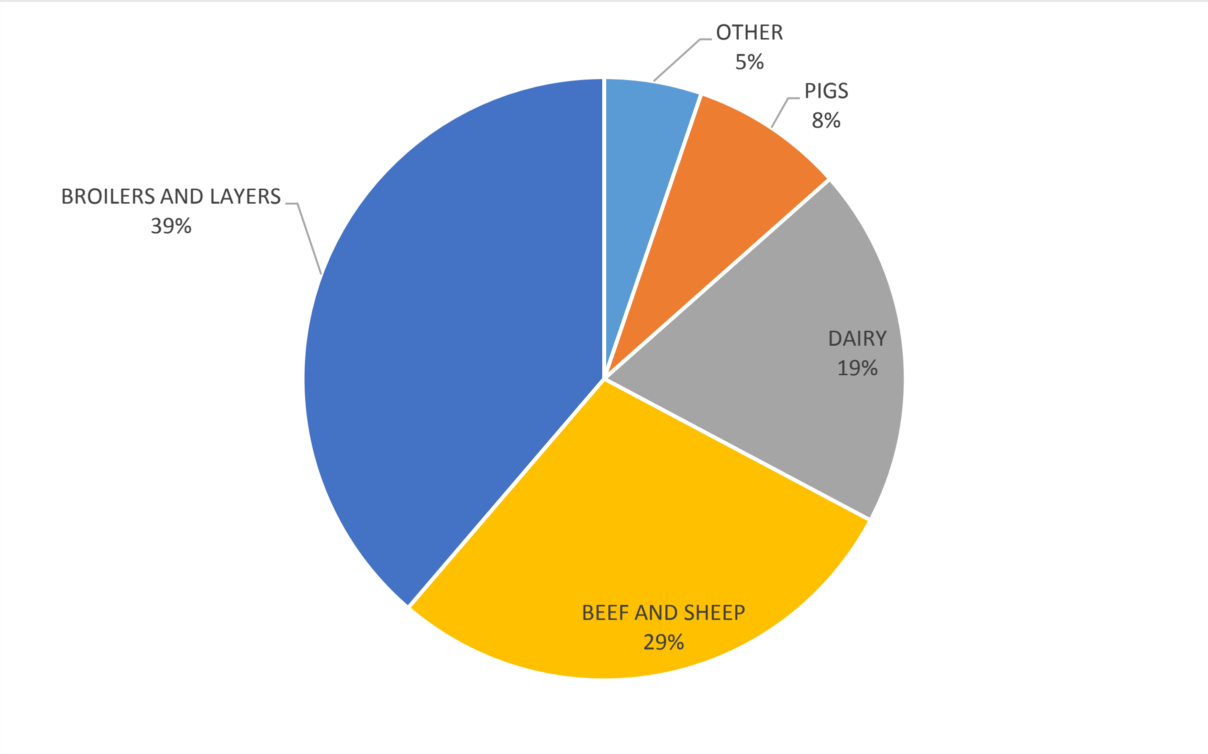

Figure 2.4 South African feed consumption by feed type 2017

Source: Strydom, Briedenhann and De Jager (2017)

2.3NUTRIENT CONTENT IN SOYBEAN MEAL

Nutrient content is one of two important aspects when reviewing animal nutrition, the other is feed consumption. Protein levels in feed affect animal weight and ultimately animal growth performance (Srinivasan *et al*., 2013). Soybean meal has long been considered an outstanding source of supplemental protein in diets for livestock and poultry (Cromwell, 2012) since it has the highest digestible level of lysine and tryptophan which accounts for the lysine deficiency in other grains used to manufacture animal feed (Caprita *et al*,. 2010[b]).

The protein quality of soybean meal is dependent on the digestibility of the protein content and the reduction of anti-nutritional factors present in raw soybeans (Caprita *et al*., 2010[b]). Insufficient or over-heating of the crushed flakes will result in poor quality soybean meal as insufficient heating will fail to destroy anti-nutritional factors and over-heating will reduce protein digestibility and the availability of amino acids (Caprita *et al*., 2010[a]). Feed manufacturers therefore need reliable methods to differentiate between good quality soybean meal and under- or over-processed soybean meal (Caprita *et al*., 2010[b]).

Monogastric animals, such as pigs and poultry, furthermore vary from ruminant animals in that they require a good source of protein in their diet (Korver *et al*., n.d.). Protein quality has a direct effect on the quality of feed and ultimately the growth performance of poultry, livestock and other animals that is fed on it. Protein quality is especially important in the early growth of broilers and remains equally important in the feeding of older birds as feed conversion is a determinant of technical and economic efficiency (Roosendal, 2010).

2.4THE ANALYSIS OF SOYBEAN MEAL QUALITY

2.4.1 *In Vitro* Analysis

As discussed in Section 2.3, soybean protein quality depends on the reduction of anti-nutritional factors and the optimisation of protein digestibility. Direct analysis of protein quality is challenging in routine operations. Therefore, feed formulators make use of indirect analyses namely: Urease Index (UI); Protein Dispersibility Index (PDI); Potassium Hydroxide (KOH) Protein Solubility (PS); and the Nitrogen Solubility Index (NSI) (Caprita *et al*., 2010[b]).

Caprita *et al*. (2010[b]) found that the UI is useful in determining whether the soybean meal has been under-processed. The same study however showed that the UI was not useful in identifying over-processed soybean meal. In a critical assessment of the UI, Palić *et al*. (2008) further stresses that the method could not be recommended as a reliable indicator for soybean meal quality. This is due to the fact that although test results of soybean meal quality within a laboratory did not differ significantly, the results between laboratories had a significant difference.

In contrast to the UI the KOH PS was found to be a good index for determining over-processed soybean meal, but in turn is not useful in determining under-processed soybean meal (Caprita *et al*., 2010[b]).

An additional study by Caprita *et al*. (2010[b]) concluded that, if combined, the UI and the PDI could monitor soybean meal quality best. Soybean meal containing a low UI (0.3 or below) and a high PDI (40-45%) may possibly indicate good quality meal which has been adequately processed. However, another inter-laboratory study by Palić *et al.* (2011) proved the PDI to be a poor indicator of soybean meal quality. Palić *et al.* (2011) found that although the PDI produced a good repeatability limit the reproducibility limit was too wide when taking into consideration the narrow PDI (8.5-10.3%) for adequately processed soybean meal.

Biophysical tests, the refractive index and viscosity of solutions correlates strongly and positively with protein solubility. These two methods may be preferred to the above-mentioned chemical tests as they are non-polluting and quickly performed. (Caprita *et al.*, 2010[b])

Palić and Grove (2004) ultimately determines *in vivo* monogastric animal performance to be the most relevant test for soybean meal quality as well as an excellent indicator of nutrient availability. Such trials are however extremely costly and time consuming as well as impractical for regular testing (Palić and Grove, 2004). Section 3.2.2 highlights the impracticality as well as time restraints of regular *in vivo* soybean meal quality testing, especially with reference to: animal requirements; animal housing and care; restraint of the animals; administration of medicines or substances; and the feed treatments' formulation. *In vivo* animal testing also requires vast ethical considerations. Furthermore, although this study only included one *in vivo* growth performance trial, in practice, trials conducted by feed and/ or broiler companies would be a continuous process over a prolonged period of time. The problem with i*n vivo* growth performance trials is that such trials take place for at least 5 weeks, during which time the meal may already be required for feed production.

2.4.2 Economic Feasibility Determinations Through *In Vivo* Analysis

The practice of comparing the growth performance of animals that are fed on local soybean meal mixtures to that of imported soybean meal mixtures, *in vivo*, have yet to be undertaken in South Africa. Two studies could however be found, performed in Seoul, Korea, in which the protein quality of soybean meal from various origins were compared, i.e. Chee *et al*. (2001) and Chee *et al*. (2008). These studies, published by the US Soybean Meal INFO centre, provide ground for most of the methodology in this research study.

During the studies conducted by Chee *et al*. (2001) and Chee *et al*. (2008), at the University of Korea, *in vivo* broiler growth performance testing was used to compare the feeding values of soybean meal diets originating from various origins as well as the effect of their dietary supplementations on broiler growth performance. These studies made use of *in vitro* and *in vivo* digestibility testing and came to an end by evaluating the soybean meal diets in economic terms. Statistical analysis was done through a one-way Analysis of Variance (ANOVA) table. During the economic feasibility study the price of each soybean meal mixture was calculated based on the average import price during the period of the study. As production costs included only feed intake and chick prices, the return over production was calculated by obtaining the difference between the income and production cost per bird. In order to compare economic advantages a single price was formulated (as an average of the various soybean meal diets) and then applied to all the diets to determine a final return over production. (Chee *et al*., 2001 and Chee *et al*., 2008)

There are however numerous other studies which tested the growth performance of broilers, *in vivo*, for various feed quality and economic determinations. A few examples of such studies include: Ali *et al.* (1993); Rostagno and Pupa (1995); Srinivasan *et al*. (2013); Trevisan *et al*. (2014); Tahir, Batal and Pesti (2015); Hafsa, Basyony and Hassan (2015); Ali, El Sanhoury and Abdelaziz (2015); El-Faham, Ali and Abdelaziz (2016); and Giannenas *et al*. (2017). These studies support *in vivo* broiler growth performance testing to be a suitable method for determining feed quality, and therefore ultimately protein quality in soybean meal, as well as the economic feasibility for different broiler feed diets. The methodology followed in these studies are briefly discussed below. One should however importantly note that, although most of these studies were accompanied by an *in vitro* analysis of soybean meal quality, the overarching aim of these studies was not to compare the *in vivo* analysis results to that of the *in vitro* analysis results.

In 1993 Ali *et al*. conducted a study to compare the growth performance, as well as economics, of feeding broilers on commercial formula to that of broilers which were fed a corn-soybean meal diet. Population response parameters which were recorded from day 1 until slaughter on day 49 included: daily feed consumption; weekly bird weight gain; weekly mortalities; production cost and general flock performance. During this study four meal mixtures (i.e. a commercial broiler diet; a commercial broiler diet where all protein sources were replaced by soybean meal; a soybean and corn only diet; and lastly a diet containing corn, soybean meal and 25% full-fat soybeans) were randomly allocated with three replicates each containing 250 birds. Statistical analysis, to determine the significance between net profits of the various diets, were done through the ANOVA method. The *in vivo* trial was accompanied by an *in vitro* analysis of feed quality. (Ali *et al.*, 1993)

Rostagno and Pupa (1995) conducted an *in vivo* broiler growth performance trial to evaluate whether or not various broiler diets, formulated to have the same nutritional contents of sulphur amino acids and digestible lysine, would undeniably show similar broiler growth performance.

During the *in vivo* trial three soybean meal treatments (i.e. a corn-soybean diet with a high amino acid digestibility; a diet with low amino acid digestibility which contained a wide range of by-products to partially replace corn and soybean meal; and thirdly a diet similar to the second but supplemented to obtain the same level of true digestible lysine and sulphur amino acids as the first diet) of ten replicates each were fed to male Ross broilers. Population response parameters recorded for two periods, i.e. days 1 to 21 and days 21 to 42, included feed intake and weight gain. These parameters were then used to determine feed conversion. To test for any significant differences between treatment's results the authors made use of the Student-Newman-Keuls Test. Economic evaluations were made by comparing the cost per ton of a treatment and then calculating the feed cost per kilogram of live broiler weight. (Rostagno and Pupa, 1995)

In 2013, Srinivasan *et al*. conducted an *in vivo* trial in order to establish what the effect of the removal of fibre from ground corn (GC), distilled dried grain with solubles (DDGS) and soybean meal (SBM), by means of Elusieve Processing, would be on broiler growth performance. The study also aimed to determine what the economic effect of this processing technique would be in broiler production. During this study six feed treatments were formulated (i.e. three diets containing regular materials of GC, DDGS and SBM and three diets containing enhanced materials of GC, DDGS and SBM) with eight replicates each containing 45 *Cobb 500* birds. Population response parameters included: live weight; feed intake and mortalities. Broiler performance per treatment was determined by using the General Linear Model method of SAS and Duncan's Multiple Range Test was used to identify any significant differences in broiler growth performance. The *in vivo* trial was accompanied by an *in vitro* analysis of feed quality. (Srinivasan *et al*., 2013)

In response to the development of various feed technologies in Brazil, Trevisan *et al*. (2014) analysed different feeding programs to establish their effect on broiler performance and economic indexes. During this *in vivo* broiler growth performance study five feed treatments were formulated with eight replicates each containing 30 male *Cobb 500* broilers. Population characteristics calculated weekly included: feed intake; bird weight gain, viability, metabolizable energy consumption; and caloric conversion. These performance indicators were analysed using SAS's statistical analysis software and differences between treatments' results were analysed by means of the Tukey Test. The authors furthermore calculated the average diet cost as well as the gross trade margin for each treatment in order to compare their economic implications. Lastly the productive efficiency index was calculated at the end of the trial. (Trevisan *et al*., 2014)

More recently, Tahir, Batal and Pesti (2015) conducted an *in vivo* growth performance trial to evaluate the economic importance of two dietary feed enzymes, i.e. Hostazym X and Avizyme 1505, in *Cobb 500* broilers. During this study four meal mixtures (i.e. a corn, soybean meal and dried grains (CSDG) diet; a CSDG diet with Hostazym X; a CSDG diet with Avizyme 1505; and a CSDG diet with increased energy, serving as the negative control) were randomly allocated with eight replicates each containing 24 birds. Technical response parameters, recorded on days 0, 19, 35 and 49, was used to determine the economic value of the different feed options. The ANOVA test was used to determine feed efficiency and a one way-ANOVA as well as Tukey's test was applied to separate the means. The *in vivo* trial was accompanied by an *in vitro* analysis of feed quality. (Tahir, Batal and Pesti, 2015)

In an *in vivo* broiler growth performance trial (also accompanied by an *in vitro* analysis of soybean meal quality) Hafsa, Basyony and Hassan (2015) attempted to determine what the effect on broiler growth performance and overall economic efficiency would be when soybean meal is partially replaced by that of guar korma meal, in broiler diets. In the study researchers formulated four meal diets (i.e. a diet where no, 25%, 50% and 75% of the soybean meal is replaced by guar korma meal) with five replicates each containing 15 unsexed *Cobb 400* broilers. Diets were furthermore formulated as to meet the guidelines of the National Research Council of the United States (1994). Population response parameters, recorded weekly, included live body weight and feed consumption. Input-output analysis data were used to calculate the economic as well as relative economic efficiency. (Hafsa, Basyony and Hassan, 2015)

Ali, El Sanhoury and Abdelaziz (2015) conducted an *in vivo* broiler growth performance trial to analyse the effects of replacing vegetable oil with full-fat soybeans as an energy source in broiler diets. The researchers formulated five iso-nitrogenous feed diets (i.e. a corn-soy-bean meal diet, serving as the negative control, and diets were soybean oil was replaced with full-fat soybeans at 2%, 4%, 8% and 10% for starter diets and at 4%, 6%, 10% and 12% for grower diets) with three replicates each containing ten *Hubbard* broilers. Population response parameters, recorded over two periods (i.e. day 1 to 21 and 22 to 35) included live bird body weight and feed consumption. The economic efficiency of each treatment was determined by using local market prices which existed during the trial. Data from the *in vivo* trial were analysed by means of the General Linear Model (GLM) method of SAS and Duncan's Multiple Range Test was used to establish if significant differences between feed treatments existed. The *in vivo* trial was accompanied by an *in vitro* analysis of feed quality. (Ali, El Sanhoury and Abdelaziz, 2015)

In a similar *in vivo* broiler growth performance study, El-Faham, Ali and Abdelaziz (2016) aimed to determine the effect of using full-fat soybeans in broiler diets on growth performance and overall economic efficiency. For the study five iso-nitrogenous diets were formulated (i.e. a corn-soy-bean meal diet free of full-fat soybeans, serving as the negative control, and diets where soybean meal, soybean oil and corn were replaced with full-fat soybeans at 2%, 4%, 8% and 10% for starter diets and at 4%, 6%, 10% and 12% for grower diets) with three replicates, each containing ten *Hubbard* broilers. Population response parameters, recorded over two periods (i.e. day 1 to 21 and 22 to 35) were used to calculate feed consumption, feed conversion, protein conversion and energy conversion. Data from the *in vivo* trial were again analysed by means of the GLM method of SAS and Duncan's Multiple Range Test was used to establish if significant differences between feed treatments existed. The *in vivo* trial was also accompanied by an *in vitro* analysis of feed quality. (El-Faham, Ali and Abdelaziz, 2016)

Giannenas *et al*. (2017) attempted to determine the effects of adding protease whilst replacing soybean meal with corn gluten meal in broiler diets on broilers' growth and health performance. Three diets were formulated (i.e. a corn-soybean meal diet; a corn-soybean meal diet with protease; and a corn-corn gluten meal with protease diet) with six replicates each containing 30 *Ross 308* birds. Body weights and feed intake were recorded on a weekly basis whereas mortalities were recorded on a daily basis. Statistical analysis was done by means of an ANOVA table and Duncan's Multiple Range Test was used to determine if the differences in results were significant or not. (Giannenas *et al*., 2017)

Furthermore, the US Poultry Science Association publishes the Poultry Science Journal and Journal of Applied Poultry Research. These journals contain a vast number of *in vivo* broiler growth performance studies which aimed to determine whether or not significant differences, in nutrient content, between various feed options exist. These studies, as well as the studies listed in Section 2.4.2, although not exactly similar to the *in vivo* broiler growth performance trial conducted in this study, support *in vivo* broiler growth performance testing to be a suitable method for determining protein quality in soybean meal and therefore the economic feasibility for different broiler feed diets. Therefore, these studies consequently provide ground for the methodology of this research study as described in the Research Design and Protocol in Section 3.2.

When summarizing the *in vivo* broiler growth performance studies listed above it is noted that, although testing different hypotheses, these studies' methodologies were similar. All the *in vivo* studies discussed above were accompanied by an *in vitro* analysis of soybean meal quality. Each study's economic implications was determined and the statistical analysis of growth performance differences included either the ANOVA method or the GLM method of SAS. Multiple comparison *post hoc* tests included: the Student-Newman-Keuls Test; Tukey Test; and Duncan's Multiple Range Test. For each study three to six feed treatments were formulated with anything from three to ten replicates each, randomly distributed throughout the broiler houses. The most common population response parameters recorded included: feed intake; weight gain; and mortalities. The studies took place for 35, 42 or 49 days and broilers used for the studies included: Ross; Cobb; and Hubbard.

2.5 TESTING FOR STATISTICALLY SIGNIFICANT DIFFERENCES AMONG SAMPLES

Tests of significance are methods used to make inference about a statement regarding a population. When researchers gather data, they cannot make use of subjective interpretations and hence need to make use of a statistical test to make inference about a population (Mindrila and Balentyne, n.d.). Since various tests of significance exist researchers need to examine their data to determine which test is the most appropriate for their specific set of data, since most tests are based on certain sets of assumptions. When violating assumptions the results of the analysis might be misleading. For parametric testing the following assumptions are usually made: the data considered exhibit a normal distribution; data from various groups have homogeneity in their variances; there is a linear relationship between the data; and the data gathered is independent (Zaiontz, 2013[a]).

When testing for differences amongst the means for two or more populations the ANOVA is the most commonly used method (Lane, 2007). A one-way ANOVA compares the means between populations considered and determines whether or not the differences between the means are statistically significant. It is however important to note that a one-way ANOVA test can only indicate that a significant difference between at least two or more of the population means considered exist, since the test statistic is omnibus. Therefore, this test cannot indicate which population means differ significantly from the other. Consequently, researchers need to make use of multiple comparison *post hoc* tests to determine which population means differ significantly from the other. (Statistics.laerd.com, 2013[b])

Post hoc tests are used to analyse gathered data when a one-way ANOVA test concluded that a significant difference between the means of two or more populations exist. This means that *post hoc* tests are used to determine exactly which means differ significantly. Some of the most commonly used *post hoc* tests include: Tukey's Test; Duncan's Multiple Range Test; and the Student-Newman-Keuls Test (Statistics How To, 2015[b]). Although the Student-Newman-Keuls Test is a more powerful test when compared to the Tukey Test its chances of producing a Type I error (incorrect rejection of the null hypothesis) is greater (Graphpad.com, 2009). Duncan's Multiple Range Test was designed as an alternative to the Student-Newman-Keuls Test since it guards against a Type I error as it requires larger differences between means (Statistics How To, 2015[a]). Duncan's Multiple Range Test is furthermore not only more powerful than the Student-Newman-Keuls Test and Tukey's Test but also differs from the latter two tests in that it does not require an initial significant ANOVA test. The fact that Duncan's Multiple Range Test does not require an initial significant ANOVA test makes it a more powerful alternative to most *post hoc* tests (Salkind, 2010).

Although it is better to design a study which allows for the use of parametric procedures (since these tests are more powerful) Heiman (2011) recognises that researchers are sometimes unable to obtain data which fit parametric procedures. When parametric testing is used on data of which the dependant variables are nominal variables, ordinal scores or when the populations are severely skewed, the probability of a Type I error is much larger.

Non-parametric testing does not assume a homogenous variance or normal distribution. However, according to Heiman (2011), these procedures can still be used for inferential statistics. Buthmann (2000) further emphasises that since nonparametric tests do not make assumptions about the distribution of a population these tests safeguard against drawing incorrect inferences. This means that non-parametric testing allows for testing if differences between populations are accurately represented by the differences between samples (Heiman 2011).

According to Statistics Solutions (2017) the Kruskal-Wallis H Test is considered to be the nonparametric alternative to the one-way ANOVA test for significance when the normality assumption does not hold. As with the case of the one-way ANOVA, i.e. the test statistic being omnibus, the Kruskal-Wallis H Test can only provide an indication that a significant difference between at least two or more population means exist. It follows that this test also requires *post hoc* tests to establish which means differ significantly. The Kruskal-Wallis H Test is furthermore a rank-based test and can be used for both ordinal and continuous variables. It is also considered an extension to the Mann-Whitney *U*-Test. (Statistics.laerd.com, 2013[a])

McDonald (2014) however argues that the one-way ANOVA test for significance is not very sensitive to deviations from normality and therefore, based on the author's research, does not recommend the Kruskal-Wallis H Test as a useful alternative to the one-way ANOVA. Although the Kruskal-Wallis H Test does not assume normality is does assume homoscedasticity. If data is therefore heteroscedastic McDonald (2014) suggests that one rather makes use of Welch's ANOVA test. The author also stresses that when original values are substituted by scores during the ranking process, information is lost which in turn decreases the test's power. The Kruskal-Wallis H Test is however preferred to Mood's Median Test since the former is a more powerful test and it takes the ranking of data into account whereas the latter only considers whether a specific data element is smaller or larger than the median (Zaiontz, 2013[b]). It is also worthy to note that Mood's Median Test is furthermore used to establish whether or not the medians of two or more populations are equal (Buthmann, 2000).

For normally distributed data, the Independent Sample *t*-test is used to determine whether or not the means of two samples differ significantly. According to Butler (1985) the Mann-Whitney *U*-test is an alternative to the Independent Sample *t*-test when nonparametric data is considered. The Mann-Whitney *U*-test is a useful method to determine whether or not there is a significant difference in the overall degree of a variable considered for two independent samples, as the test is based on the ranking of scores and assumes an ordinal level of measurement. Since the Mann-Whitney *U*-test is almost as powerful as the *t*-test it is therefore considered a useful alternative when parametric testing is not possible. (Butler, 1985)

2.6FACTORS INFLUENCING PRICE DISTORTIONS THROUGHOUT MARKETS

Zungo (2011) describes price distortions as a state where the price of a commodity strays from the equilibrium price as a result of disturbances in the market system. The author lists several examples of sources of price disturbances in Agriculture, namely: producer and consumer subsidies; taxes and subsidies to factors of production; export taxes; import tariffs; trade quotas and trade policy interventions by government.

The price of grain is determined by considering: domestic demand and supply; regional demand and supply; international demand and supply; international prices as well as the exchange rate (Kirsten *et al.*, 2009). Future price expectations also have an effect on the price of a commodity as it in turn influences demand and supply. Importantly, Kirsten *et al.* (2009) emphasise that markets do not only function based on essential factors but on emotions and perceptions as well.

Geman and Shih (2008) further stresses that it is important to take into consideration that commodities differ from financial securities when considering the implications of determinants of price and therefore exhibit unique characteristics. The prices of commodities are reflected through the balance or imbalance of production and consumption as well as factors such as: quality; balancing stocks; weather events; geopolitical events; seasonality in production or consumption; etc.

Penson *et al.* (1996) adds on that tastes and preferences (or so called noneconomic factors) influence the demand for a product which in turn influence that product's price. Non-economic factors which influence demand include: the composition of the population; attitudes towards nutrition; food safety; lifestyles; technological forces and advertising.

2.7CONCLUDING REMARKS

Soybean meal is considered the dominant protein source in South Africa as national soybean meal consumption constitutes the largest portion of total oilcake production in South Africa (Strydom, Briedenhann and De Jager, 2017). Since the South African boiler industry is the main consumer of locally produced soybean meal Strydom, Briedenhann and De Jager (2017) and Dunn (2017) emphasises the significant role this industry plays in the growth and continued existence of the local soybean meal industry.

Nutrient content in feed is an important aspect when bearing in mind animal nutrition (Srinivasan *et al*., 2013) as protein levels affect animal weight and ultimately animal growth performance (Korver *et al*., n.d.). Soybean meal is considered to be an outstanding source of protein in animal feed diets (Cromwell, 2012). The protein quality in soybean meal is determined when the crushed flakes are heated. Feed formulators therefore need reliable methods to differentiate between good quality soybean meal and under- or over-processed soybean meal (Caprita *et al*., 2010[b]).

In South Africa, feed manufacturers rely only on *in vitro* analysis to determine protein quality of soybean meal as direct analysis of soybean protein quality is challenging in routine operations. Various studies have however drawn the validity of these *in vitro* methods of quality analysis into question (Palić and Grove, 2004; Caprita *et al*., 2010[b]; Palić *et al*., 2008 and Palić *et al.*, 2011). *In vivo* broiler growth performance studies, in which feed quality determinants are analysed, have been recorded for more than 20 years. These studies as well as the findings of Palić and Grove (2004) have shown *in vivo* monogastric animal performance to be the most relevant test for soybean meal quality.

The practice of comparing the growth performance of animals that are fed on local soybean meal mixtures to that of imported soybean meal mixtures, *in vivo*, have yet to be undertaken in South Africa. Two studies could however be found in which the protein quality of soybean meal from various origins were compared, i.e. Chee *et al*. (2001) and Chee *et al*. (2008). These two studies provide ground for most of the methodology in this research study. There are also numerous other studies which tested the growth performance of broilers, *in vivo*, for various feed quality and economic determinations (Ali *et al.*, 1993; Rostagno and Pupa, 1995; Srinivasan *et al*., 2013; Trevisan *et al*., 2014; Tahir, Batal and Pesti, 2015; Hafsa, Basyony and Hassan, 2015; Ali, El Sanhoury and Abdelaziz, 2015; El-Faham, Ali and Abdelaziz, 2016; and Giannenas *et al*., 2017). The latter studies, although not exactly similar to the *in vivo* broiler growth performance trial conducted in this study, support *in vivo* broiler growth performance testing to be a suitable method for determining protein quality in soybean meal and therefore the economic feasibility for different broiler feed diets.

Tests of significance are methods used to make inference about a statement regarding a population. When testing for differences amongst the means for two or more populations the ANOVA is the most commonly used method (Lane, 2007). It is however important to note that a one-way ANOVA test can only indicate that a significant difference between at least two or more of the population means considered exist. This test therefore cannot indicate which population means differ significantly from the other. Consequently, researchers need to make use of multiple comparison *post hoc* tests to determine which population means differ significantly from the other (Statistics.laerd.com, 2013[b]). Some of the most commonly used *post hoc* tests include: Tukey's Test; Duncan's Multiple Range Test; and the Student-Newman-Keuls Test (Statistics How To, 2015[b]).

Although it is better to design a study which allows for the use of parametric procedures Heiman (2011) recognises that researchers are sometimes unable to obtain data which fit parametric procedures. The Kruskal-Wallis H Test is considered to be the nonparametric alternative to the one-way ANOVA test for significance. As with the case of the one-way ANOVA the Kruskal-Wallis H Test can only provide an indication that a significant difference between at least two or more population means exist. It follows that this test also requires *post hoc* tests to establish which means differ significantly. Since the Mann-Whitney *U*-test is a good alternative when nonparametric data is considered (Butler, 1985), the method will be used for the purposes of this study (see Section 3.4).

No record of a significant *in vivo* broiler growth performance study, supporting inferior protein quality claims, could be found by the researcher. From existing work (Panda, 2008) it is evident that the importance of a false perception surrounding a commodity cannot be underemphasised. Therefore, the discounted price received by South African produced soybean meal, based on the perception of underperformance in animal growth, is drawn into question. An *in vivo* soybean meal quality analysis is vital in measuring the economic competitiveness of the South African soybean industry. Quantifying the difference in growth potential between local soybean meal feed options and imported soybean meal feed options could serve as a tool to base a price discount or premium on scientific findings rather than perceptions. Hence the economic impact of the potential growth difference between these two feed options, should be calculated on the back of an *in vivo* study.

CHAPTER 3 METHODOLOGY

3.1 INTRODUCTION

This study was essentially a multi-disciplinary approach involving researchers from the Department of Agricultural Economics, Extension and Rural Development as well as the Department of Animal- and Wildlife Sciences within the Natural and Agricultural Sciences (NAS) Faculty of the University of Pretoria (UP). The methodology of this project stems out of the literature obtained and presented in Chapter 2 of this thesis. Therefore, the methodology consisted out of the following pillars:

(1) An *in vitro* analysis of soybean meal quality;
(2) An *in vivo* broiler growth performance trial testing soybean meal quality;
(3) A statistical analysis of growth performance differences by means of the Mann-Whitney *U*-test; and
(4) An economic feasibility check on the back of the *in vivo* broiler growth performance trial.

The first part of the methodology discusses the research design and protocol, i.e. the *in vitro* analysis of soybean meal quality, the *in vivo* broiler growth performance trial testing soybean meal quality as well as the feed treatments' formulation. Animal requirements, animal housing and care, restraint of the animals as well as administration of all medicines or substances are discussed with reference to the *in vivo* analysis of soybean meal quality.

This is followed by an in-depth explanation of the efficiency calculations (which includes feed conversion and production efficiency) and the statistical analysis of broiler growth performance differences by means of the Mann-Whitney *U*-test. Since the overarching aim of this study was to determine whether or not price distortions in the South African soybean meal value chain could be based on inferior protein quality claims regarding the local product, the economic feasibility of the various soybean meal treatments needed to be determined.

The study recognises its limitations therefore some concluding remarks are made at the end of this Chapter.

It is worthy to note that although this study was done in collaboration with industry participants, the names of these participants, i.e. the manufacturing plants of both the local and imported soybean meals as well as the laboratories were the *in vitro* analysis of soybean meal quality was conducted, may not be revealed. This is due to a non-disclosure agreement signed by the researchers of this study. The non-disclose agreement came as a result of sponsorship obtained by an industry participant.

3.2 RESEARCH DESIGN AND PROTOCOL

3.2.1 *In Vitro* Analysis of Soybean Meal Quality

3.2.1.1 Inter-laboratory In Vitro Analysis of Soybean Meal Quality Result Comparison

As discussed in Section 1.3 and Section 2.4.1, Palić *et al*. (2008) argues that although *in vitro* soybean meal quality test results within laboratories do not differ significantly, *in vitro* test results between laboratories indicate a significant difference. The researchers of this study tested this argument by referring four soybean meal samples to three independent laboratories, with each laboratory replicating the tests three times. These laboratories tested the soybean meal samples for, amongst other, urease levels by means of the UI. The soybean meal in these samples, although obtained from the same source, were not used for the purposes of the broiler growth performance trial. The four soybean meal treatments therefore included:

(1) An imported soybean meal from Argentina;
(2) A RSA day-shift produced soybean meal;
(3) A RSA night-shift produced soybean meal; and
(4) A RSA under-processed soybean meal product.

3.2.1.2 Broiler Growth Performance Trial In Vitro Results

Section 2.3 of this thesis explains that protein quality within soybean meal depends on the optimisation of protein digestibility whilst simultaneously reducing anti-nutritional factors. Since the establishment of protein content and quality is necessary in order to formulate feed as to achieve optimal growth performance for all animals, soybean meal samples underwent substantial laboratory testing. The *in vitro* analysis of soybean meal quality included: a general analysis testing for dry matter, moisture and ash content; a nitrogen analysis; fat and fibre analysis; as well as a urease activity check.

According to Reiling (2011) water and dry matter constitutes the two major portions of feed. Whilst water is a physiologically crucial element, nutrients (i.e. protein, energy, vitamins and minerals) are found in the dry matter of feed. Furthermore, feed ingredients are dispensed to animals according to the weight of the feed. The weight of a certain feed ingredient is determined either from the moisture present in the feed or from the dry matter portion. When individual feed ingredients are fed according to the weight of the feed it is only accurately done if the moisture content in the feed is the same as the moisture content when the ration was formulated. Therefore, feed formulators need to know the exact moisture content of a feed ingredient since moisture content affects the weight of the feed, but in turn moisture content does not provide any nutritional value to the animal (Articles.extension.org, 2012). Lastly, Ismail (2017) adds on that ash content provides a proximate analysis for mineral content present in the feed and therefore forms an integral part in the quality determination of certain feed ingredients. The dry matter and ash content of the soybean meal was analysed according to the official method of analysis 942.05 of the Association of Analytical Communities (AOAC), whereas moisture content was determined according to the official method of analysis 943.01 of the AOAC (Horwitz, 2000).

The analysis of nitrogen in animal feed is important since it provides an indication of the protein content (meal crude protein) in the feed (Gerhardt.de, 2015). Krotz *et al*. (2016) further argue that protein analysis in animal feed is an issue of economic and social significance due to the nutritional, health and safety, legal, as well as the economic implications it holds for animal feed manufacturers. Nitrogen content was determined according to the official method of analysis 988.05 of the AOAC (Horwitz, 2000).

Crude fat, also termed ether extract, refers to the amount of fat and fat-solubles in feed. It furthermore provides an indication of the fat-soluble vitamins present in the feed (DuPonte, 1998). Crude fibre content on the other hand provides an indication of the digestibility of the feed and therefore the energy present in the feed. During the determination of crude fibre, carbohydrates are divided into digestible and indigestible fractions. Therefore, when the crude fibre content in feed is high the energy content of the feed is low hence the crude fibre is considered indigestible (Critical Factors in Determining Fibre in Feeds and Forages, 2017). Crude fat content in the soybean meal was determined according to the official method of analysis 920.39 of the AOAC whereas crude fibre content was determined according to the official method of analysis 962.09 of the AOAC (Horwitz, 2000).

Trypsin inhibitors prevent the digestion of protein by inhibiting the activity of enzymes, i.e. trypsin and chymotrypsin (Hill, 2003). Soybean meal furthermore contains the enzyme urease that hydrolyses urea to produce ammonia and carbon dioxide. By heating (cooking) the soybean meal urease is destroyed and this destruction of urea is highly correlated to the destruction of trypsin inhibitors and anti-nutritional factors. Since the growth in monogastric animals is reduced when fed on feed containing high levels of raw soybean meal (Hill, 2003), the primary purpose of the urease activity check is to determine whether or not soybean meal has been sufficiently cooked (Caprita *et al.*, 2010[b]). The urease activity check was performed according to the official method of analysis 984.13 of the AOAC (Horwitz, 2000).

3.2.2 *In Vivo* Analysis of Soybean Meal Quality

The protocol for the *in vivo* trial was approved by the Animal Ethics Committee of the NAS Faculty of the UP (reference number EC032-14).

3.2.2.1 Animal Requirements

As the broiler industry is the largest consumer of soybean meal in the world, broiler chickens were used for the *in vivo* trial, i.e. the Ross 308. The Ross 308 is a fast growing, robust and feed efficient broiler (Ross broiler performance objectives, 2012). Consistency throughout the trial was improved by placing day old chicks in single-sex populations (Ross Broiler Management Manual, 2009). Ross 308 broiler chicks can be sexed by looking at the birds' feather development on the wing tip on the day of hatch. Since males grow faster, are more feed efficient and have less carcass fat than females, the *in vivo* trial consisted only out of male birds.

3.2.2.2 Animal Housing and Care

The *in vivo* boiler growth performance trial was conducted in the Broiler Research Facility and Poultry Metabolic House on the UP's Experimental Farm situated in Hatfield. Day old chicks of good quality and weight (between 40 and 42 grams) were bought from Eagles Pride Hatchery (PTY) Ltd, a commercial hatchery in Pretoria. Prior to placing the day-old chicks, the broiler house was: washed using a high-pressure pump; disinfected by spraying Vercon S on all areas; and pre-heated to the comfort zone of broiler chicks, i.e. 36°C ambient temperature and at least 34°C litter (floor) temperature. Clean pine shavings were spread on the floor of the pens as to absorb waste and to help with insulation from the concrete floor.

Regardless of dietary treatment large variations may exist in the growth, feed conversion and liveability between individual birds, sexes and seasons. Therefore, adequate quantities of birds and replications are needed to minimise the risk of producing a Type I error. The broiler house was therefore equipped with 64 adjacent pens (each pen being an experimental unit). All pens were stocked with 26 birds, totalling to 1 664 birds. Stocking density was lower than subscribed in section 2.4.1 of the South African Poultry Association's Code of Practice (2012) as to ensure wellbeing as well as enough available floor space for the birds.

Housing and care of the birds were done in such a way as to represent commercial conditions as far as possible. All birds had free access to feed and water at all times, i.e. *ad libitum*, provided by a tube feeder and bell drinker. Automatic heaters provided the optimum temperature to keep the birds in their desired comfort zone. Ventilation was controlled manually as to ensure optimum oxygen supply and removal of ammonia and carbon dioxide. Up to a weight of approximately 160g birds were provided with 1-hour darkness and 23 hours light, thereafter the birds received 8 hours of darkness in a 24-hour period.

Monitoring of birds occurred on a daily basis by the principal investigator as well as students and staff on the farm as to ensure optimum growing conditions and bird comfort. Birds were observed at least three times per day by the Experimental Farm's Poultry Manager. Birds were considered abnormal, diseased, or ill if they showed signs of lethargy, disease symptoms or were injured. Birds in a poor condition were observed more frequently. Birds that were considered abnormal, ill, or unable to move without difficulty (e.g. sprayed legs) by stipulation were humanely euthanized.

Feed intake was measured on a weekly basis and mortalities were measured on a daily basis. This was done in order to calculate feed conversion and to allow for adjustments when determining the production efficiency of the different soybean meal treatments.

3.2.2.3 Restraint of the Animals

Birds were weighed as a group (per pen) on the day of placement and every week after placement i.e. days 7, 14, 21, 28 and day 35, which was the end of the trial. Birds were placed into clean, specifically designed portable bird weighing crates when they were weighed. Birds were caught individually and handled with both hands for full body support. Each crate contained a lid which was secured to prevent harm to the birds.

At the end of the trial the birds were placed inside the same crates used for weighing and transported to the abattoir. No more than 8 birds were placed per transport crate. Birds were loaded onto a specifically designed truck to ensure sufficient airflow to the birds and transported for a maximum of 2 hours.

3.2.2.4 Administration of All Medicines/ Substances

A coccidiostat (Salinomycin) was added to the feed at a rate of 500g per ton of feed, whereas a broad-spectrum antibiotic (Zinc bacitracin) was added to the feed at a rate of 333g per ton of feed. Chicks were furthermore vaccinated according to the Experimental Farm’s vaccination programme as advised by a responsible veterinarian with poultry experience. The Experimental Farm’s Poultry Manager was responsible for carrying out the appropriate vaccination programme.

3.2.3 Feed Treatments’ Formulation

Feed treatments, mixed by Pennville Animal Feeds, were formulated to achieve optimum performance for all birds. A coccidiostat and broad-spectrum antibiotic was included in the treatments to ensure the health of the birds and to simulate standard commercial conditions as closely as possible. The feed treatments were formulated using values of the proximate analyses from the various batches of soya as to ensure that the feed of the different treatments contained similar amounts of macronutrients. Therefore, the only difference between experimental feeds was the specific batch of soybean meal used.

Treatment designation of pens was a completely randomised block design in order to minimise the influence of variations in the housing environment. Four soybean meal mixtures, to provide enough variation in quality as to determine the correlation between *in vivo* performance data and *in vitro* values, were used and allocated to 16 pens each. The soybean meal feed mixtures included:

(1) An imported soybean meal from Argentina (positive control);
(2) A RSA day-shift produced soybean meal;
(3) A RSA night-shift produced soybean meal and

(4) A RSA under-processed soybean meal product (negative control).

3.3 EFFICIENCY CALCULATIONS

3.3.1 Feed Conversion Ratio

The feed conversion ratio (FCR) provides an indication of how well feed intake is converted into live body weight (Optimizing Broiler FCR, 2011). Differently stated, the FCR provides an indication of how much kilogram feed is required in order to produce one kilogram of meat. A lower feed conversion is deemed preferable since it indicates that less feed is required to produce a certain amount of carcass weight. Equation 3.1 provides the method for calculating the FCR.

$$FCR = \frac{Feed\ intake\ (kg)}{Live\ weight\ gain\ (kg)}$$

Equation 3.1 Feed conversion ratio

3.3.2 Production Efficiency Factor

The production efficiency factor (PEF), also known as the European Broiler Index (EBI), is the preferred method for determining *in vivo* growth performance as it does not only focus on weight gain but also takes feed consumption and mortality rates into consideration (Equation 3.2). A higher PEF indicates better technical performance (Ross Broiler Management Manual, 2009).

$$PEF = \frac{Liveability\ \times Live\ Weight\ (kg)}{Age\ in\ days\ \times FCR} \times 100$$

Equation 3.2 Production efficiency factor[4]

[4] Where liveability refers to the percentage survival rate.

3.4 STATISTICAL TESTING

Because each soybean meal feed treatment was assigned to only 16 pens, the sample was deemed too small for parametric testing. Thus, non-parametric testing was done, by means of the Mann-Whitney *U*-test, in order to determine if the growth performance of birds which were fed on different feed treatments differed significantly.

Since the Mann-Whitney *U*-test is almost as powerful as the *t*-test, it is a suitable alternative when parametric testing is not possible. The Mann-Whitney *U*-test is a useful method to determine whether or not there is a significant difference in the overall degree of a variable considered for two independent samples. Since the test is based on the ranking of scores it assumes an ordinal level of measurement. (Butler, 1985)

When setting up a hypothesis under the Mann-Whitney *U*-test, the null hypothesis states that the treatments being compared are from the same population with analogous distributions. This means that when combining the samples and assigning ranks to all variables, the scores from the two samples should be spread randomly. The samples were therefore combined and ranked so that each observation was assigned a rank, with the first rank allocated to the smallest observation.

Since all samples were of equal size ($N_1 = N_2$), the test statistic *U*, for the Mann-Whitney *U*-test, was calculated by determining the sum of the ranks for the two samples (R_1 and R_2). These values were then substituted into the following two equations and the smaller of the two values was regarded as *U*, the test statistic:

$$U_1 = N_1 N_2 + \frac{N_1(N_1 + 1)}{2} - R_1$$

And

$$U_2 = N_1 N_2 + \frac{N_2(N_2 + 1)}{2} - R_2$$

Equation 3.3 The Mann-Whitney U-test statistic

The critical value for a one-tailed test at a 0.5% level of significance is 83. Accordingly, the null hypothesis was rejected if the test statistic was less than or equal to the critical value.

In order to establish whether or not broilers fed on feed mixtures containing soybean meal from various origins showed significant growth performance differences, hypotheses regarding the following were tested for:

(1) Weekly average live bird body weight (Kg) per treatment;
(2) Mortality rate (%) per treatment;
(3) Cumulative feed consumption (Kg) per treatment;
(4) FCR per treatment; and
(5) PEF per treatment.

3.4.1 Weekly Average Live Bird Body Weight (Kg) per Treatment

(1) H_0: The weekly average live weight (ALW) of birds fed on the Argentine diet = the weekly ALW of birds fed on the RSA day-shift diet.
H_A: The weekly ALW of birds fed on the Argentine diet is significantly higher than the weekly ALW of birds fed on the RSA day-shift diet (one-tailed test).
(2) H_0: The weekly ALW of birds fed on the Argentine diet = the weekly ALW of birds fed on the RSA night-shift diet.
H_A: The weekly ALW of birds fed on the Argentine diet is significantly higher than the weekly ALW of birds fed on the RSA night-shift diet (one-tailed test).
(3) H_0: The weekly ALW of birds fed on the Argentine diet = the weekly ALW of birds fed on the RSA under-processed diet.
H_A: The weekly ALW of birds fed on the Argentine diet is significantly higher than the weekly ALW of birds fed on the RSA under-processed diet (one-tailed test).

(4) H_0: The weekly ALW of birds fed on the RSA day-shift diet = the weekly ALW of birds fed on the RSA night-shift diet.

H_A: The weekly ALW of birds fed on the RSA day-shift diet is significantly higher than the weekly ALW of birds fed on the RSA night-shift diet (one-tailed test).

(5) H_0: The weekly ALW of birds fed on the RSA day-shift diet = the weekly ALW of birds fed on the RSA under-processed diet.

H_A: The weekly ALW of birds fed on the RSA day-shift diet is significantly higher than the weekly ALW of birds fed on the RSA under-processed diet (one-tailed test).

(6) H_0: The weekly ALW of birds fed on the RSA night-shift diet = the weekly ALW of birds fed on the RSA under-processed diet.

H_A: The weekly ALW of birds fed on the RSA night-shift diet is significantly higher than the weekly ALW of birds fed on the RSA under-processed diet (one-tailed test).

3.4.2 Mortality Rate (%) per Treatment

(7) H_0: The mortality rate of the Argentine diet = the mortality rate of the RSA day-shift diet.

H_A: The mortality rate of the Argentine diet is significantly lower than the mortality rate of the RSA day-shift diet (one-tailed test).

(8) H_0: The mortality rate of the Argentine diet = the mortality rate of the RSA night-shift diet.

H_A: The mortality rate of the Argentine diet is significantly higher than the mortality rate of the RSA night-shift diet (one-tailed test).

(9) H_0: The mortality rate of the Argentine diet = the mortality rate of the RSA under-processed diet.

H_A: The mortality rate of the Argentine diet is significantly higher than the mortality rate of the RSA under-processed diet (one-tailed test).

(10) H_0: The mortality rate of the RSA day-shift diet = the mortality rate of the RSA night-shift diet.

H_A: The mortality rate of the RSA day-shift diet is significantly higher than the mortality rate of the RSA night-shift diet (one-tailed test).

(11) H_0: The mortality rate of the RSA day-shift diet = the mortality rate of the RSA under-processed diet.

H_A: The mortality rate of the RSA day-shift diet is significantly higher than the mortality rate of the RSA under-processed diet (one-tailed test).

(12) H_0: The mortality rate of the RSA night-shift diet = the mortality rate of the RSA under-processed diet.

H_A: The mortality rate of the RSA night-shift diet is significantly lower than the mortality rate of the RSA under-processed diet (one-tailed test).

3.4.3 Cumulative Feed Consumption (Kg) per Treatment

(13) H_0: The feed consumption of the Argentine diet = the feed consumption of the RSA day-shift diet.

H_A: The feed consumption of the Argentine diet is significantly higher than the feed consumption of the RSA day-shift diet (one-tailed test).

(14) H_0: The feed consumption of the Argentine diet = the feed consumption of the RSA night-shift diet.

H_A: The feed consumption of the Argentine diet is significantly lower than the feed consumption of the RSA night-shift diet (one-tailed test).

(15) H_0: The feed consumption of the Argentine diet = the feed consumption of the RSA under-processed diet.

H_A: The feed consumption of the Argentine diet is significantly higher than the feed consumption of the RSA under-processed diet (one-tailed test).

(16) H_0: The feed consumption of the RSA day-shift diet = the feed consumption of the RSA night-shift diet.

H_A: The feed consumption of the RSA day-shift diet is significantly lower than the feed consumption of the RSA night-shift diet (one-tailed test).

(17) H_0: The feed consumption of the RSA day-shift diet = the feed consumption of the RSA under-processed diet.

H_A: The feed consumption of the RSA day-shift diet is significantly lower than the feed consumption of the RSA under-processed diet (one-tailed test).

(18) H_0: The feed consumption of the RSA night-shift diet = the feed consumption of the RSA under-processed diet.

H_A: The feed consumption of the RSA night-shift diet is significantly higher than the feed consumption of the RSA under-processed diet (one-tailed test).

3.4.4 Feed Conversion Ratio per Treatment

(19) H_0: The FCR of the Argentine diet = the FCR of the RSA day-shift diet.

H_A: The FCR of the Argentine diet is significantly lower than the FCR of the RSA day-shift diet (one-tailed test).

(20) H_0: The FCR of the Argentine diet = the FCR of the RSA night-shift diet.

H_A: The FCR of the Argentine diet is significantly higher than the FCR of the RSA night-shift diet (one-tailed test).

(21) H_0: The FCR of the Argentine diet = the FCR of the RSA under-processed diet.

H_A: The FCR of the Argentine diet is significantly higher than the FCR of the RSA under-processed diet (one-tailed test).

(22) H_0: The FCR of the RSA day-shift diet = the FCR of the RSA night-shift diet.

H_A: The FCR of the RSA day-shift diet is significantly higher than the FCR of the RSA night-shift diet (one-tailed test).

(23) H_0: The FCR of the RSA day-shift diet = the FCR of the RSA under-processed diet.

H_A: The FCR of the RSA day-shift diet is significantly higher than the FCR of the RSA under-processed diet (one-tailed test).

(24) H_0: The FCR of the RSA night-shift diet = the FCR of the RSA under-processed diet.

H_A: The FCR of the RSA night-shift diet is significantly higher than the FCR of the RSA under-processed diet (one-tailed test).

3.4.5 Production Efficiency Factor per Treatment

(25) H_0: The PEF of the Argentine diet = the PEF of the RSA day-shift diet.

H_A: The PEF of the Argentine diet is significantly higher than the PEF of the RSA day-shift diet (one-tailed test).

(26) H_0: The PEF of the Argentine diet = the PEF of the RSA night-shift diet.

H_A: The PEF of the Argentine diet is significantly lower than the PEF of the RSA night-shift diet (one-tailed test).

(27) H_0: The PEF of the Argentine diet = the PEF of the RSA under-processed diet.

H_A: The PEF of the Argentine diet is significantly higher than the PEF of the RSA under-processed diet (one-tailed test).

(28) H_0: The PEF of the RSA day-shift diet = the PEF of the RSA night shift diet.

H_A: The PEF of the RSA day-shift diet is significantly lower than the PEF of the RSA night-shift diet (one-tailed test).

(29) H_0: The PEF of the RSA day-shift diet = the PEF of the RSA under-processed diet.

H_A: The PEF of the RSA day-shift diet is significantly lower than the PEF of the RSA under-processed diet (one-tailed test).

(30) H_0: The PEF of the RSA night-shift diet = the PEF of the RSA under-processed diet.

H_A: The PEF of the RSA night-shift diet is significantly higher than the PEF of the RSA under-processed diet (one-tailed test).

3.5 ECONOMIC FEASIBILITY

The significance of determining the economic feasibility lies within the principle that it is possible to determine an approximate price discount or premium for South African soybean meal, on the back of the *in vivo* broiler growth performance trial. The economic feasibility per treatment was determined by considering the producer realisation and total cost of live weight gain (Equation 3.4).

$$Total\ profit = producer\ realisation - total\ live\ weight\ gain\ cost \qquad (1)\text{-}(2)$$

Equation 3.4 Economic feasibility per treatment

Where

$$Producer\ realisation = \ broiler\ meat\ price\ \times\ meat\ produced \qquad (1)$$

And

$$Total\ live\ weight\ gain\ cost = Total\ variable\ cost + total\ fixed\ cost \qquad (2)$$

Where

$$Total\ variable\ cost = feed\ consumption\ \times\ average\ meal\ price$$

And

$$Total\ fixed\ cost = day\ old\ chicks +\ vaccination + energy +\ labour + housing +\ other$$

The cost of day-old chicks as well as vaccination costs was deemed fixed for all treatments since each treatment was allocated the same number of day-old-chicks. Furthermore, the cost of energy, labour and housing was also deemed fixed for all treatments since the treatment designation of pens was a completely randomised block design. Thus, due to the characteristics of the research design, the fixed costs were excluded when determining the difference between the economic feasibility of the various soybean meal feed treatments.

3.6 LIMITATIONS

This study recognises that the findings are limited since only one *in vivo* growth performance trial was performed (due to a lack of funding). This limitation means that seasonal fluctuations in soybeans, soybean meal as well as broiler production could possibly have an effect on the outcomes of this study.

Furthermore, conducting only one *in vivo* trial means that this study only made use of one supplier of Argentine soybean meal and one supplier of RSA soybean meal. Therefore, the findings of this study cannot be used to make inference about soybean meal produced by the entire soybean meal industry. As a result, industry participants should prompt to analyse various local sources of soybean meal in order to determine which local protein sources should be used when formulating animal feed.

Other limitations relate to time and labour restrictions. Birds were caught, weighed and released within no more than 5 minutes as to minimise stress. The consequence is a large number of people that needed to be managed with extreme caution as to ensure that all responsibilities were carried out with precision and care.

Lastly, as discussed in Section 2.3, crushed soybean flakes need to be adequately processed (cooked/ heated) as to reduce anti-nutritional factors present in raw soybeans. In turn, over-processing of soybean meal reduces protein digestibility and the availability of amino acids. The UI is used to determine whether or not soybean meal has been under-processed, whereas the KOH PS and PDI is used to determine if soybean meal has been over-processed. This study only tested for under-processed soybean meal, which means that if broilers fed on RSA day-shift, RSA night-shift or imported Argentine meal treatments showed similar growth performance to broilers fed on the under-processed product, researchers would not be able to ascertain the cause. It could be that the aforementioned treatments is over-processed or that under-processed soybean meal might not have such a significant influence on broiler growth performance as stated in literature.

3.7 CONCLUDING REMARKS

The research design and protocol for determining soybean meal quality was essentially based on two pillars, i.e. an *in vivo* broiler growth performance trial which was accompanied by an *in vitro* analysis of soybean meal quality. The *in vitro* analysis of soybean meal quality included: a general analysis testing for dry matter, moisture and ash content; a nitrogen analysis; fat and fibre analysis; as well as a urease activity check.

Four soybean meal samples, i.e. an Argentine sample (positive control), RSA day-shift produced, RSA night-shift produced and RSA under-processed soybean meal sample (negative control), were fed to Ross 308 broilers, over a period of 35 days, for the purposes of the *in vivo* trial. Response parameters analysed during the *in vivo* boiler growth performance trial included: average weekly live bird body weight; mortality rates per treatment; and cumulative feed consumption. These parameters were used to determine the FCR and PEF.

The testing for any significant growth performance differences between the various soybean meal treatments was done by means of the Mann-Whitney *U*-test, since the samples obtained during the *in vivo* trial were too small for parametric testing. The results from the *in vivo* trial were also used to determine the economic feasibility of the various soybean meal treatments.

CHAPTER 4 DATA DISCUSSION AND INTERPRETED RESULTS

4.1 INTRODUCTION

Data collected from the controlled *in vivo* broiler growth performance experiment was used for the purposes of this study. Population parameter response variables for analysis included: average weekly live bird body weight; mortality rates per treatment; and cumulative feed consumption.

This chapter firstly compares the results obtained from the inter-laboratory *in vitro* analysis of soybean meal quality. Thereafter the *in vitro* test results, of the various soybean meal feed mixtures used during the *in vivo* broiler growth performance trial, is analysed. This is followed by an in-depth discussion of the *in vivo* trial results. This is accompanied by a statistical analysis, testing for any significant broiler growth performance differences between the various feed options. The economic feasibility per treatment is calculated on the back of the *in vivo* broiler growth performance trial. Lastly some concluding remarks are made.

4.2 INTER-LABORATORY *IN VITRO* ANALYSIS OF SOYBEAN MEAL QUALITY RESULT COMPARISON

Although there were not enough data points to allow for statistical significance testing, Janse van Rensburg (2018) regards a test result difference of more than 5% to be meaningful. When analysing test results of the UI between the three laboratories it seems as if the argument of Palić *et al*. (2008) holds (Table 4.1).

Table 4.1 Inter-laboratory UI results comparison

Treatment	Laboratory number			% Difference in results between laboratories		
	LAB 1	LAB 2	LAB 3	LAB 1 TO LAB 2	LAB 1 TO LAB 3	LAB 2 TO LAB 3
Argentine	0.143	0.106	0.105	25.67%	26.58%	1.23%
RSA day-shift	0.594	0.460	0.475	22.53%	19.94%	3.24%
RSA night-shift	0.526	0.260	0.340	50.57%	35.38%	23.51%
Under-processed	1.874	1.832	2.009	2.23%	6.73%	8.81%

On the other hand, when comparing test results of the UI within each laboratory it seems as if test results within a laboratory also differs meaningfully (Table 4.2; Table 4.3; and Table 4.4). The following questions therefore present:

(1) Are laboratory testing standards adhered to at all times?

(2) Are current sampling practices efficient?

(3) Is the UI a reliable indicator of under-processed soybean meal?

Table 4.2 UI test results comparison within Laboratory 1

Treatment	Sample ID number			% Difference in results within laboratory 1		
	ID 1	ID 2	ID 3	ID 1 TO ID 2	ID 1 TO ID 3	ID 2 TO ID 3
Argentine	0.129	0.154	0.139	16.23%	7.19%	9.74%
RSA day-shift	0.529	0.537	0.607	1.49%	12.85%	11.53%
RSA night-shift	0.344	0.407	0.650	15.48%	47.08%	37.38%
Under-processed	1.859	1.824	1.811	1.88%	2.58%	0.71%

Table 4.3 UI test results comparison within Laboratory 2

Treatment	Sample ID number			% Difference in results within laboratory 2		
	ID 1	ID 2	ID 3	ID 1 TO ID 2	ID 1 TO ID 3	ID 2 TO ID 3
Argentine	0.060	0.150	0.100	60.00%	40.00%	33.33%
RSA day-shift	0.470	0.450	0.480	4.26%	2.08%	6.25%
RSA night-shift	0.300	0.230	0.220	23.33%	26.67%	4.35%
Under-processed	1.800	1.790	1.880	0.56%	4.26%	4.79%

Table 4.4 UI test results comparison within Laboratory 3

Treatment	Sample ID number			% Difference in results within laboratory 3		
	ID 1	ID 2	ID 3	ID 1 TO ID 2	ID 1 TO ID 3	ID 2 TO ID 3
Argentine	0.097	0.089	0.080	18.04%	18.04%	10.67%
RSA day-shift	0.464	0.500	0.468	7.21%	0.96%	6.31%
RSA night-shift	0.327	0.344	0.357	4.95%	8.54%	3.78%
Under-processed	2.017	1.989	2.023	1.41%	0.27%	1.68%

4.3 BROILER GROWTH PERFORMANCE TRIAL *IN VITRO* RESULTS

According to McDonald *et al.* (2011) the chemical composition (general analysis) for soybean meal dry matter (DM) should be 90g/ 100g with an ash content of 6.20g/ 100g. The DM content for RSA day-shift soybean meal was the lowest (91.603g/ 100g), followed by the Argentine meal (92.130g/ 100g), RSA night-shift meal (92.155g/ 100g) and lastly the RSA under-processed meal (92.699g/ 100g) (Table 4.5). With regards to ash content the RSA day-shift soybean meal again had the lowest score (5.393g/ 100g) followed by the RSA under-processed meal (5.511g/ 100g), Argentine meal (5.638g/ 100g) and lastly the RSA night-shift meal (5.671g/ 100g) (Table 4.5). Although the dry matter content for all four soybean meal samples were slightly higher than the requirements, and the ash content slightly lower, all four soybean meal samples tested within industry requirements.

Table 4.5 *In vitro* trial results: general and nitrogen analysis (g/ 100g)

Treatment	g/ 100g						
	DM	Moisture	Ash	Nitrogen	CP	CF	EE
Argentine	92,130	7,870	5,638	7,391	46,196	4,849	2,057
RSA day-shift	91,603	8,397	5,393	7,304	45,652	4,749	2,004
RSA night-shift	92,155	7,845	5,671	7,446	46,536	4,625	1,894
RSA under-processed	92,699	7,301	5,511	7,614	47,586	4,543	1,690

The chemical composition of soybean meal with respect to crude protein (nitrogen analysis) should be 50.30g/ 100g (McDonald *et al.*, 2011). The crude protein for RSA day-shift soybean meal was the lowest (45.652g/ 100g) followed by the Argentine meal (46.196g/ 100g), the RSA night-shift meal (46.536g/ 100g) and lastly the RSA under-processed meal (47.586g/ 100g) (Table 4.5). Although the crude protein content for all four soybean meal samples were slightly lower than the industry requirements, all four samples met the industry requirements.

Table 4.6 represents an average calculation of the urease activity for all four soybean meal samples tested. Soybeans have been sufficiently cooked if the pH difference is less than 0.3 pH units. A pH value between 0.3 and 0.5 is uncertain and a pH difference of more than 0.5 means that the soybeans have been undercooked (Caprita *et al.*, 2010[b]). The test results confirm that the RSA under-processed sample was indeed undercooked (1.803) and that the other three samples had been adequately processed, i.e. Argentine meal (0.176), RSA day-shift meal (0.290) and RSA night-shift meal (0.254). Unfortunately, the UI is not useful to determine whether or not the RSD day-shift, RSA night-shift and Argentine soybean meal were over-processed.

Table 4.6 *In vitro* trial results: urease activity check

Treatment	With urea	PO4 Buffer	pH-difference	Average Difference
Argentine	7,229	7,053	0,176	0,176
RSA day-shift	7,354	7,064	0,290	0,290
RSA night-shift	7,330	7,076	0,254	0,254
RSA under processed	8,844	7,040	1,803	1,803

4.4 BROILER GROWTH PERFORMANCE TRIAL *IN VIVO* RESULTS

4.4.1 Weekly Average Live Bird Body Weight per Treatment

Figure 4.1 below provides the ALW of a broiler fed on a specific diet of soybean meal. Although ALW at day 35 of birds fed on soybean meal diets originating from Argentina were numerically higher (2.181Kg) than the ALW of birds which were fed soybean meal diets originating from the RSA, i.e. RSA day-shift soybean meal (2.169Kg), RSA night-shift meal (2.163Kg) and RSA under-processed meal (2.147Kg), there were no significant differences in the ALW of a bird at day 35 between any of the soybean meal diets (Table 4.7).

According to Phillips (2014) the ALW of broilers at day 35 in South Africa is, on average, 1.8Kg and 2.7Kg in Argentina at day 49. It can therefore be concluded that the ALW at day 35 of a broiler fed during this *in vivo* broiler growth performance trial was meaningfully higher than the industry standards.

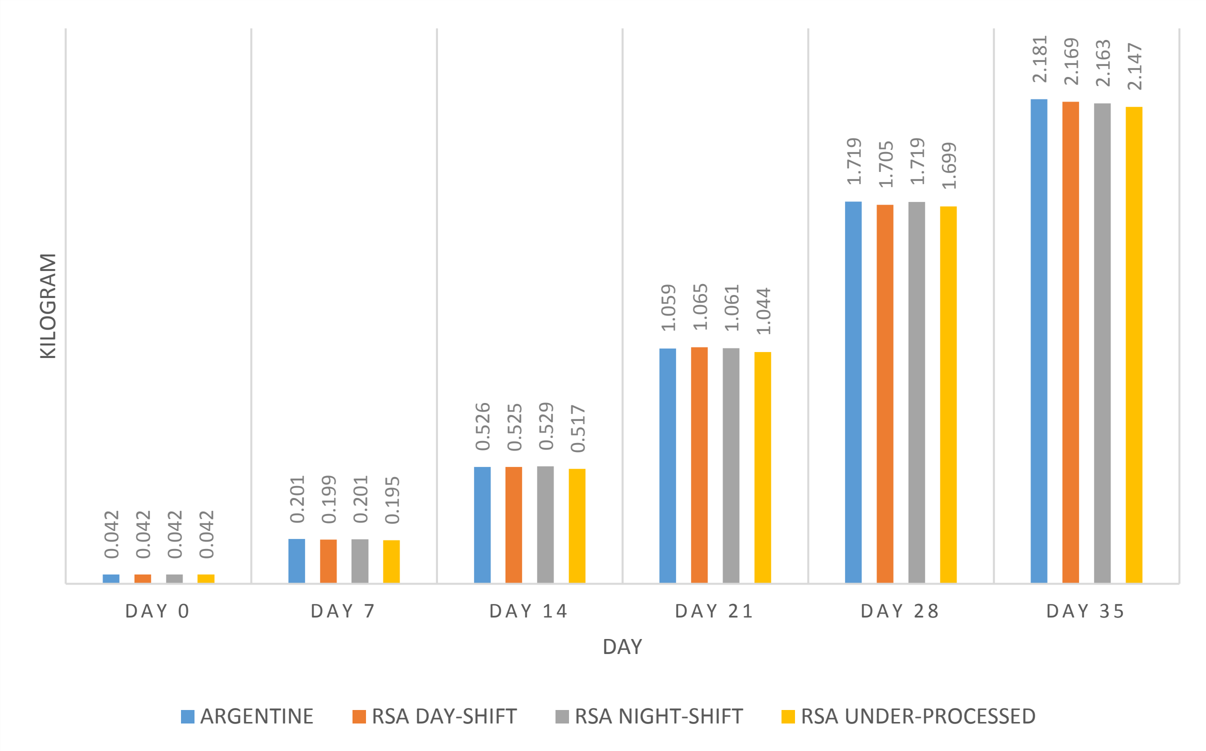

Figure 4.1 Weekly average live bird body weight (Kg) per treatment

Table 4.7 Statistical significance testing: Weekly average live bird body weight (Kg) per treatment

Test	R_1	R_2	R	U_1	U_2	U	Test statistic	Reject H_0
1	280,0	248,0	528,0	112,0	144,0	112,0	112,0	Cannot reject
2	278,5	249,5	528,0	113,5	142,5	113,5	113,5	Cannot reject
3	302,0	226,0	528,0	90,0	166,0	90,0	90,0	Cannot reject
4	261,5	266,5	528,0	130,5	125,5	125,5	125,5	Cannot reject
5	286,0	242,0	528,0	106,0	150,0	106,0	106,0	Cannot reject
6	281,5	246,5	528,0	110,5	145,5	110,5	110,5	Cannot reject

4.4.2 Mortality Rate (%) per Treatment

The mortality rate during the broiler growth performance trial was 13.82% of which 80.87% were due to natural deaths and 19.13% due to culls. According to the Poultry Hub (2018) the industry standard for mortality rates are usually between 3% and 5%. The mortality rates of this study therefore differed meaningfully from the industry standards.

Furthermore, 10.43% of the mortalities occurred during the first week of the trial and 20.87%, 16.52%, 26.96% and 25.22% in weeks two to five respectively (Figure 4.2). The Poultry Hub (2018) further states that most of the mortalities during a broiler production cycle should occur in the first week. The weekly mortality distribution of this study is again in contrast to the industry standard as most of this study's mortalities occurred in week four and the least of the mortalities in week one.

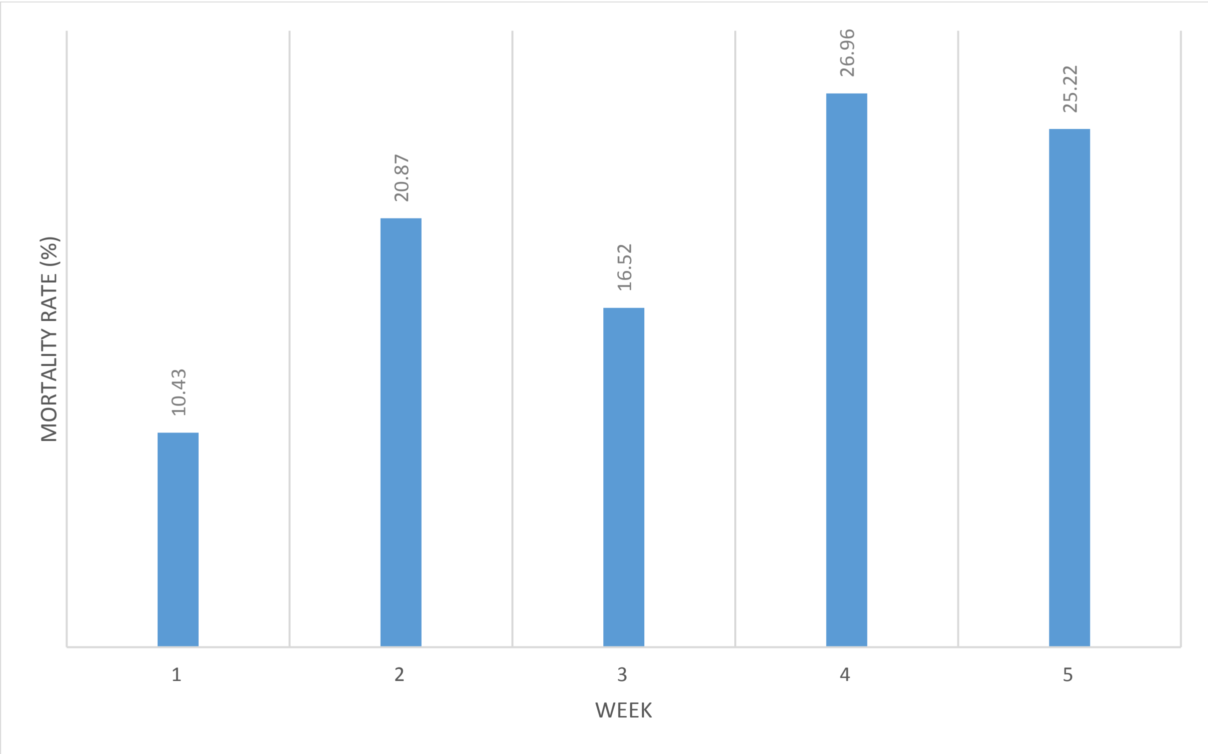

Figure 4.2 Mortality rate (%) per week

Treatments containing RSA night-shift soybean meal showed the lowest mortality rate (11.06%), followed by the RSA under-processed diet (12.50%), Argentine diet (14.90%) and lastly RSA day-shift diet (16.83%) (Figure 4.3). Mortalities which occurred in pens where diets containing RSA night-shift soybean meal were fed was significantly lower than the mortalities which occurred in pens where diets containing RSA day-shift soybean meal were fed (Table 4.8).

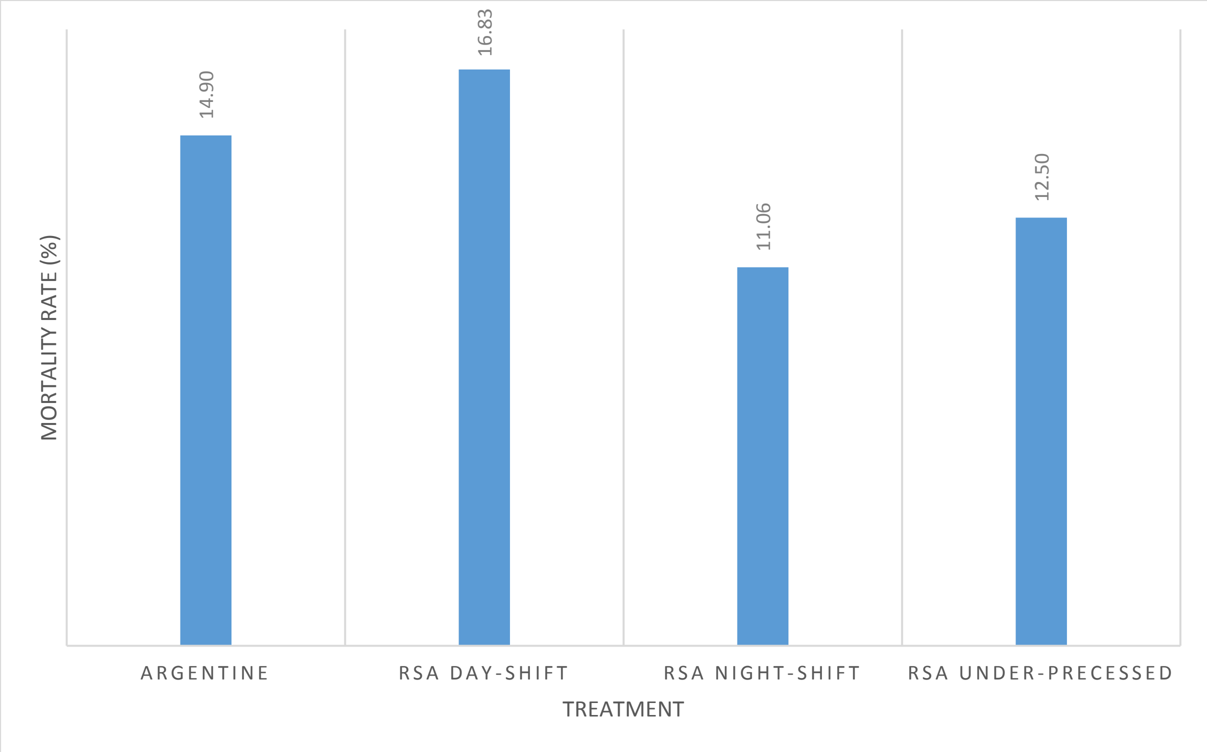

Figure 4.3 Mortality rate (%) per treatment

Table 4.8 Statistical significance testing: Mortality rate (%) per treatment

Test	**R_1**	**R_2**	**R**	**U_1**	**U_2**	**U**	**Test statistic**	**Reject H_0**
7	242,5	282,5	525,0	149,5	109,5	109,5	109,5	Cannot reject
8	303,0	225,0	528,0	89,0	167,0	89,0	89	Cannot reject
9	290,5	237,5	528,0	101,5	154,5	101,5	101,5	Cannot reject
10	318,5	209,5	528,0	73,5	182,5	73,5	73,5	Reject
11	302,5	225,5	528,0	89,5	166,5	89,5	89,5	Cannot reject
12	254,5	273,5	528,0	137,5	118,5	118,5	118,5	Cannot reject

4.4.3 Feed Consumption (Kg) per Treatment

Even though the feed consumption of the RSA night-shift and Argentine soybean meal diets (i.e. 1806.73Kg and 1805.86Kg respectively) were numerically higher than the feed consumption of the under-processed and RSA day-shift soybean meal diets (i.e. 1780.85Kg and 1780.35Kg respectively), there were no significant differences in the feed consumption of the various soybean meal treatments (Figure 4.4) (Table 4.9).

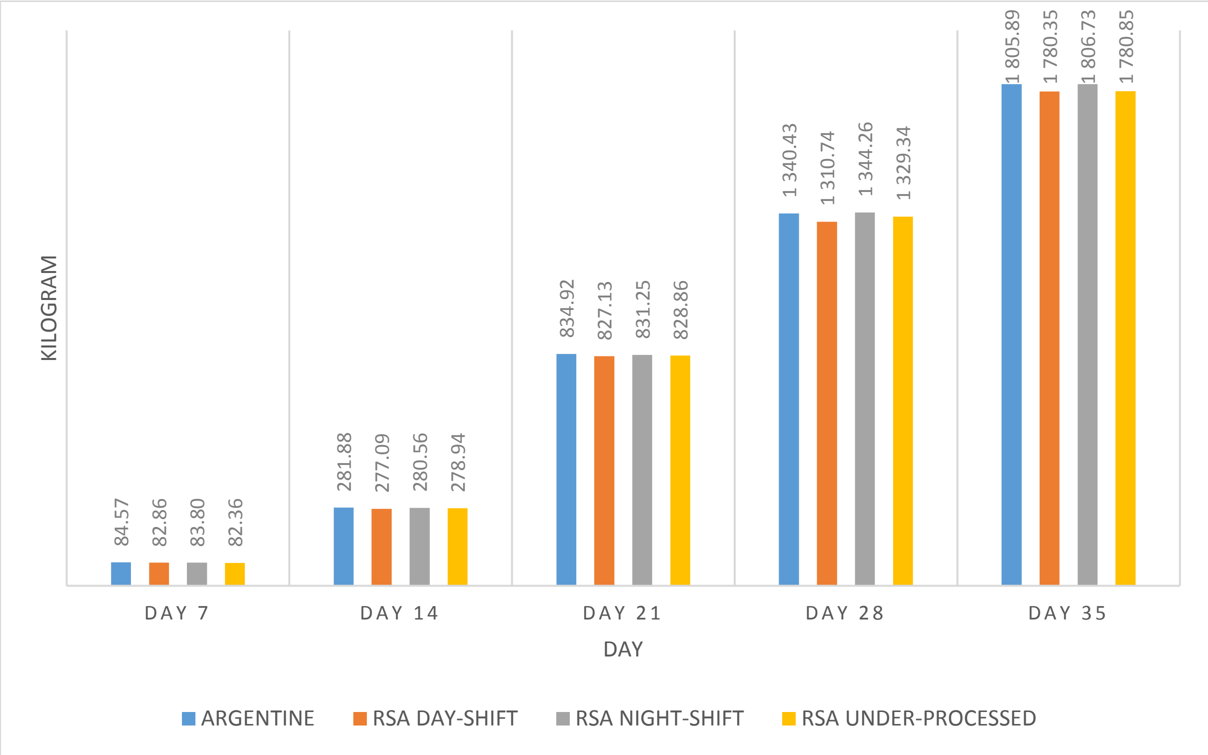

Figure 4.4 Cumulative feed consumption (Kg) per treatment

Table 4.9 Statistical significance testing: Cumulative feed consumption (Kg) per treatment

Test	R_1	R_2	R	U_1	U_2	U	Test statistic	Reject H_0
13	299,0	229,0	528,0	93,0	163,0	93,0	93	Cannot reject
14	263,0	265,0	528,0	129,0	127,0	127,0	127	Cannot reject
14	297,0	231,0	528,0	95,0	161,0	95,0	95	Cannot reject
16	232,0	296,0	528,0	160,0	96,0	96,0	96	Cannot reject
17	259,5	268,5	528,0	132,5	123,5	123,5	123,5	Cannot reject
18	300,0	228,0	528,0	92,0	164,0	92,0	92	Cannot reject

4.5 EFFICIENCY CALCULATIONS

Table 4.10 considers the efficiency of each soybean meal treatment. The RSA night-shift soybean meal diet had the most favourable FCR (2.175) followed by the RSA under-processed (2.203), Argentine (2.232) and lastly the RSA day-shift (2.248) diets. The FCR of the RSA night-shift soybean meal diet were significantly lower than the diets containing Argentine and RSA day-shift soybean meal (Table 4.11).

According to Phillips (2014) the average FCR for broilers in South Africa is 1.670 and 2.00 in Argentina. Thus, the FCR for all four soybean meal treatments used in this *in vivo* broiler growth performance trial differed meaningfully from the industry standards.

Table 4.10 Average bird performance per treatment

Treatment	Average Live weight per bird (Kg)	Average Feed consumption per bird (Kg)	Mortality rate (%)	FCR	PEF
Argentine	2,181	4,868	14,90	2,232	279,230
RSA day shift	2,169	4,875	16,83	2,248	275,792
RSA night shift	2,163	4,702	11,06	2,175	284,122
RSA under-processed	2,147	4,727	12,50	2,203	278,579

Table 4.11 Statistical significance testing: FCR

Test	R_1	R_2	R	U_1	U_2	U	Test statistic	Reject H_0
19	264	264	528	128	128	128	128	Cannot Reject
20	314	214	528	78	178	78	78	Reject
21	283	245	528	109	147	109	109	Cannot Reject
22	325	203	528	67	189	67	67	Reject
23	292	236	528	100	156	100	100	Cannot Reject
24	242	286	528	150	106	106	106	Cannot Reject

Although the PEF of the RSA night-shift soybean meal diet had the highest PEF (284.122) followed by the Argentine (279.230), RSA under-processed (278.579) and lastly the RSA day-shift (275.792) diets (Table 4.10), there were no significant differences between the PEF of the various soybean meal diets (Table 4.12).

Table 4.12 Statistical significance testing: PEF

Test	R_1	R_2	R	U_1	U_2	U	Test statistic	Reject H_0
25	276	252	528	116	140	116	116	Cannot reject
26	235	293	528	157	99	99	99	Cannot reject
27	265	263	528	127	129	127	127	Cannot reject
28	220	308	528	172	84	84	84	Cannot reject
29	259	269	528	133	123	123	123	Cannot reject
30	288	240	528	104	152	104	104	Cannot reject

4.6 ECONOMIC FEASIBILITY

This studied showed that, during the period of the broiler growth performance trial (June and July 2015), the economic feasibility of using any of the South African soybean meal feed diets were greater than the Argentine soybean meal feed diet. On average, the RSA night-shift soybean meal diet showed the greatest level of economic feasibility (26.73% higher than the Argentine diet) followed by the RSA under-processed diet (21.03% higher than the Argentine diet) and the RSA day-shift diet (7.43% higher than the Argentine diet) (Table 4.13).

Table 4.13 Economic feasibility [5]

Treatment	Feed consumption (kg)	Meat production (kg)	Average meal price (R/ MT)	Broiler meat price (R/ kg)	Total profit ('R)
Argentine	1805,89	765,49	5646	18,23	3758,65
RSA day shift	1780,35	752,80	5440	18,23	4037,91
RSA night shift	1806,73	800,43	5440	18,23	4763,23
RSA under-processed	1780,85	780,96	5440	18,23	4549,08

4.7 CONCLUDING REMARKS

When comparing the inter-laboratory UI test results of this trial, it seems as if the argument of Palić *et al*. (2008) only holds partially. As discussed in Section 1.3, Section 2.4.1 and Section 3.2.1.1, Palić *et al*. (2008) argues that although test results of soybean meal quality within a laboratory do not differ significantly test results between laboratories differ significantly. During this research trial the inter-laboratory test results did differ meaningfully. However, when comparing the UI test results within each laboratory it seems as if test results within a laboratory also differ meaningfully.

The general *in vitro* analysis and nitrogen *in vitro* analysis of the various soybean meal diets showed that all four soybean meal samples had tested within industry requirements. The results from the urease activity check showed that the RSA under-processed sample was indeed the only soybean meal diet which contained soybean meal which was not adequately cooked. It is worthy to note that according to the *in vitro* analysis there were no meaningful differences in nutrient quality between the four soybean meal treatments.

Statistical analysis of the *in vivo* results showed the following:

[5] Calculations based on results obtained during the *in vivo* broiler growth performance trial; Seaboard (2017); and SAPA (2015)

(1) There were no significant differences in the ALW of a bird at day 35 between any of the soybean meal diets;
(2) Mortalities which occurred in pens where diets containing RSA night-shift meal were fed was significantly lower than the mortalities which occurred in pens where diets containing RSA day-shift meal were fed;
(3) There were no significant differences in the feed consumption of the various soybean meal treatments;
(4) The FCR of the RSA night-shift soybean meal diet were significantly lower than the diets containing Argentine and RSA day-shift soybean meal;
(5) There were no significant differences between the PEF of the various soybean meal diets.

The in-depth *in vivo* analysis of the soybean meal diets showed that the RSA night-shift soybean meal diet was the most favourable soybean meal for broiler producers during the period of the trial, based on: mortality rates; feed conversion; production efficiency as well as economic feasibility. Hence the findings of this study prove that the perception, which dictates that the protein quality of South African soybean meal is inferior to that of Argentinian meal, to be ungrounded.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 IN A NUTSHELL

5.1.1 The South African Soybean Meal Industry

As explained in Section 1.1 of this thesis, large price discounts and premiums are common in the market of South African produced soybean meal. Price premiums received by the local product typically aroused when the demand for imported soybean meal outweighed the supply of the imported product due to, amongst other, production shortages in the exporting country or difficulties experienced when importing soybean meal into South Africa. In such cases users of soybean meal have no choice but to buy the South African produced product even if it meant paying a premium for the local product.

On the other hand, price discounts for South Africa produced soybean meal seem to be based on the perception associated with a lower protein quality of the local product. The perception dictates that animals which are fed on feed containing local soybean meal show suboptimal growth in relation to animals fed on feed containing imported soybean meal. This perception ultimately manifests in a price discount received by the local product. In Section 1.1's consideration of the daily Argentine (imported) as well as South African (locally produced) price of soybean meal it is evident that price discounts received by the local product sometimes reaches as much as R950 per ton, approximately 13% of the local price. As supported by Kaszaz (2015), only in rare instances does there exist a suitable explanation for price discounts received by South African produced soybean meal, i.e. May to June 2014 and again in June 2016 (Section 1.1). For the other months considered price discounts received by the local product are most likely related to inferior protein quality claims.

The South African soybean meal value chain, as quantified in Section 1.2 (Figure 1.3), explains that the local soybean complex consists out of three parts, i.e. soybeans, soybean meal and soybean oil (Jooste *et al.*, 2011). The major role players in the soybean meal value chain include: soybean suppliers; soybean traders; soybean crushers; and animal feed manufacturers (BFAP, 2009).

Whilst having their own supply and demand chains, the markets for soybeans, soybean meal and soybean oil are interdependent. A derived soybean price is used to determine the profit or loss from crushing soybeans, i.e. the crushing spread (Jooste *et al*., 2011). The crushing spread is a useful tool to analyse market efficiency as the fairly stable amount of soybean meal and oil produced from crushing soybeans allows for predictable value relationships between the relevant futures contracts Mitchell (2010). Jooste *et al*. (2011) further argues that the economic profitability of producing soybean meal in South Africa is significantly higher than the market profitability of producing soybean meal. This suggests that there are substantial distortions in the prices of production factors and outputs. BFAP (2017) further add on that South African soybean meal crushers have not been benefitting from an improved bean to meal ratio as what can be seen in other international soybean meal markets.

In South Africa soybeans are utilised mainly for crushing purposes, i.e. soybean meal and soybean oil. Section 1.2.2, Section 1.2.3 and Section 2.2.1 discussed local soybean meal demand and supply growth over the last decade as well as predictions for future growth. It is however worthy to note that although South Africa produced 67% of its local soybean meal demand in the 2017/2018 production season (PRF, 2018) far less than 80% of its dual crushing capacity was utilised (BFAP, 2017). This shows that there is still significant room to increase local soybean meal production in the future.

As Section 2.2.2 empathised, soybean meal is considered the dominant protein source in South Africa as national soybean meal consumption constitutes the largest portion of total oilcake production in South Africa (Strydom, Briedenhann and De Jager, 2017). Since the South African boiler industry is the main consumer of locally produced soybean meal Strydom, Briedenhann and De Jager (2017) and Dunn (2017) emphasises the significant role this industry plays in the growth and continued existence of the local soybean meal industry.

5.1.2 The Research Study

As discussed in Section 2.3, nutrient content is one of two important aspects when reviewing animal nutrition as protein levels affect animal growth and ultimately performance (Srinivasan *et al*., 2013). Protein quality has a direct effect on the quality of feed and ultimately the growth performance of livestock that is fed on it (Roosendal, 2010). The protein quality of soybean meal is dependent on the digestibility of the protein content and the reduction of anti-nutritional factors present in raw soybeans (Caprita *et al*., 2010[b]). Protein quality in soybean meal is determined when the crushed flakes are exposed to heat treatment. Insufficient or over-heating of the crushed flakes will result in poor quality soybean meal as insufficient heating will fail to destroy anti-nutritional factors and over-heating will reduce protein digestibility and the availability of amino acids (Caprita *et al*., 2010[a]). Therefore, feed formulators need reliable methods to differentiate between good quality soybean meal and under- or over-processed soybean meal (Caprita *et al*., 2010[b]).

In South Africa, feed manufacturers rely only on indirect analysis, i.e. *in vitro* analysis, to determine protein quality of soybean meal as direct analysis of soybean protein quality, i.e. *in vivo* analysis, is challenging in routine operations (Caprita *et al*., 2010[b]). As discussed in Section 2.4.1, various studies have drawn the validity of these *in vitro* methods of quality analysis into question (Palić and Grove, 2004; Caprita *et al*., 2010[b]; Palić *et al*., 2008 and Palić *et al.*, 2011). *In vivo* broiler growth performance studies, in which feed quality determinants are analysed, have been recorded for more than 20 years. These studies as well as the findings of Palić and Grove (2004) have shown *in vivo* monogastric animal performance to be the most relevant test for soybean meal quality.

As no record of a published *in vivo* study performed in South Africa can be found which substantiates inferior protein quality claims, the discounted price received by the local product, based on quality considerations, is draw into question. Therefore, the economic feasibility of the potential growth difference between local soybean meal and imported soybean meal should be determined on the back of controlled *in vivo* growth performance studies. Feed manufacturers in general rely far too much on *in vitro* analysis with little or no reference to *in vivo* studies.

From existing work (Panda, 2008), it is evident that the importance of a false perception surrounding a commodity cannot be underemphasised. A negative perception concerning the protein quality of local soybean meal necessarily not only affects the profitability in the soybean meal industry but supresses the entire soybean value chain. Section 1.3 calculates an estimated loss for the South African soybean meal industry, due to price discounts received by the local product, for the 2014/2015, 2015/2016, 2016/2017 and 2017/2018 production seasons (Table 1.1). Considering the average price discount per ton received by locally produced soybean meal during these production seasons the local industry forfeited R229.9 million, R209.4 million, R430.6 million and R459.3 million respectively. This is a total of more than R1.3 billion over four production seasons. Thus, in order to promote the use of local soybean meal as a source of protein in animal feed, the emphasis of this study was to test the ungrounded, negative market perception towards local soybean meal.

Therefore, the overarching aim of this study was to challenge price distortions in the South African soybean meal value chain. The multi-disciplinary research approach, as discussed in Chapter 3, was based on an *in vivo* broiler growth performance trial accompanied by an *in vitro* analysis of the soybean meal feed quality. The study also did an inter-laboratory comparison on the UI test results as to test the argument of Palić *et al*. (2008), as discussed in Section 1.3 and Section 2.4.1.

The *in vitro* analysis of soybean meal quality included: a general analysis testing for dry matter, moisture and ash content; a nitrogen analysis; fat and fibre analysis; as well as a urease activity check. During the in vivo broiler growth performance trial four soybean meal feed mixtures were formulated, i.e. an Argentine soybean meal diet; a RSA day-shift soybean meal diet; a RSA night-shift soybean meal diet and a RSA under-processed soybean meal diet. The feed treatments were formulated using values of the proximate analyses from the various batches of soya as to ensure that the feed of the different treatments contained similar amounts of macronutrients. Therefore, the only difference between the experimental feeds was the specific batch of the soybean meal as obtained from various sources. Tests of significance between the various soybean meal treatments was done by means of the Mann-Whitney *U*-test, since the samples obtained during the *in vivo* trial were too small for parametric testing. The results from the *in vivo* trial were also used to determine the economic feasibility of the various soybean meal treatments.

5.2 CONCLUSIONS

As discussed in Section 2.4.1, Palić *et al*. (2008) makes two statements regarding *in vitro* analysis of soybean meal quality, i.e. (1) test results between laboratories differ significantly; (2) test results within a laboratory do not differ significantly. The inter-laboratory comparison of the UI test results indicates meaningful differences between test results obtained from three laboratories. However, a comparison of the UI test results within each laboratory also indicated meaningful differences. The findings of this study thus only partially align with that of Palić *et al*. (2008). One could thus provide an argument for the inspection of local laboratory sampling and testing practices (Section 4.2).

The general and nitrogen *in vitro* soybean meal analysis of the various soybean meal diets showed that all four soybean meal samples had tested within industry requirements. The results from the urease activity check showed that the RSA under-processed sample was indeed the only soybean meal diet which contained soybean meal which was not adequately cooked (Section 4.3).

Statistical analysis of the *in vivo* results showed the following (Section 4.4):

(1) There were no significant differences in the ALW of a bird at day 35 between any of the soybean meal diets;

(2) Mortalities which occurred in pens where diets containing RSA night-shift meal were fed was significantly lower than the mortalities which occurred in pens where diets containing RSA day-shift meal were fed;

(3) There were no significant differences in the feed consumption of the various soybean meal treatments;

(4) The FCR of the RSA night-shift soybean meal diet were significantly lower than the diets containing Argentine and RSA day-shift soybean meal;

(5) There were no significant differences between the PEF of the various soybean meal diets.

The in-depth *in vivo* analysis of the soybean meal diets furthermore showed that the RSA night-shift soybean meal diet was the most favourable soybean meal for broiler production in the *in vivo* broiler growth performance trial, based on: mortality rates; feed conversion; production efficiency as well as economic feasibility. This means that the first null hypotheses, as stated in Section 1.6 of this thesis, can be rejected but that the second null hypothesis stands.

Hence the findings of this study have shown that the perception that locally produced soybean meal deserves a discount relative to imported Argentine soybean meal is unsubstantiated. Thus, based on the findings of this study industry participants may be inclined to replace imported protein sources by that of local protein sources. An increase in the demand for local soybean meal products will shift the demand curve outward, ultimately increasing local soybean meal market prices. Higher market prices and thus greater profitability could in the end lead to an expansion in soybean meal production. This in turn could ultimately improve South Africa's self-sufficiency in protein for animal production for human consumption and as a result improve the country's trade balance in the future. Furthermore, if local soybean meal production is stimulated the opportunities for employment creation (and ultimately poverty alleviation) up and down the soybean meal value stream could be enormous.

5.3 RECOMMENDATIONS FOR FUTURE STUDY

The following question therefore presents: To what factor(s) should a price discount received by the local product, if any, be attributed to?

Literature states that prices are formulated based on various determinants such as domestic demand and supply, regional demand and supply, international demand and supply, international prices, future price expectations, the prices of substitute products, the exchange rate, tastes and preferences, etc. (Section 2.6). It could therefore be stated that further analysis of the soybean value chain is necessary to determine which factors contribute to the formulation of local soybean meal prices, as well as the significance of any distortions or arbitration opportunities which may exist in the soybean meal market.

Furthermore, the onus of ensuring thorough traceability of the animal feed produced lies with feed formulators. Other considerations for possible inconsistency in the protein quality of soybean meal, which should be investigated by these industry participants, include:

(1) The cultivar of the soybeans being crushed as different cultivars could exhibit different quality in plant and bean material;
(2) The season in which the soybeans are crushed as seasonality has a direct effect on the moisture content of the beans which in turn could affect nutrient content;
(3) The soil composition in which the beans are planted as nitrogen is a determinant of protein quality;
(4) The quality of a crushing plant's equipment and therefore its technical efficiency;
(5) The ability to crush soybeans consistently as inconsistent volumes have an effect on crushing quality.

In certain instances, locally produced soybean meal could be superior to imported soybean meal, in terms of broiler production. Animal feed manufacturers should therefore prompt to analyse various local sources of soybean meal in order to determine which local protein sources should be used when formulating animal feed. This could have the result that more and improved soybean meal is produced locally, therefore stimulating the entire soybean value chain.

The possible argument could also be made that soybean meal crushers in South Africa may warrant a premium for their product. History has shown that the importation of a product does not come without various possible difficulties, and even in the absence of these difficulties can the consistent quality of the product not be guaranteed, due to international quality specifications. Therefore, local crushers should even be able to secure a premium for their product, based on the fact that local crushers can provide feed formulators with consistent volumes of product.

Lastly, the Southern African Grain Laboratory (SAGL) yearly undertakes a complete survey of samples to test maize and wheat quality independently (both the local product and imported shipments as they arrive). Unfortunately, this is not done for any other grains or oilseeds. Engaging with SAGL in an agreement could be one way of addressing the quality issues on local versus imported soybean meal.

REFERENCES

Ali, A., Azim, A., Zehid, S., Rasool, Z. and Rehman, K. (1993). Comparative performance of boiler chicks on commercial and corn-soybean meal based rations. *Asian-Australasian Journal of Animal Sciences*, [Online] 6(1), pp.115-122. Available at: http://www.ajas.info/upload/pdf/6-18.pdf [Accessed 22 Apr. 2015].

Ali, N., El Sanhoury, M. and Abdelaziz, M. (2015). FULL-FAT SOYBEAN AS AN ENERGY SOURCE IN BROILER CHICKEN DIETS. *Egyptian Poultry Science Journal*, [Online] 35(1), pp. 277-289. Available at: http://www.epsaegypt.com/wp-content/uploads/2015/04/1560-Publishing.pdf [Accessed 10 Aug. 2017].

Articles.extension.org. (2012). Dry Matter Determination - eXtension. [Online] Available at: http://articles.extension.org/pages/11315/dry-matter-determination [Accessed 30 Jan. 2015].

Bureau for Food and Agricultural Policy (2009). *The protein for animal feed game*. [Online] Pretoria: Protein Research Foundation, pp.4-6. Available at: https://www.proteinresearch.net/imgs/crops/soybeans/general-info/protein-for-animal-feed.pdf [Accessed 11 Sep. 2016].

Bureau for Food and Agricultural Policy (2016). *BFAP Baseline: Outlook 2016-2025*. Putting plans into action: Agriculture and economic growth in South Africa. [Online] Pretoria, pp.57-63. Available at: http://www.bfap.co.za/documents/baselines/BFAP_Baseline_2016.pdf [Accessed 20 Sep. 2016].

Bureau for Food and Agricultural Policy (2017). *BFAP Baseline: Outlook 2017-2026*. Managing Agriculture's footprint in an uncertain environment. [Online] Pretoria, pp.55. Available at: http://bfap.co.za/documents/baselines/BFAP_Baseline_2017.pdf [Accessed 28 May 2017].

Buthmann, A. (2000). *Understanding the Uses for Mood's Median Test*. [Online] Isixsigma.com. Available at: https://www.isixsigma.com/tools-templates/hypothesis-testing/understanding-uses-moods-median-test/ [Accessed 9 Oct. 2015].

Butler, C. (1985). *Statistics In Linguistics*. 1st ed. Oxford: B. Blackwell, pp.89-101.

Caprita, R., Caprita, A. and Cretescu, I. (2010[a]). Protein solubility as quality index for processed soybean. *Animal Science and Biotechnologies*, [Online] 43(1), pp.375-378. Available at: http://www.usab-tm.ro/fileadmin/fzb/Simp%202010/vol1/FUNDAMENTAL_SCIENCES_IN_ANIMAL_HUSBANDRY/BIOCHHEMISTRY,BIOPHYSICS,MATHEMATICS/Caprita2%20ref.pdf [Accessed 25 Nov. 2014].

Caprita, R., Caprita, A., Ilia, G., Cretescu, I. and Simulescu, V. (2010[b]). Laboratory Procedures for Assessing Quality of Soybean Meal. In: *Proceedings of the World Congress on Engineering and Computer Science*. [Online] pp.791-794. Available at: http://www.iaeng.org/publication/WCECS2010/WCECS2010_pp791-794.pdf [Accessed 25 Nov. 2014].

Chee, Kew Mahn, Jae Youn Hoen, Jin Ho Choi, Min Woo Kim, Kee Daae Kim, Youn Yung Sim, Uun Jeong Choi, Inn Sung Ahn and Sung Youn Kim (2001). *Evaluation of Comparative Feeding Values of Soybean Meals of Foreign Origin in Broilers*. Annual Report (1770-1001-0020). [Online] Seoul, Korea: Korea University, pp.1-3, 5, 8, 9, 12. Available at: http://www.soymeal.org/ResearchProjectRpts/EvaluationComparativeFeedingForeign2001.pdf [Accessed 26 Aug. 2016].

Chee, Kew Mahn, Mi Hyang Oh, You Jee Won and Jong Geon Kim (2008). *Broiler Feeding Trial to Compare Feeding Values of the Soybean Meals from Different Countries*. Annual Report on project 8751-1208-0020. [Online] Seoul, Korea: College of Life Science and Biotechnology, Korea University, pp.2, 6, 7, 9, 12. Available at:

http://www.soymeal.org/ResearchProjectRpts/BroilerFeedingTrialKorean2008.pdf [Accessed 26 Aug. 2016].

CME Group (2015). *CBOT Soybeans vs. DCE Soybean Meal and Soybean Oil – Crush Spread*. [Online] p.2. Available at: https://www.cmegroup.com/trading/agricultural/files/pm374-cbot-soybeans-vs-dce-soybean-meal-and-soybean-oil.pdf [Accessed 28 May 2018].

Code of Practice 2012: Pullet Rearing and Table Egg Production. (2012). [PDF] South African Poultry Association, p.7. Available at: https://www.sapoultry.co.za/pdf-docs/code-practice-layers.pdf [Accessed 29 Jan. 2015].

Critical Factors in Determining Fiber in Feeds and Forages. (2017). 1st ed. [PDF] AAFCO's Laboratory Methods and Services Committee, pp.1, 2. Available at: http://www.aafco.org/Portals/0/SiteContent/Laboratory/Fiber_Best_Practices_Working_Group/Fiber-Critical-Conditions-R1.pdf [Accessed 27 Apr. 2017].

Cromwell, G. (2012). *Soybean Meal – An Exceptional Protein Source*. [PDF] p.1. Available at: http://www.soymeal.org/ReviewPapers/SBMExceptionalProteinSource.pdf [Accessed 2 Aug. 2015].

Department of Agriculture, Forestry and Fisheries (2014). *Quarterly soybean market analysis & Outlook Bulletin 2 of 2014*. p.4.

Dunn, L. (2017). South African feed industry - threats and opportunities. *Oilseeds Focus,* [online] (Volume 3 No 1), p.1. Available at: https://www.opot.co.za/html_images/newsletters-magazines/oilseeds-focus/2017/oilseeds-focus-vol-3-no-1-march-2017.pdf [Accessed 30 May 2018].

DuPonte, M. (1998). *Livestock Feed Analysis: How to Interpret the Results*. [PDF] Hilo: Cooperative Extension Service - College of Tropical Agriculture and Human Resources, University of Hawaii, pp.1, 2. Available at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/livestock_feed_analysis.pdf [Accessed 31 Jan. 2016].

El-Faham, A., Ali, N. and Abdelaziz, M. (2016). EFFECT OF USING FULL-FAT SOY-BEAN IN BROILER DIETS ON PERFORMANCE, CARCASS PARTS, MEAT COMPOSITION, BONE TRAITS AND ECONOMIC EFFICIENCY. *Egyptian Poultry Science Journal*, [Online] 36(3), pp.755 -766. Available at: http://www.epsaegypt.com/wp-content/uploads/2016/09/1657-Publishing.pdf [Accessed 10 Aug. 2017].

Festing, M. and Altman, D. (2002). Guidelines for the Design and Statistical Analysis of Experiments Using Laboratory Animals. *ILAR Journal*, [Online] 43(4), pp.244-258. Available at: http://www.3rs-reduction.co.uk/assets/applets/Festing_Altman.pdf [Accessed 6 Aug. 2015].

Gerhardt.de. (2015). *Nitrogen determination*. [Online] Available at: http://www.gerhardt.de/en/analysis-methods/nitrogen-determination/ [Accessed 29 Jan. 2016].

Geman, H. and Shih, Y. (2008). Modeling Commodity Prices under the CEV Model. *The Journal of Alternative Investments*, 11(3), pp.65-84.

Giannenas, I., Bonos, E., Anestis, V., Filioussis, G., Papanastasiou, D., Bartzanas, T., Papaioannou, N., Tzora, A. and Skoufos, I. (2017). Effects of Protease Addition and Replacement of Soybean Meal by Corn Gluten Meal on the Growth of Broilers and on the Environmental Performances of a Broiler Production System in Greece. *PLOS ONE*, [Online] 12(1), p.e0169511. Available at: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0169511 [Accessed 8 Aug. 2017].

Graphpad.com. (2009). *GraphPad - FAQ 1093 - Why we recommend you do not use the Newman-Keuls multiple comparison test*. [Online] Available at: https://www.graphpad.com/support/faq/why-we-recommend-you-do-not-use-the-newman-keuls-multiple-comparison-test/ [Accessed 9 Oct. 2015].

Hafsa, S., Basyony, M. and Hassan, A. (2015). Effect of Partial Replacement of Soybean Meal with Different Levels of Guar Korma Meal on Growth Performance, Carcass Traits and Blood Metabolites of Broiler Chickens. *Asian Journal of Poultry Science*, [Online] 9(3), pp.112-122. Available at: http://scialert.net/qredirect.php?doi=ajpsaj.2015.112.122&linkid=pdf [Accessed 10 Aug. 2017].

Heiman, G. (2011). *Basic statistics for the behavioral sciences*. 1st ed. Belmont: CA: Wadsworth Cengage Learning, pp.351, 352.

Hill, G. (2003). Plant anti-nutritional factors |Characteristics. In: *Encyclopedia of Food Sciences and Nutrition*, 2nd ed. Academic Press, pp.4578-4587.

Horwitz, W. (2000). *Official methods of analysis of AOAC International*. 17th ed. Gaithersburg, Md.: AOAC International.

Ismail B.P. (2017) Ash Content Determination. In: Food Analysis Laboratory Manual. Food Science Text Series. Springer, Cham

Janse van Rensburg, C. (2018). *Inter-laboratory test results*.

Jooste, A., Swart, L., Joubert, C., Dempers, C., Phahlane, H., Thabethe, L. and Stroebel, L. (2011). *The South African Soybean Value Chain.*

Joubert, R. (2013). Soya bean processing plant growth. *Farmer's Weekly*. [Online] Available at: https://www.farmersweekly.co.za/crops/field-crops/soya-bean-processing-plants/ [Accessed 11 Sep. 2016].

Joubert, C. (2016). *Emailing: Capacity processing August 2013 (4).pptx*. [Email].

Kaszaz, J. (2015). *The South African soybean meal industry*.

Kirsten, J., Geyser, M., Jooste, A. and Schalkwyk, H. (2009). *The functioning of the Agricultural Futures Market for Grains and Oilseeds in the light of concerns expressed by GRAINSA*. [Online] pp.3,4. Available at: https://www.google.co.za/search?rlz=1C1CAFB_enZA634ZA634&q=According+to+Kristen,+Geyser,+Jooste+and+van+Schalkwyk+(2009)+the+price+of+grain+is+determined+by+considering+the+following:+domestic+demand+and+supply;+regional+demand+and+supply;+international+demand+and+supply;+international+prices+as+well+as+the+exchange+rate.+The+authors+however+further+stress+that+markets+do+not+only+function+based+on+essential+factors+but+on+emotions+and+perceptions+as+well.&spell=1&sa=X&ved=0ahUKEwjoyrnAqMjXAhWBUlAKHU3xDN8QBQgiKAA&biw=1600&bih=769 [Accessed 18 Jan. 2016].

Korver, D., Moehn, S., Novak, S. and Yegani, M. (n.d.). Monogastric nutrition. In: *Encyclopedia of Life Support Systems (EOLSS)*. Edmonton, Canada: Department of Afgriculture, Food and Nutritional Science, University of Alberta, p.1.

Krotz, L., Leone, F. and Giazzi, G. (2016). *Nitrogen/ Protein Determination in Food and Animal Feed by Combustion Method (Dumas) using the Thermo Scientific FlashSmart Elemental Analyzer*. [PDF] p.1. Available at: https://tools.thermofisher.com/content/sfs/brochures/AN-42262-OEA-Nitrogen-Protein-Food-Animal-Feed-FlashSmart-AN42262-EN.pdf [Accessed 29 Jan. 2017].

Lane, D. (2007). *Introduction to Analysis of Variance*. [Online] Onlinestatbook.com. Available at: http://onlinestatbook.com/2/analysis_of_variance/intro.html [Accessed 9 Oct. 2015].

McDonald, P., Edwards, R., Greenhalgh, J., Morgan, C., Sinclair, L. and Sinclair, R. (2011). *Animal nutrition*. 7th ed. Harlow, Essex, England: Pearson, p.634.

McDonald, J. (2014). *Handbook of Biological Statistics*. 3rd ed. Baltimore, Maryland: Sparky House Publishing, pp.157-164.

Mindrila, D. and Balentyne, P. (n.d.). *Tests of Significance*. [PDF] University of West Georgia, pp.2, 3. Available at: https://www.westga.edu/academics/research/vrc/assets/docs/tests_of_significance_notes.pdf [Accessed 9 Oct. 2015].

Mitchell, J. (2010). Soybean Futures Crush Spread Arbitrage: Trading Strategies and Market Efficiency. *Journal of Risk and Financial Management*, 3(1), pp.63-96.

National Planning Commission (2009). *National Development Plan: Vision for 203 - Chapter 6*. p.197.

Nkuna, C. (2018). *State of the Poultry Industry*.

Optimizing Broiler FCR. (2011). *Arbor Acres Service Bulletin*, [online] p.1. Available at: http://ap.aviagen.com/assets/Uploads/AAServiceBulletinFCRJuly2011.pdf [Accessed 29 May 2018].

Palić, D. and Grove, A. (2004). Validation of Methods for Determining the Degree of Soya Processing. In: *Joint GSSA – SASAS Congress*.

Palic, D., Levic, J., Sredanovic, S. and Djuragic, O. (2008). Quality control of full-fat soybean using urease activity: Critical assessment of the method. *Acta periodica technologica*, [Online] (39), pp.47-53. Available at: http://www.doiserbia.nb.rs/img/doi/1450-7188/2008/1450-71880839047P.pdf [Accessed 25 Nov. 2014].

Palić, D., Modika, K., Oelofse, A., Morey, L. and Coetzee, S. (2011). The protein dispersibility index in the quality control of heat-treated full-fat soybeans: an inter-laboratory study. *South African Journal of Animal Science*, [Online] 41(4), p.418. Available at: http://www.sasas.co.za/sites/sasas.co.za/files/Palic41Issue4_0.pdf [Accessed 25 Nov. 2014].

Panda, T. (2008). *Marketing management*. 2nd ed. New Delhi: Excel Books, p.392.

Paradza, T. (2016). *Importers and exporters take note: trade deal with South America is in effect.* [Online] BusinessLive. Available at: https://www.businesslive.co.za/opinion/2016-10-23-importers-and-exporters-take-note-trade-deal-with-south-america-is-in-effect/ [Accessed 30 May 2018].

Penson, J., Capps, O., Rosson, C. and Woodward, R. (1996). *Introduction to agricultural economics*. 5th ed. Upper Saddle River, N.J.: Pearson Prentice-Hall.

Poultry Hub. (2018). *Broiler Production - Poultry Hub*. [Online] Available at: http://www.poultryhub.org/family-poultry-training-course/trainers-manual/broiler-production/ [Accessed 10 Feb. 2018].

Reiling, B. (2011). *Feed dry matter conversions*. [PDF] University of Nebraska - Lincoln Extension, Institute of Agriculture and Natural Resources, p.1. Available at: http://extensionpublications.unl.edu/assets/pdf/g2093.pdf [Accessed 30 Jan. 2015].

Phillips, L. (2014). Broilers: SA vs Argentina. *Farmer's Weekly*. [Online] Available at: https://www.farmersweekly.co.za/animals/cattle/broilers-sa-vs-argentina/ [Accessed 13 Feb. 2018].

Roosendal, B. (2010). Soybean meal use in the South African poultry industry: Formulation and quality considerations. 1st ed. [PDF] *Protein Research Foundation*, pp.1-10. Available at: http://www.proteinresearch.net/html_images/_completed_projects/000504/1_9_1a_poppub_roosendaalb_2010.pdf [Accessed 25 Nov. 2014]

Ross Broiler Management Manual. (2009). [PDF] p.80. Available at: http://www.natchix.co.za/pdf/management_manual.pdf [Accessed 14 Oct. 2015].

Ross Broiler Performance Objectives. (2012). [PDF] Available at: http://www.arya-dan-roshd.ir/images/general/articale/sub/rahnema/ros%20308.pdf [Accessed 14 Oct. 2015].

Rostagno, H. and Pupa, J. (1995). Diet formulation for broilers based on total versus digestible amino acids. *Journal of Applied Poultry Research*, [Online] 4(1), pp.293-299. Available at: https://oup.silverchair-cdn.com/oup/backfile/Content_public/Journal/japr/4/3/10.1093/japr/4.3.293/2/japoulres4-0293.pdf?Expires=1502468328&Signature=e38TFnrddtN208swE-zrzwKplC0oa~-6htpdHKn0~dBsXP7x~m7Wt5DjZC5Ayp6AnaTGp82v76Nv1xelyn5~JGif3JDYAxSzwfj~pxjT2jWZVVoRmIfKkoWPOkKv8UQbjL7dA4Iuv5giYSjQbOJH6HWs0pqwXNKD52yIBig85Dm6cdVefUjIMknO4viNPHU3UVPFzgHCYqjnimBfa59QczssTCs~5t-u8ayy0NLh0u2ZnKBN1o-ngxZhfK2y~ZD4R--acUi-HUlP3z0fixU0j60VU92vIDd-iTivZd25DwTJ-nl~-A1vkmkGyUqlbCwheFEwKBYy-HWHGugTvkREzQ__&Key-Pair-Id=APKAIUCZBIA4LVPAVW3Q [Accessed 10 Aug. 2017].

RussellStone (2017). Soya bean Crushing: An Industry Coming of Age. [Blog] Available at: http://www.russellstone.co.za/2017/11/09/soya-bean-crushing-industry-coming-age/ [Accessed 30 May 2018].

SAGIS (2018[a]). *Tariff line 2304.00 Oilcake - Soybeans*. p.1.

SAGIS (2018[b]). *Soybeans: Supply and demand table based on SAGIS's info (Tons)*. p.1.

Salkind, N. (2010). Duncan's Multiple Range Test. In: *Encyclopedia of Research Design*. SAGE Publications.

SAPA (2015). *Broiler producer price report for July 2015*. Broiler producer price report. [Online] p.2. Available at: http://www.sapoultry.co.za/pdf-statistics/broiler-price-report.pdf [Accessed 10 Sep. 2015].

SAPA (2018). *Broiler industry production report: January 2018*. Broiler industry production report. [Online] pp.5, 6. Available at: https://www.sapoultry.co.za/pdf-statistics/broiler-industry-report.pdf [Accessed 2 Jun. 2018].

Shurtleff, W. and Aoyagi, A. (2007). *History of Soybean Crushing: Soy Oil and Soybean Meal - Part 1*. [Online] Soyinfocenter.com. Available at: http://www.soyinfocenter.com/HSS/soybean_crushing1.php [Accessed 4 Dec. 2015].

Seaboard, J. (2017). *Hisoriese meel pryse*. [Email].

Southern Africa Regional Soybean Roadmap Final report. (2011). 1st ed. [PDF] Technoserve, p.4. Available at: http://www.technoserve.org/files/downloads/technoserve-bmgf-regional-report.pdf [Accessed 15 Nov. 2014].

Srinivasan, R., Lumpkins, B., Kim, E., Fuller, L. and Jordan, J. (2013). Effect of fiber removal from ground corn, distillers dried grains with solubles, and soybean meal using the Elusieve process on broiler performance and processing yield. *The Journal of Applied Poultry Research*, [Online] 22(2), pp.177-189. Available at: http://www.weightycorn.com/broiler_economics.pdf [Accessed 8 May 2015].

Statistics How To. (2015[a]). *Duncan's Multiple Range Test (MRT)*. [Online] Available at: http://www.statisticshowto.com/duncans-multiple-range-test/ [Accessed 9 Oct. 2015].

Statistics How To. (2015[b]). *Post-Hoc Definition and Types of Post Hoc Tests*. [Online] Available at: http://www.statisticshowto.com/post-hoc/ [Accessed 9 Oct. 2015].

Statistics.laerd.com. (2013[a]). *Kruskal-Wallis H Test in SPSS Statistics | Procedure, output and interpretation of the output using a relevant example*. [Online] Available at: https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php [Accessed 9 Oct. 2015].

Statistics.laerd.com. (2013[b]). *One-way ANOVA - An introduction to when you should run this test and the test hypothesis | Laerd Statistics*. [Online] Available at: https://statistics.laerd.com/statistical-guides/one-way-anova-statistical-guide.php [Accessed 9 Oct. 2015].

Statistics Solutions. (2017). *Kruskal-Wallis Test - Statistics Solutions*. [Online] Available at: http://www.statisticssolutions.com/kruskal-wallis-test/ [Accessed 9 Oct. 2015].

Strydom, D., Briedenhann, E. and De Jager, W. (2017). *Projected protein requirements for animal consumption in South Africa*.

Tahir, M., Batal, A. and Pesti, G. (2015). Broiler response model to estimate the economic importance of dietary feed enzymes1. *The Journal of Applied Poultry Research*, [Online] 24(1), pp.37-48. Available at: https://oup.silverchair-cdn.com/oup/backfile/Content_public/Journal/japr/24/1/10.3382_japr_pfv004/2/pfv004.pdf?Expires=1502469281&Signature=To7WFAnOrWSi1eVTnmw-ye-mf2L4HLmjCF6H8iBqdKO8p-mdnPDX5OHwmLc5ih388sKLZ82ckniOGRORkaD6tyGnHZ2PhzftJyT6a6d0QK3KVCStr~RrwBm3aZfJ64yDTJKXz7sSX97t2Oi8B6YGNT4--xKc2PZhbsDoSHotFkiWyuZly~kwDsfGCrHPnewFxo6iukKwhJaX3nOcd9f55m-OGa2HY7RkNJazMD6UKb4d7GPH0ir8raGUxvPVZX5HFGfiKC8s-GGUzolIi8fXPmpXch9rueUmRthsVN5NKd5Bmljch9cwfGCVMqToMPaq71AdUpiZeg71pq-Xg8S5jg__&Key-Pair-Id=APKAIUCZBIA4LVPAVW3Q. [Accessed 8 May 2015].

The Protein Research Foundation (PRF). (2005). Mission statement of the Protein Research Foundation. [Online] Available at: https://www.proteinresearch.net/index.php?page=prf-mission [Accessed 29 Jan. 2015].

The Protein Research Foundation (PRF). (2018). *Short and medium term requirements for and usage for fishmeal and oilcake.* [Online] Available at: https://proteinresearch.net/index.php?page=protein-statistics-2018-february. [Accessed 28 May 2018].

Trevisan, R., Nakagi, V., Bravo, P. and Faria, D. (2014). Feeding programs and their effects on broiler performance and economic indexes. *The Journal of Applied Poultry Research*, [Online] 23(4), pp.593-604. Available at: https://oup.silverchair-cdn.com/oup/backfile/Content_public/Journal/japr/23/4/10.3382_japr.2013-00884/1/593.pdf?Expires=1502469292&Signature=R2cs47nA42Pl75ajSp-

I3jNizIXtbceGYX2jGFeaXu2puV6JIZ1TrY7UPUpn1ssXgbP37U8uDlpbiAebeXA-kQYTGiJTsRHkHV-f2161TfLGmCNbceqH5cKy-pWqmb8lBV8E4ggrIaxvg4Z8EW8D-3gjpzawEP7yZ2HGlAEvToy1qWn~TRkzS8qVLEfgvkDwE-Igphn7hZeHBzJqcWKzr7~tqk7mx0VfaZssy2w3DnSnJS3M8AmZcWbI63lNXC-8IJY2wg6kM1j~PdfGouZKuQqpkU5CswjAqMizj9jwBi8TNUkDCuNRaT5m-VBpzJtRxYHb8~QxFYODa9hMFwdwtA__&Key-Pair-Id=APKAIUCZBIA4LVPAVW3Q [Accessed 10 Aug. 2017].

Wto.org. (2018). WTO | *Glossary - dumping*. [Online] Available at: https://www.wto.org/english/thewto_e/glossary_e/dumping_e.htm [Accessed 2 Jun. 2018].

Zaiontz, C. (2013[a]). *Assumptions for Statistical Tests | Real Statistics Using Excel*. [Online] Real-statistics.com. Available at: http://www.real-statistics.com/descriptive-statistics/assumptions-statistical-test/ [Accessed 9 Oct. 2015].

Zaiontz, C. (2013[b]). *Mood's Median Test | Real Statistics Using Excel*. [Online] Real-statistics.com. Available at: http://www.real-statistics.com/one-way-analysis-of-variance-anova/moods-median-test/ [Accessed 9 Oct. 2015].

Zungo, M. (2011). *A review of price distortions.* [Online] pp.1, 2. Available at: https://www.scribd.com/doc/87440905/PRICE-DISTORTIONS [Accessed 4 Dec. 2015].