Beta-adrenergic agonists, ractopamine hydrochloride and salbutamol, as performance enhancers in the finisher pig

by

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Declaration

I, Jean-Pierre de Jager, declare that this thesis, submitted for the MSc (Agric) Animal Science: Animal Nutrition degree at the University of Pretoria, is my own work and has not previously been submitted by me or any other individual for a degree at this or any other institution.

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Abstract

Ractopamine HCl and salbutamol are beta-adrenergic agonists that enhance the performance indicators of pigs when administered in their diet. The aim of the study was to determine the effect of ractopamine HCl and salbutamol on the performance of the finisher pig.

A total of 440 pigs (Topigs TN70) served as the subject. The pigs were divided into 40 pens of 11 each. The pigs were fed 5 different treatments in the finisher phase, the 5 treatments were:

1. Negative control (NC): No additives included (16% crude protein (CP) in finisher diet)
2. Positive control: Ractopamine HCl inclusion (6 mg/kg of feed) and current recommendation of 16% CP in the finisher diet.
3. Ractopamine HCl (6 mg/kg of feed), but only 13% CP in the finisher diet while dietary essential amino acid concentrations were similar to the positive control diet.
4. NC diet + salbutamol 10% at 6 mg/kg
5. NC diet + salbutamol 10% at 4 mg/kg

The pigs were fed the same diets in the grower phases 1, 2 and 3, the diets consisted of mainly maize, soya, wheat bran sunflower oil cake and a grower vitamin and mineral premix.

Feed intake, live weight gain and feed conversion ratio (FCR) were measured. Cold carcass weight, warm carcass weight, lean percentage, dressing percentage and moisture loss were also measured.

There were significant differences ($p<0.05$) in live weight gain, FCR, feed intake and lean percentage when comparing the group fed salbutamol with the group fed ractopamine HCl and the group without the beta-agonist in their diet.

The group of pigs fed salbutamol in their diet had performed significantly ($p<0.05$) better. However, this group, together with the group of pigs fed ractopamine HCl, exhibited a higher return on investment (ROI) during the study.

In conclusion, ractopamine HCL and salbutamol enhanced the performance of finisher pigs during this study, although it is expedient to validate these findings for future studies.

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List of Abbreviations

ADG	Average daily gain
ADI	Acceptable daily intake
AFMA	Animal Feeds and Manufacturers Association
ATP	Adenosine triphosphate
BAA	Beta-adrenergic agonist
BAR	Beta-adrenergic receptor
BFAP	Bureau for Food and Agricultural Policy
BW	Body weight
cAMP	Cyclic adenosine monophosphate
CCW	Cold carcass weight
CP	Crude protein
DALRRD	Department of Agriculture, Land Reform and Rural Development
DFD	Dark, firm and dry
EU	European union
F:G	Feed to gain ratio
FA	Fatty acid
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
Fat	Fat thickness measured between the 2nd and 3rd last ribs, 45 mm from the dorsal midline in millimetres
FCR	Feed conversion ratio
G:F	Gain to feed ratio
GnRH	Gonadotropin-releasing hormone
HGP	Hennessy Grading Probe
Kg	kilogram
LD	*Longissimus dorsi*
LH	Luteinizing hormone
LM%	Lean meat percentage
LW	Live weight
ME	Metabolizable energy
mm	millimetre
MUFA	Monounsaturated fatty acid
n	Number
NDA	National Department of Agriculture
P2	Position 65 mm from the dorsal midline at the level of the posterior edge of the head of the last rib
PKA	Protein kinase A
PSE	Pale, soft and exudative
PUFA	Poly-unsaturated fatty acid
r	Pearson's correlation coefficient
R^2	Coefficient of determination
RAC HCl	Ractopamine hydrochloride
SAPPO	The South African Pork Producers' Organisation
SFA	Saturated fatty acid
WCW	Warm carcass weight
WHC	Water holding capacity

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Chapter 1: Introduction

As the global human population increases, an increased demand for food supply comes. Whilst modern technologies need to be applied to meet this demand and improve the efficiency of animal production, these technologies need to do so in a sustainable manner. The task is therefore to find a balance between applying the latest technologies while monitoring animal welfare, human safety, and sustainability. With a global increase in consumer awareness regarding sustainable and ethical food processing, producers have a higher need to monitor food safety, animal welfare, and sustainability.

Whilst various studies evaluate sustainable animal production in cattle and poultry, this study aimed to determine whether beta-agonists like salbutamol and ractopamine HCl will improve the performance as well as the carcass characteristics of grower and finisher pigs. This study aims to reassess the use of ractopamine HCl and other beta-agonists within the context of modern pig genetics, determine whether beta-agonists are still effective, and determine if the recommended use is still effective. Advancement in pig genetics has focused on improving lean meat yield and improving feed conversion ratio (FCR), two components that beta-agonists are used for to improve performance, and pig genetic companies have achieved that to such an extent that it may be necessary to rethink the use of beta-agonists. Beta-agonists are expensive products, and therefore, if the advancement of modern pig genetics on its own is effective enough to improve the FCR and lean meat yield, pig farmers could save money and improve their return on investment.

In South Africa the PORCUS classification system classifies pig carcasses, based on fat content, weight and carcass conformation, this in combination with additional factors such as damage to the carcass such as bruising, age and sex to provide an overall classification (Bruwer, 1992; Department of Agriculture, 2006; Siebrits *et al.,* 2012). The PORCUS classification system categorizes pig carcasses based on the thickness of backfat and the percentage of lean meat. The warm carcass is used to separate the carcass classes into P, O, R, C, U, and S regardless of genotype and production system. This system rewards producers for producing leaner pigs by awarding a higher classification and price for leaner carcasses (Soji *et al.,* 2015).

The PORCUS system meets the consumer's demand for lean meat. However, it does not account for the consumer's concern for sustainably produced meat that is safe to consume, and free of dangerous residues. More recently there has been an increased demand for products that meet criteria based on animal well-being. Concerns such as

possible side-effects due to the administration of drugs on animals as test subjects (Hill and Dalrymple, 1987) and of possible negative effects to consumers because of drug residues (Salleras *et al*., 1995) have meant that clearance to use drugs such as beta-agonists in commercial animal production, has become extremely cumbersome and difficult.

Beta-agonists (BAAs) are structurally like that of epinephrine and norepinephrine (It is important to consider the ethical and environmental implications of using beta-agonists in animal production. As consumers become more conscious of the origin and processing of food, there is a growing demand for sustainably and ethically produced meat. This includes concerns about the use of drugs such as beta-agonists and the potential impact on animal welfare and human health.

Furthermore, the classification system used to classify pig carcasses, such as the PORCUS system in South Africa, emphasizes lean meat production but may not adequately address consumer concerns regarding sustainability and safety. Consumers are increasingly interested in products that meet specific animal well-being criteria and are free from potentially harmful residues.

It's also worth considering the financial aspect of return on investment of pig farming. Beta-agonists are expensive products, and if advancements in pig genetics alone can effectively improve feed conversion ratio and lean meat yield, farmers could potentially save money and improve their return on investment by re-evaluating the use of beta-agonists.

Lastly, while beta-agonist supplementation has been shown to result in leaner carcasses and improved feed efficiency in finishing pigs, there are concerns about the impact on meat tenderness and fatty acid composition. These factors also need to be considered when evaluating the overall effectiveness and implications of using beta-agonists in pig production.

Beta-agonists (BAAs) are structurally like that of epinephrine and norepinephrine. Adrenocorticoids are a group of xenobiotic catecholamine analogues (Beerman, 2001; Mills, 2002). Beta-adrenergic agonists bind specifically to alpha-1, alpha-2, beta-1, and beta-2 receptors and are known for their effects on adipose tissue and muscle tissue; when activated, they cause muscle-specific muscular function. Beta-1 and beta-2 receptors are primarily found in muscle tissue. Beta-adrenergic agonists are, therefore, receptor-specific and have selective effects. Most animal species' adipose tissue has beta-receptors that stimulate lipolysis when activated (Muir, 1998). The beta-2 adrenoceptor is a classic example of a G protein-coupled receptor, with extensive knowledge available about its structure, function, and regulation. Selective beta-2 agonists, such as salbutamol, terbutaline, and salmeterol, target

these receptors. Beta-2 adrenoceptors play a role in various physiological processes, particularly within the pulmonary and cardiovascular systems (Bylund, 2007).

Beta-agonist supplementation results in leaner carcasses with better conformation (Webb & O'Neill, 2008). Supplementation with beta-adrenergic agonists also improves the FCR of finishing pigs (Rikard-Bell *et al.,* 2009; Hinson *et al.,* 2012). Webb and Casey (1995) provide evidence suggesting the fat content and composition of fatty acids in meat from cattle treated with beta-agonists may be more favourable for human health. However, meat from animals fed beta-adrenergic agonists might not be as tender as animals that were not fed beta-agonists (Dunshea *et al.,* 2005; O'Neill *et al.,* 2010; Strydom *et al.,* 2011).

Animal performance, as measured by average daily gain (ADG), FCR, and percentage lean tissue, is improved by feeding beta-adrenergic agonists, such as ractopamine HCl, to finishing pigs (Watkins *et al*., 1990; Stites *et al*., 1991; Armstrong *et al*., 2004).

1.1 Ractopamine hydrochloride

The ractopamine HCl-containing product, Paylean (Elanco Animal Health, USA), is extensively used by pig producers worldwide. The US Food and Drug Administration (FDA) approved Ractopamine HCl for use in pigs in 1999. However, ractopamine HCl makes pigs more difficult to work with, cause elevated concentrations of circulating catecholamines, and increase heart rates according to some studies (Marchant-Forde *et al*., 2003). According to the FDA (2002), pigs are more likely to become fatigued during handling. Furthermore, in 160 countries ractopamine HCl is either banned or restricted, this includes Russia, China, and some members of the European Union (EU), due to possible human health risks. Twenty-seven countries, including Canada, Japan, the United States of America, Brazil, and South Korea, have, however, deemed meat from livestock-fed ractopamine HCl safe for human consumption (Abbas *et al*., 2022). Meat from livestock fed ractopamine HCl is also deemed safe for human consumption in South Africa (Smith, 2014).

The inclusion and feeding duration of ractopamine HCl supplementation are key factors in maximizing animal performance. It has been noted that both growth performance and carcass quality improved with an increase in the dose of ractopamine HCl when pigs were fed a constant 16% crude protein (CP) diet for 21-28 days (Herr *et al*., 2000).

Pig genetic companies artificially select more lean animals with less fat deposition and higher lean accretion rates (Knap and Rauw, 2009). Modern genetics of the pig are leaner than in previous years and, therefore, deposit less fat tissue; the question arises whether beta-

agonists like ractopamine HCl are still as effective in converting fat to lean tissue when the pigs are bred leaner. Furthermore, diet formulations are increasingly based on the ideal amino acid profile. The question must, therefore, be asked whether a 16% CP diet is still valid for the effective use of ractopamine HCl or if dietary CP concentrations can be lowered due to diets being formulated with a focus on the amino acid profile. This calls for re-evaluating the 16% CP inclusion in the finisher diet with the supplementation of ractopamine HCl at 6 mg/kg of feed. Could the total CP be lowered while ensuring that the essential amino acid requirements are met? This could be more economical and efficient. With the high prices of protein sources, any reduction in total dietary CP will result in a decreased cost of pig production (Knap and Rauw, 2009).

1.2 Salbutamol

Salbutamol, a commonly prescribed medication known for its global safety record, is utilized as a bronchodilator in asthma treatment for humans, targeting the beta-2 receptor (Hoffman *et al.*, 1996). Salbutamol functions by expanding the airways and easing breathing. The half-life of salbutamol in the human body ranges from 2.7 to 5 hours following oral administration. The use of salbutamol in livestock is aimed at increasing lean percentage yield and decreasing fat (Korthumarit, 1999). Keefe (2000) noted that salbutamol can cross the blood-brain barrier and placenta. Oksibjerg *et al.* (1996) and Hansen *et al.* (1997) concluded that salbutamol could potentially be used as a repartitioning agent in the pig industry. Salbutamol has been approved and registered in South Africa since 2020 for use as a beta-agonist in pigs, but very limited research results are available on its efficacy in pigs under South African conditions.

1.3 Aim and Objectives

The first aim of the trial was to compare the effect of salbutamol and ractopamine HCl on the performance of finishing pigs as well as the carcass characteristics after slaughter. The second aim of the trial was to determine whether the recommended crude protein percentage of 16% for ractopamine HCl is still valid and whether it could be decreased to 13% while meeting the essential amino acid levels.

To achieve the aims of the study, the following objectives were identified:

1. Growth performance and carcass characteristics of finisher pigs that received either ractopamine HCl or salbutamol were compared to pigs that did not receive a beta-agonist.
2. Growth performance and carcass characteristics of finisher pigs that received 13% dietary CP with ractopamine HCl at 6 mg/kg compared to finisher pigs that received 16% dietary CP with ractopamine HCL at 6 mg/kg, both these feeds met the requirement of essential amino acids.

1.4 Hypotheses

H0: Ractopamine HCl supplementation will not affect pig production parameters.

H1: Ractopamine HCl supplementation will improve pig production parameters, even with reduced crude protein %.

H0: Salbutamol supplementation will not affect pig production parameters.

H1: Salbutamol supplementation will improve pig production parameters and can be considered as a viable alternative to ractopamine HCl

Chapter 2: Literature Review

2.1 The South African pork industry

Relative to poultry and beef, pork production is a small industry in South Africa; unlike the global trend where pork is the animal protein most consumed (BFAP, 2020). It has been one of the most actively growing industries in South Africa, with consumption growing by 42% in the last decade. Pork production increased by 48% over the same space of time, reducing imported pork to total consumption from 13% to 8%. With this, the industry has outperformed the targeted growth for 2030 under the national development plan. Because it is such a small industry, pork prices are sensitive to changes in supply and demand, and the price of other meat products. A listeriosis outbreak that started in 2018 caused a sharp decline in pork prices during 2018 - 2019, highlighting the substitutability with other meat products and resulting in a price impact in 2019. A disease outbreak (swine flu) again affected the pork industry in 2020, causing the third year in a row where disease impact intensified the typical seasonal decline in pork prices (BFAP, 2020).

2.1.1 The pork value chain

A consumer-driven process where the needs of consumer are realized is known as a *demand chain*. Said demands are met by a developed product. A supply chain uses raw materials for product development and then supplies the consumers with these products. A value chain encompasses a series of business activities and processes involved in producing a product or delivering a service. It covers multiple stages in the lifecycle of a product or service, from research and development to sales (Kaplinsky and Morris, 2001). By integrating principles from both demand and supply chains, a value chain forms a model that can predict consumer demands sustainably while ensuring efficient profitability (Spies, 2011). The South African pork value chain is vertically integrated, with companies operating in different areas to minimize inputs and reduce the final product's cost. Figure 1 illustrates the pork value chain (DALRRD, 2021).

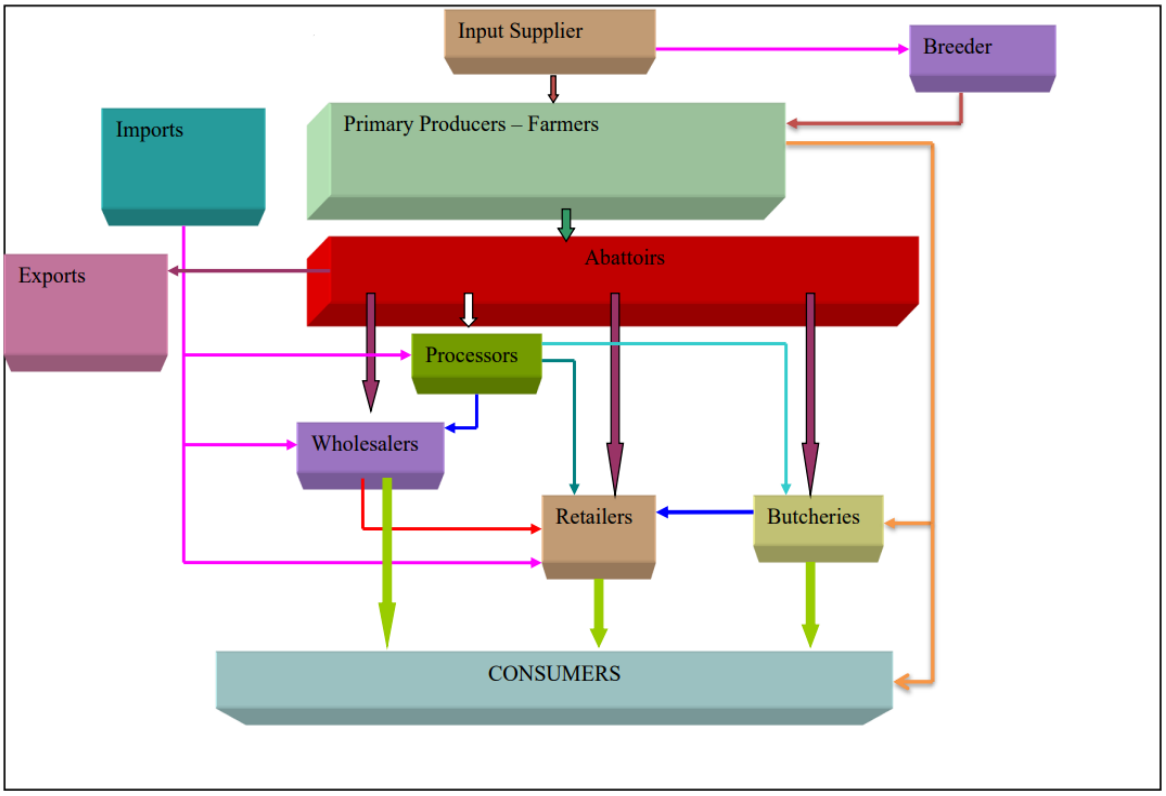

Figure 1: Pork value chain showing the different levels at which companies work to reduce costs (DALRRD, 2021)

The pork value chain encompasses various stages, including input suppliers, primary breeders, pig producers (from farrowing to finishing), abattoirs, processors, wholesalers, retailers, restaurants, butcheries, and ultimately the consumer. In South Africa, the livestock industry is divided into feed manufacturers (who process feed for direct sales), feedlots, and informal feed milling. Feed manufacturers are further categorized into those specializing in balanced feed and those focusing on pre-mixed feed production. According to Vermeulen and Louw (2020), nearly 75% of commercial pig producers mix their own feed rations, allowing for diets tailored to their specific needs while meeting the dietary requirements for each growth stage. The pig industry contributed 6.4% of total feed sales in 2021/2022, which is 2.3% up from 2015/2016 (AFMA, 2023).

Pig producers typically operate farrow-to-finish units on the same farm, accommodating artificial insemination or natural impregnation of gilts or sows by a boar, weaning piglets at 21-28 days, and placing piglets into grower houses from 70 days until slaughter. In South Africa, there are an estimated 431 abattoirs and only 143 abattoirs slaughter pigs for 156 commercial pig farmers, 19 stud farmers, and 365 small-hold farmers. The total number of sows is estimated at 136,000 (DALRRD, 2021).

The South African pork industry has two distinct branches: 45% of pigs produced are sold to the fresh meat market, and 55% are sold to the processed meat market. At the processor level, significant effort is made to add value to the product before it is sold to the retailer, who primarily acts as the distributor. Some wholesalers in the fresh meat chain undertake packing and cutting operations, although these typically occur at the abattoir. In South Africa, Enterprise Foods and Eskort account for approximately 80% of the processing, due to the significant capital investment required to enter the meat processing market (Davids et al., 2014).

2.1.2 South African pork classification regulations

The regulations for classifying pig carcasses in South Africa, as described in Government Notice No. R. 55 of 2015, provide specific guidelines to ensure accurate classification and marketing of meat produced for sale. These regulations outline the classification of pig carcass characteristics based on several parameters. Pig carcasses are classified into nine different classes on the day of slaughter. These classes include "Sucking pig," "P," "O," "R," "C," "U," "S," and "Sausage pig," or "Rough." The classification is performed on either the whole carcass or a side of the carcass.

Abattoirs in South Africa use two types of probes to take carcass measurements, the Hennessey Grading Probe or the Intrascope. Both probes measure the muscle thickness and back fat thickness (BFT) between the 2nd and 3rd last rib, approximately 45 mm from the back carcass midline while the carcass is hanging. Predictive formulas developed by Bruwer (1992) use these measurements to predict the lean meat percentage. A prediction equation specific to the device used is applied. The resulting prediction of LM% is rounded to the nearest whole number before the carcass is classified into one of the above-mentioned classes.

The predictive formulas are as follows:

Hennessey % lean = 72.5114 – (0.4618 x fat thickness) + (0.057 x eye muscle thickness).

Intrascope % lean = 74.4367 – (0.4023 x fat thickness).

A pig carcass is classified as "Rough" when it has a conformation class of 1, poor appearance due to inadequate breeding characteristics, emaciation of the carcass, noticeably thick and rough skin, and excessive oiliness of the fat.

Beyond the classification categories, each pig carcass receives a conformation score determined through a visual assessment by the classifier. The damage extent is rated on a scale from one to three: Class 1 denotes slight damage, Class 2 indicates moderate damage, and Class 3 signifies severe damage.

The P, O, R, C, U, and S, classification system classes pig carcasses according to their lean meat percentage and backfat thickness (Hugo & Roodt, 2015).

P classification lean meat percentage is 70% or higher and the lowest BFT of 12 mm or less.
O classification lean meat percentage ranges from 68-69% and BFT ranges from 13-17 mm.
R classification lean meat percentage ranges from 66-67% and BFT ranges from 18-22 mm.
C classification lean meat percentage ranges from 64-65% and BFT ranges from 23-27 mm.
U classification lean meat percentage ranges from 62-63% and BFT ranges from 28-32 mm.
S classification lean meat percentages are the lowest at 61% or less and BFT the thickest at more than 32 mm (Siebrits *et al.*, 2012).

The South African payment system encourages the production of lean pigs because it has a lean meat rewarding strategy, meaning that consumers pay more per kilogram of lean meat and farmers receive higher payment when producing P and O carcasses. P and O classification is often awarded the same price per kilogram. Suppliers find it more cost-effective to produce pigs in the P and O groups, which have a high lean meat percentage and low BFT (Roodt, 2003).

As of November 26, 2023, the pork classification amended by Regulation R3450 GG48654 must be implemented by all (classification) abattoirs. The regulation stipulates the following:

- Boars under 23 weeks of age (not older than 22 weeks of age) up to 110 kg live weight can be classified.
- Boars of unknown age can be classified as up to 100 kg live weight.
- Boars, females, and castrates of unknown age over 100 kg will be marked as a 'sausage pig'.

Regulation R863 of 1 September 2006 states that animals that show signs of late castration, including immuno-castrates, are classified as boars. Thus, immuno-castrates of unknown age over 100 kg will be classified as ‘sausage pigs. Immuno-castrates are deemed as castrates by the standards set by Pork 360. The Pork 360 abattoir standard also states that immuno-castrated boars are excluded from this age requirement if they classify as P, O, or

R. It should be noted that older immune-castrated males between 100 kg and 110 kg will be marked as sausage pigs and are eligible to be Pork 360 if the immune-castrates are not overfat (i.e. C, U, or S). Abattoirs /buyers cannot apply a price penalty on these pigs (SAPPO, 2023).

2.1.3 Consumer preferences

The South African pork industry is consumer-driven, so much so that pig breeders in the past have adopted their breeding goals according to the needs of the producers, processors, and consumers and have made significant genetic improvements in the traits of interest. However, it is becoming challenging to meet the market needs and expectations of consumers in general (Merks *et al.,* 2011). It is important to note that genetic progress in individual traits is inversely related to the number of traits included in the breeding goal and that negative or positive genetic correlations between traits exist. Therefore, it is important to choose traits with great care. The choice of breeding goals and successful breeding has led to the genetic improvement of economically important traits such as daily gain, backfat thickness, feed efficiency, and litter size, especially during the last decade. Breeding goals have been, or are presently being, set up more broadly to include traits that are important to society (Dekkers *et al.*, 2011). In pig breeding, this means that by the time the desired trait is in the product, consumer expectations and trends have changed. The time between formulating the breeding goal and the actual consumption of pork can take several years, depending on the generation interval and genetic lag.

There is increasing societal pressure and desire from several pig producers to include traits such as pork safety and improved quality, the health and welfare of pigs, and the environmental impact of pig production (Kanis *et al.*, 1995; Verbeke and Viaene, 1999). Furthermore, the health of the pigs is becoming more important due to the concentration and increasing scale of pig production. This requires strict biosecurity measures, high-health breeding farms, and selection for general disease resistance under commercial conditions (Merks, 2000).

South African Pork Producers Organisation (SAPPO) educates consumers about the nutritional and health benefits of pork products. They also assure the consumer of a safe product because of the quality assurance and traceability scheme (Lubinga *et al.*, 2017). From 2018 to 2020, the average pork consumption per capita was 4 kg, compared to the respective 13 kg and 35 kg for average beef and poultry consumption in South Africa (BFAP, 2020),

possibly due to the consumer education/promotion initiative funded through the statutory levies' income.

Market research indicates that pork consumption has significant growth potential. To boost pork consumption, marketing strategies emphasize enhancing pork's visibility through consumer education and promotions (Lubinga et al., 2017). For increased pork consumption, the industry must provide consumers with affordable, high-quality end products (Davids et al., 2014). SAPPO communicates to consumers that pork is healthy, affordable, and offers great value in terms of nutrition and taste. Both loyal consumers and those unfamiliar with pork are encouraged to purchase it with confidence. The initiative addresses common misconceptions about fat content, nutritional value, and quality consistency of pork products. The consumer education and promotion efforts aim to build trust in the health and safety of pork, as well as its brand identity. In South Africa, pigs are bred to produce leaner products with lower fat content. SAPPO highlights that pork is nutrient-dense, containing protein, vitamins, and minerals. Pork protein is highly digestible, contains all essential amino acids, and is considered a complete protein (Lubinga et al., 2017).

2.2 Factors influencing carcass composition and quality and fat deposition

According to Irshad *et al.* (2013), the factors influencing carcass composition and quality are genetics, physiological age, sex, nutrition, environment, and abnormal growth factors. Carcass composition differs between species and breeds and within breeds, and differs in carcass parameters (Wagner *et al.,* 1999). Adipose tissue deposition is influenced by intrinsic factors like body weight, sex, genotype, and environmental factors like diet, temperature, and the use of exogenous hormones (Kouba & Sellier, 2011).

2.2.1 Genetics

In recent decades, pig genetics have advanced significantly in measuring growth, backfat, and feed efficiency. Pig geneticists have eliminated defects by targeting genetic markers and selecting for enhanced animal performance, focusing on traits like feed efficiency, growth rate, meat quality, and litter size. The ability to genotype animals for thousands of genes to identify those responsible for specific traits, combined with genomic selection, accelerates genetic improvement and reduces inbreeding. Recently, there has been an increased focus on traits and responses such as disease susceptibility and heat stress. These genetic advancements could lead to more sustainable production and improved pork products for consumers (Mote and Rothschild, 2020). As animals age, the ratio of muscle to bone increases and a decrease in muscle growth rate occurs, increasing the ratio of fat to muscle (Lawrie, 2006). The rate of development and average mature weight differ between breeds. Standardising to the same stage of maturity of body weight causes much less variation in carcass composition than age or weight standardisation. Strains and hybrids of modern pigs used in pork and bacon production have better carcass composition when compared to traditional pig breeds, due to increased lean meat percentage (Irshad *et al.,* 2013). When comparing Duroc to modern pig strains it was found that Duroc has a high portion of intramuscular fat (Wood *et al.,* 2008). Leaner and lighter breeds react differently to pre-slaughter and slaughter processing methods and tend to suffer more from cold shortening.

The word breed has become rudimentary in the term pig breeds, because slaughtered pigs are no longer purebred and pig genetic companies produce synthetic lines composed of multiple breeds (Causer *et al.,* 2006). Sire synthetic lines are employed to enhance production traits like growth rate, feed efficiency, meat quality, and carcass yield. On the other hand, sow lines focus on improving key traits such as fertility, milk production, maintenance efficiency, and litter size (Bourdon, 2000).

2.2.2 Age

Age is a significant factor that influences carcass composition, quality, and fat deposition in animals. It can be categorized into physiological age, which refers to the stage of development, and chronological age, which represents the actual number of days, months, or years an animal has lived. Understanding the effects of age on growth and tissue deposition is essential for optimising production and ensuring desired carcass characteristics. The rate of growth and tissue deposition varies within breeds and even within age groups, with some animals performing above or below breed averages. Crampton (1908) noted the variation in

growth rates among animals of the same age, highlighting the importance of considering individual differences within age categories.

Both physiological and chronological age play a role in determining the rate of growth and the relative development of different tissues in the animal's body. During the initial stages of the growing period, muscle growth tends to outpace fat deposition. This means that the muscle development rate is higher than the fat tissue accumulation rate. However, as animals progress in age, the rate of fat deposition increases, surpassing the rate of muscle growth. This shift in the balance of tissue development is a natural physiological process and can impact the overall carcass composition (Irshad *et al*., 2013).

Bosch *et al*. (2012) investigated the effect of age on the amount of polyunsaturated fatty acids (PUFA) in intramuscular fat and subcutaneous backfat. The study found that, as animals age, the levels of PUFA in these fat deposits decrease. This suggests that older animals tend to have lower levels of unsaturated fats in their tissues, which can have implications for meat quality and nutritional attributes.

Another study conducted by Schönfeldt and Strydom (2011) focused on the impact of age on the tenderness of cooked beef. The research indicated that age did not significantly affect collagen content, which is a connective tissue component associated with meat toughness. However, age did have a noticeable effect on tenderness and collagen solubility, with both tenderness and collagen solubility decreasing as animals age. This suggests that older animals may exhibit reduced tenderness and lower collagen solubility, potentially influencing the sensory attributes and palatability of the meat.

2.2.3 Gender

Gender plays a significant role in determining carcass composition, quality, and fat deposition in pigs, making it an important factor to consider in modern pig genetics. Boars, in general, exhibit superior performance in terms of daily weight gain and feed conversion ratio compared to gilts and barrows. However, the advantage in lean meat content associated with boars is often accompanied by compromised meat quality (Latorre *et al*., 2003; Dube *et al.*, 2011).

One notable aspect is the higher stress susceptibility observed in boars compared to gilts and barrows. This increased sensitivity to stress leads to rapid postmortem muscle glycogen degradation, resulting in elevated levels of lactic acid and subsequently reducing the meat pH. A low pH value negatively impacts the water-holding capacity of the meat, leading to significant water losses during storage and cooking. This phenomenon ultimately results in pale meat, a

characteristic more pronounced in boars than in barrows. Gender differences can also influence fatty acid deposition in the body, primarily due to the hormonally determined variations in fat accumulation rates. This aspect has implications for the dietetic value and shelf life of meat and meat products (Jaturasitha *et al*., 2006).

Male carcasses that have not been castrated are typically leaner and have less fat, whereas castrated males and females produce fatter carcasses. Castrated carcasses exhibit greater backfat thickness and higher fat content over the *gluteus medius* muscle compared to gilts. Gilts, however, have a higher percentage of total carcass trimmed cut yield of loin compared to castrates (7.3% versus 6.9%), with no significant differences observed for hams and shoulders (Latorre et al., 2003). Similar findings were reported by Schiavon et al. (2015). This difference may be attributed to the higher feed intake of castrates compared to gilts (Dube et al., 2011). Additionally, gilts have a larger loin eye area compared to boars (Beattie et al., 1999), while intact males tend to have poorer fat quality than barrows and females (Wood et al., 2008).

2.2.4 Body weight

Body weight is an intrinsic factor that influences adipose tissue deposition in animals. It refers to the animal's actual weight and plays a crucial role in determining carcass composition and characteristics. As body weight increases, various changes occur in carcass composition, including muscle area, lean content, and the lean-to-fat ratio (Wagner *et al*., 1999).

Studies have demonstrated the impact of body weight on carcass composition characteristics. For instance, Beattie *et al*. (1999) observed that increasing carcass weight from 70 kg to 100 kg resulted in a significant increase in eye muscle area, a decrease in lean content, and a decrease in the lean-to-fat ratio. These findings suggest that, as animals gain weight, there is an increase in muscle size and a decrease in the relative proportion of lean tissue compared to fat.

Wagner *et al*. (1999) conducted a comprehensive study to assess body composition changes in different weight groups, genetic populations, and between genders (barrows and gilts). Their research focused on variables such as backfat thickness, loin muscle area, and last rib backfat thickness. The study revealed that body weight, genetic population, and gender had a significant effect on these carcass characteristics. Specifically, as the weight group increased, the difference in backfat thickness between barrows and gilts also increased until a weight of 152 kg was reached. Beyond this weight, the difference in backfat thickness between genders remained the same. This finding indicates that body weight influences the development of

backfat thickness differently in barrows and gilts, with the effect becoming more pronounced as animals become heavier.

2.2.5 Environment

The environment plays a crucial role in the development and growth of pigs, ultimately influencing carcass composition and quality. Starting from the time of the fetus in the uterus to reaching slaughter weight, various environmental factors come into play. Powell & Aberle (1981) discovered that runt piglets, characterised by lower birth weights (0.97 ± 0.2 kg), exhibited a higher percentage of red type II muscle fibres in the semimembranosus muscle compared to their littermates with higher birth weights (1.56 ± 0.03 kg),

Seasonal variations have also been found to impact pig carcass composition. For instance, a study by Dube *et al*. (2011) reported that Landrace pigs tested during winter exhibited greater leanness ($P < 0.001$) compared to those tested during summer. Furthermore, Gajana *et al*. (2013) observed seasonal differences in meat quality, with a higher incidence of PSE (pale, soft, exudative) meat during autumn (68% of carcasses) and a higher incidence of DFD (dark, firm, dry) meat during winter (32% of carcasses).

2.2.6 Nutrition

Nutrition plays a critical role in the growth, composition, and quality of carcasses in pigs. Adequate nutrition ensures optimal development and deposition of tissues, including muscle and fat. Different factors related to nutrition influence carcass composition and fat deposition in pigs.

One important aspect of nutrition is the concept of nutrient partitioning within the body. The body prioritises the allocation of nutrients based on the rank of functions. Tissues of vital organs and those involved in physiological processes receive nutrients first, followed by bone, muscle, and fat deposition (Irshad *et al*., 2013). This hierarchy ensures that the body's essential functions are supported before allocating nutrients to tissue growth. It highlights the importance of providing a well-balanced diet that meets the pig's nutritional requirements for optimal growth and body composition.

Pigs are typically fed diets specific to their growth phases, weaners, growers, and finishers. Multiple-phase feeding programs have shown benefits compared to single-phase feeding, as they align nutrient requirements with the pig's changing growth stage. This approach

minimises under- and overfeeding, optimising nutrient utilisation and optimising growth efficiency (Van Heugten, 2010).

Studies have shown that nutrition during early growth stages can have long-lasting effects on body composition. Piglets fed a high plane of nutrition have different body compositions compared to those on a low plane of nutrition at 16 weeks-of-age, according to McMeekan (1940). The piglets on a high plane of nutrition had higher fat deposition, whereas the low plane piglets had higher muscle composition. Notably, the high plane piglets exhibited a higher bone-to-muscle ratio, indicating good meat quality.

The protein content of the diet is another crucial aspect of nutrition. Researchers have explored the effects of low-protein diets on pig performance, carcass composition, and the environment (Wood *et al*., 2013). Low-protein diets have shown negative impacts on feed efficiency and carcass composition, including a decrease in loin proportion and alterations in fatty acid composition. However, Wood *et al*. (2013) concluded that reducing protein content by 11% in the diet for pigs from 40 kg to 115 kg could help reduce nitrogen emissions while maintaining similar carcass fat levels. Proper diet formulation and phase feeding can effectively match nutrient requirements and minimise nutrient wastage, contributing to environmental sustainability.

The fatty acid composition of adipose tissue in pigs is influenced by diet, fat content of the diet, and gender, and it can significantly impact meat quality (Wood *et al*., 2008). The ratio of saturated fatty acids (SFA) to polyunsaturated fatty acids (PUFA) affects the melting point and texture of fat, influencing its separation from muscle. Higher backfat thickness is associated with increased SFA and decreased PUFA content, resulting in firmer fat that is less likely to separate from the muscle.

2.3 Beta-agonists in animal production

Beta-adrenergic agonists, or beta-agonists, are analogues of adrenaline that bind to beta-receptors. Initially used as medications for pulmonary diseases in both humans and animals, beta-agonists were later adopted in animal production to enhance carcass characteristics. They achieve this by reducing adipose tissue deposition and promoting muscle gain, making their use in this context quite widespread (Croubles et al., 2004).

2.3.1 History of use and development

The use and development of beta-adrenergic agonists in animal production have a significant history, particularly in the context of pigs and cattle. Beta-adrenergic agonists have been used for several decades in the treatment of lung diseases such as asthma and bronchitis, both in animals and humans. Additionally, they have been employed to inhibit uterine contractions in both animal and human applications (Anderson *et al*., 2005; Pleadin *et al*., 2012a; Pleadin *et al*., 2012b). Figure 2 illustrates the structure of the wide variety of beta-agonists in use.

One of the key properties of beta-adrenergic agonists is their ability to repartition nutrients, redirecting them towards muscle growth rather than adipose tissue deposition. This characteristic has earned them the designation of repartitioning agents. Beta-adrenergic agonists stimulate three metabolic actions: they increase metabolic rate, decrease adipose lipid deposition, and enhance muscle accretion. These metabolic effects contribute to improved performance metrics such as dressing percentage, leanness, weight gain, and feed efficiency. The positive effects of beta-adrenergic agonists have been observed in various livestock species, including sheep, cattle, chickens, and pigs. These effects encompass enhanced growth and performance and reductions in the time required to reach ideal slaughter weight. By accelerating growth and improving feed efficiency, beta-adrenergic agonists can potentially lead to increased profit margins by reducing overall maintenance costs (Moody *et al*., 2000; Anderson *et al*., 2005).

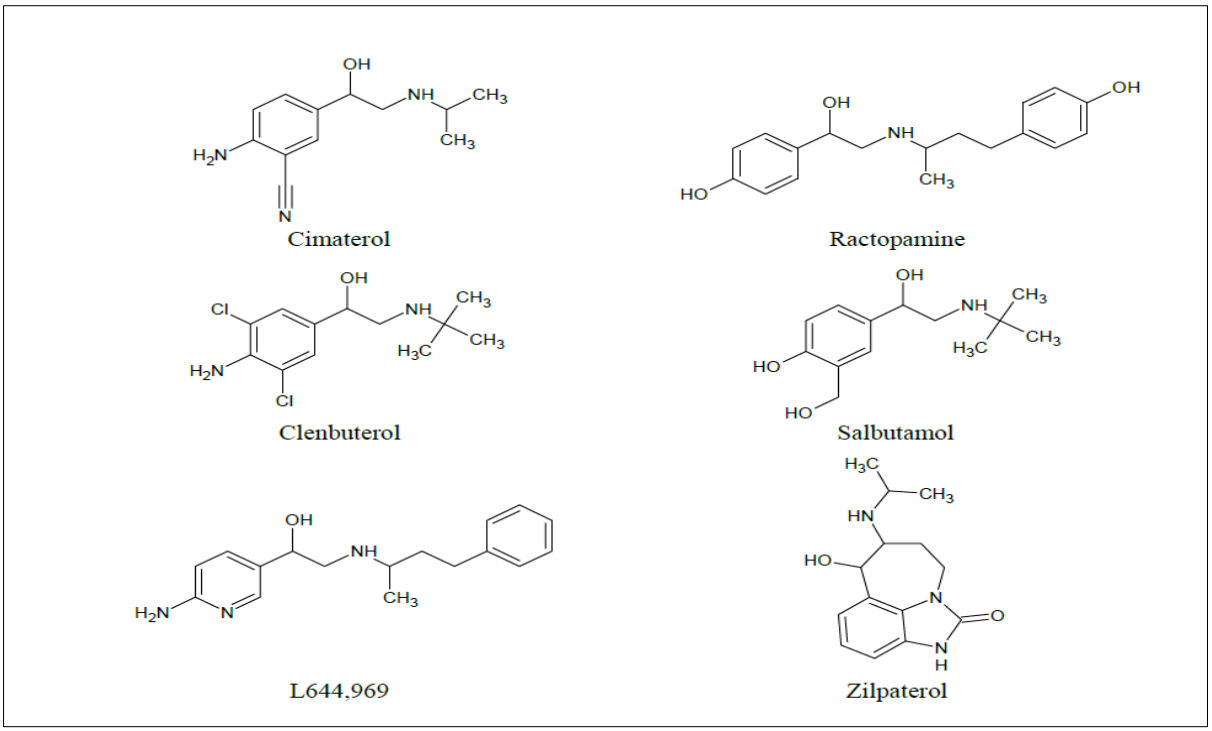

Figure 2: Structures of multiple beta-adrenergic agonists (adapted from Anderson *et al.,* 2005).

2.3.2 Mode of action of beta-adrenergic agonists

The mode of action of beta-adrenergic agonists in pig production involves the binding of ractopamine or other beta-agonists to beta-adrenergic receptors present in both fat cells and skeletal muscle cells. This binding initiates a series of biochemical signals that trigger a complex pathway involving the activation of various enzymes. In fat cells, these signals lead to a reduction in the rates of fat synthesis and storage, a process known as lipogenesis, while simultaneously promoting the mobilisation of fat from the cells, referred to as lipolysis (Anderson and Johnson, 2004).

The resulting changes brought about by beta-adrenergic agonists in fat cells contribute to a slower rate of fat accumulation in the animal. The magnitude of these changes is influenced by factors such as the dose or amount of beta-agonist consumed and the duration of consumption (Armstrong *et al*., 2004). Additionally, it is worth noting that skeletal muscle cells, specifically muscle fibres, also possess beta-adrenergic receptors on their surface.

When beta-agonists interact with these receptors in muscle fibres, they trigger similar signalling pathways as observed in fat cells. However, in muscle cells, these signalling events lead to an increase in the synthesis of ribonucleic acid (RNA), which subsequently promotes the synthesis of muscle proteins within the cells. As a result, the overall effect of beta-agonists

on muscle tissue is an increase in cell size, a phenomenon known as hypertrophy, without an increase in cell number. It is important to highlight that the total number of muscle fibres in a muscle is primarily determined at birth in most domestic animal species, and subsequent growth occurs through the elongation and expansion of existing cells (Beermann, 2001; Du *et al*., 2010).

These changes in muscle tissue induced by beta-agonists closely resemble the physiological adaptations observed in humans during intense weightlifting or exercise, leading to muscle enlargement and growth. In the case of pigs fed with beta-agonists like ractopamine HCl for 4-6 weeks, it has been found that muscle cell growth rates are approximately 20-30% greater compared to non-supplemented animals. However, it is crucial to note that the effects on muscle tissue are not progressive and do not persist over extended periods (Beermann, 2001).

Therefore, it is recommended to administer beta-agonists towards the end of the finishing period, as longer feeding periods do not provide significant growth benefits or improve output and may result in diminished economic returns. Since muscle growth requires less energy compared to adipose tissue or fat growth, the utilisation of feed for growth purposes in animals fed with beta-agonists for short periods proves to be more efficient overall. The stimulation of muscle growth by beta-agonists reduces the rate of nutrient allocation for adipose tissue growth, resulting in a reduced feed requirement to achieve the same animal weight. Consequently, the administration of beta-agonists to meat-producing animals leads to the production of less animal waste and a reduced environmental impact (Muir, 1998; Beermann, 2001).

The beta-adrenergic receptors organise a precise chain of biological interactions upon activation, playing a pivotal role in cellular signalling. This process is fundamentally connected with Gs proteins a type of G protein that activate signalling pathways in response to cell surface receptors and the stimulation of adenyl cyclase, an enzyme responsible for the conversion of adenosine triphosphate (ATP), into cyclic adenosine monophosphate (cAMP). As an intracellular signalling molecule, cAMP exhibits a high affinity for the regulatory subunit of protein kinase A (PKA), instigating the release of its catalytic subunit. Consequently, an intricate modulation of intracellular enzymes is executed via PKA-mediated phosphorylation. Following the activation of beta-adrenergic receptors, beta-agonists incite the cAMP signalling pathway, resulting in a dual outcome. Firstly, rate-limiting enzymes in lipolysis are activated, promoting the breakdown of fats. Simultaneously, the activity of lipogenic enzymes, involved in the new synthesis of fatty acids and triglycerides, is inhibited. The mechanistic interplay between beta-adrenergic receptors and beta-agonists significantly impacts muscle

physiology, inducing muscle cell hypertrophy and augmenting lean mass. This phenomenon is primarily attributed to the concerted action of the beta-adrenergic receptor pathway. The culmination of this cellular signalling cascade within the muscle leads to a surge in total RNA and myofibre proteins mRNA abundance, culminating in an increased in vivo protein synthesis rate (Moody *et al*., 2000; Anderson *et al*., 2014).

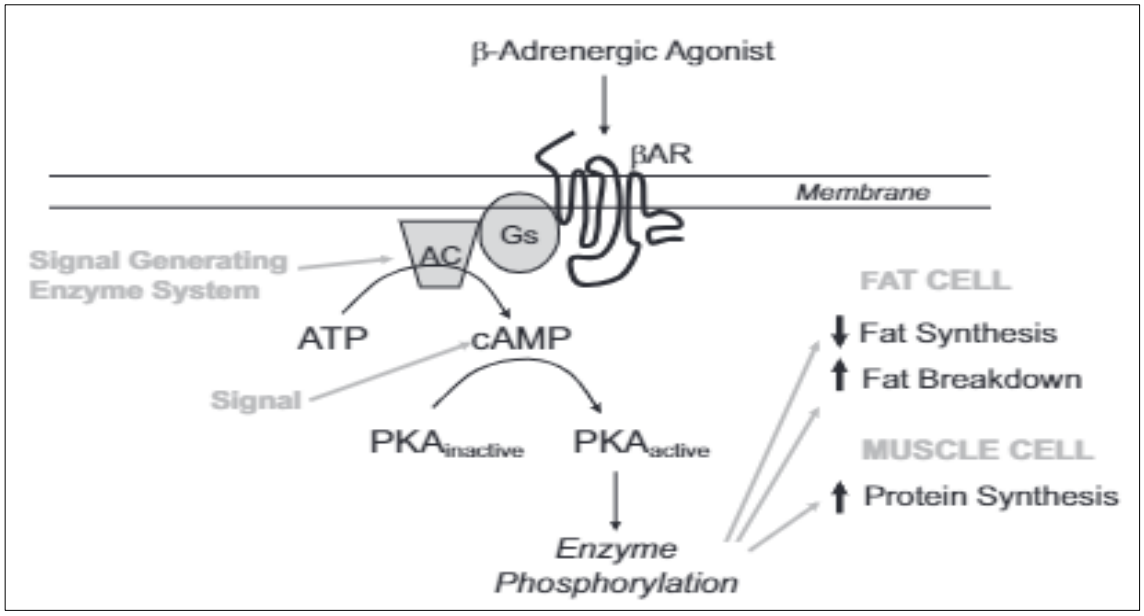

Figure 3: Mechanism of signal transduction from beta-adrenergic receptors (BAR) (adapted from D'Mello, 2000)

When an agonist activates the beta-adrenergic receptor, it stimulates Gs proteins. These proteins, in turn, activate adenylyl cyclase (AC), which converts adenosine triphosphate (ATP) into cyclic adenosine monophosphate (cAMP). cAMP serves as an intracellular signalling molecule. Elevated levels of cAMP activate protein kinase A (PKA), which phosphorylates enzymes and regulatory factors crucial for metabolic regulation (D'Mello, 2000).

2.3.3 Commercially available beta-adrenergic agonists

Beta-adrenergic agonists have been extensively studied in livestock species. Among the commercially available options are cimaterol, clenbuterol, L-644-969, ractopamine, salbutamol, and zilpaterol. These beta-adrenergic agonists are orally active and are commonly used as feed ingredients in pig production. They belong to a class of compounds known as phenethanolamines (Anderson *et al*., 2005; Arp *et al*., 2014). Phenethanolamines have a long history of safe and effective use in human medicine. For over three decades, they have been employed as bronchodilators to manage asthma, uterine

relaxants to prevent premature labour in pregnant women, and cardio stimulants to address cardiac irregularities. The extensive clinical use of phenethanolamines in human medicine attests to their safety profile in animal applications (Anderson *et al*., 2005; Gregersen *et al*., 2013).

In the context of lean efficiency, beta-adrenergic agonists have been found to significantly affect fat and muscle metabolism in livestock species. It is important to note that these compounds do not possess antibiotic properties and, as such, do not function as antibiotic growth promoters. Furthermore, they are not classified as anabolic steroids. Instead, they are often referred to as repartitioning agents due to their remarkable ability to redirect nutrients away from adipose tissue (fat) and toward muscle (Muir, 1998; McGuffey, 2022).

The administration of beta-adrenergic agonists has consistently shown positive effects on livestock production. The general effects of beta-adrenergic agonists include improved feed utilisation efficiency, increased leanness, elevated dressing percentage (carcass weight/live weight ratio), and an accelerated rate of weight gain. These effects have been observed in various livestock species, such as lambs, broilers, turkeys, beef cattle, and pigs. However, it is essential to consider several factors that can influence the response to beta-adrenergic agonists. Factors such as diet composition, dosage, duration of treatment, age, weight, and genetics have been identified as critical elements in the successful implementation of beta-adrenergic agonists in livestock production. Understanding and fine-tuning these factors are key to optimising the effectiveness and safety of beta-adrenergic agonist usage in pig production and other livestock sectors (Anderson *et al*., 2005).

2.3.4 Human safety of beta-agonist use in production animals

In the early 1990s, indiscriminate use of a beta-agonist, clenbuterol, in Spain and France led to short term food poisoning in humans. Due to public safety concerns, an outright ban of all beta-agonist use in livestock was issued in the European Union (Directive 96/22/EC). Many other countries subsequently established national monitoring systems and international trade restrictions to eliminate the misuse of beta-agonists. However, the use of ractopamine HCl in finishing pigs is allowed in South Africa and 20 other countries (Anderson *et al.,* 2005). The safety of using beta-adrenergic agonists in production animals, specifically pigs, has been a topic of great concern (Smith, 2014).

Unlike clenbuterol, ractopamine HCl belongs to a newer generation of beta-agonists that have been developed with structural modifications. These modifications result in shorter half-lives and lower oral potencies, ensuring their safe use in livestock. Clenbuterol, originally

designed as a pharmaceutical medicine with a long half-life for the treatment of respiratory and other diseases, does not possess the desired properties required for a feed ingredient. The negative consequences associated with the illegal use of clenbuterol do not apply to current beta-agonists (Moody *et al., 2000)*. Any beta-agonist approved as a lean efficiency enhancer must adhere to or exceed rigorous human food safety standards (Moody *et al*., 2000). This emphasis on safety ensures that beta-agonists used in livestock production do not pose a risk to human health.

Strict safety standards and ongoing testing are implemented to ensure the safety of feed additives and animal health products for both human health and animal welfare. While some beta-agonists, such as clenbuterol, are approved for human medical use, they are not approved for use in the meat industry. The unique structure and metabolism of specific beta-agonists affect safety considerations, including withdrawal periods and product residues. Ractopamine is approved for use in meat animals, and consuming products from animals fed ractopamine is safe, posing no risk to the animals (Beermann, 2001).

2.3.5 Ractopamine

Ractopamine is a feed ingredient used in finishing pigs that has been shown to increase muscle protein in pork carcasses and improve production efficiency (Woods *et al*., 2011). Ractopamine HCl (ractopamine HCl; Paylean, Elanco Animal Health, Greenfield, IN) is a phenethanolamine repartitioning agent with beta-adrenergic agonist activity that redirects nutrients away from fat growth and promotes increased carcass muscle growth (Ricks *et al*., 1984; Moody *et al*., 2000). Feeding finishing pigs diets containing ractopamine HCl has been found to improve feed conversion ratio (F:G) and increase the average daily gain (ADG), resulting in reduced time to market and less feed required for equivalent lean growth (Watkins *et al*., 1990; Armstrong *et al*., 2004; Anderson *et al*., 2005; Apple *et al*., 2007).

Ractopamine HCl is a drug that stimulates beta-adrenergic receptors, exerting effects similar to epinephrine, while also displaying anabolic properties that promote lean muscle conservation and reduce fat deposition. In 1999, the FDA approved the use of ractopamine in pigs, citing benefits such as increased weight gain, improved feed efficiency, and enhanced carcass leanness. This approval applies to finishing pigs fed a complete ration with at least 16% crude protein, including ractopamine HCl at 6 mg/kg of feed, during the last 21 to 28 days before slaughter. The acceptable daily intake (ADI) of ractopamine in the human diet is set at 1.25 µg/kg body weight, with tolerances established for parent ractopamine residues in pigs

liver at 0.15 mg/kg (150 µg/kg of liver) and in pigs muscle at 0.05 mg/kg (50 µg/kg of muscle). Notably, no withdrawal time is required based on FDA approval (Smith., 2014)

Following its initial approval for pigs, the FDA also approved ractopamine HCl for use in cattle in 2003 and turkeys in 2008. It is now approved as a veterinary drug for pigs in 21 countries, including Australia, Brazil, Canada, Hong Kong, Indonesia, Mexico, New Zealand, South Africa, South Korea, and the USA. Additionally, Canada, Mexico, Indonesia, and the USA have approved its use in beef production. Although Japan has not approved ractopamine HCl for domestic use, it has established acceptable daily intakes (ADIs) and maximum residue limits (MRLs) for pork and beef, acknowledging its use in other countries for import purposes. However, neither the European Union (EU) nor China has approved ractopamine for domestic use and do not allow residues of ractopamine in imported food. The EU specifically bans all beta-agonists intended solely for growth promotion without therapeutic purposes, citing unresolved safety issues and scientific concerns related to ractopamine HCl. China has expressed concerns about the safety of food from animals treated with ractopamine HCl, particularly based on residue data in pigs, especially in lung tissue (Smith, 2014).

2.3.6 Salbutamol

The use of salbutamol as an alternative to ractopamine in the pork industry has been explored in several studies. In a study conducted by Warriss *et al*. (1990), it was observed that the growth rate of pigs was not affected by salbutamol at 3 mg/kg. Both the control group and the group given salbutamol at 3 mg/kg exhibited similar average daily gains (ADG) of approximately 790 g per day. Pigs fed the control diet gained an average of 5.49 kg per week, while those given salbutamol at 3 mg/kg gained slightly more, with an average of 5.63 kg per week. When evaluating live weight, liver yield, and carcass yield and quality, no significant differences were found in the final live weight of the pigs in each group. The duration of fasting before slaughter had an impact on weight loss, with pigs subjected to a 24-hour fast losing more weight compared to those fasting for 6 hours. However, the administration of salbutamol at 3 mg/ kg did not influence this weight loss. Treated pigs showed higher hot and cold carcass weights, resulting in a 2% improvement in dressing percentage. While the longer fasting period slightly reduced carcass yield, no significant effects were observed in other measurements. Carcasses from pigs treated with salbutamol at 3 mg/kg were found to be leaner, with *longissimus dorsi* (LD) muscles exhibiting a 10% larger cross-sectional area. Salbutamol treatment did not affect the pH values in LD and *semimembranosus* muscles, drip loss from the LD, or its reflectance value. Furthermore, there was no evidence of an increased likelihood of producing pale, soft, and exudative (PSE) meat in treated animals. Moisture, fat,

and total protein concentrations in the LD muscles did not differ between the treated and control groups.

Warriss et al. (1990) found that salbutamol did not worsen the loss of fat firmness linked to increased leanness in treated pigs. Instead, salbutamol-treated pigs exhibited softer fat that tended to separate from the underlying lean muscle. The administration of salbutamol resulted in smaller livers with reduced glycogen content, especially after a short food withdrawal period. These effects were lessened with a longer fasting period, leading to non-significant differences between treated and control groups.

The lower heme pigment concentration in the LD muscle of treated pigs indicates a possible shift in muscle fiber type distribution, with a decrease in red oxidative fibers and an increase in white glycolytic and glycolytic-oxidative fibers. These fibre types have high glycogen content and glycogenolytic capacity, contributing to the observed effects (Strydom *et al*., 2011). These findings align with previous research, including studies by Coleman *et al*. (1985), supporting the positive impact of salbutamol on carcass weight, thinner backfat, and larger LD muscle cross-sectional area as found by Dunshea *et al*. (2005).

2.3.7 Environmental benefit of ractopamine and growth promotor use

The utilisation of ractopamine and other growth promoters in pork production not only offers advantages in terms of improved rate of gain, feed efficiency, and carcass leanness but also has potential environmental benefits. One notable benefit is the potential reduction in the number of animals required to meet the current levels of pork protein production in the United States, thanks to the increased lean carcass yield observed in pigs fed ractopamine (Aalhus *et al*., 1990; Stites *et al*., 1991; Uttaro *et al*., 1993). This reduction in animal numbers can lead to a decrease in the demand for cropland and natural resources.

The decreased demand for cropland would result in a corresponding reduction in water usage for irrigation, energy consumption for field operations and grain processing, as well as decreased reliance on pesticides (insecticide and herbicide) and fertilisers. Another potential environmental benefit is the improved feed utilisation efficiency of animals fed ractopamine, translating to greater weight gain per unit of feed consumed (Crome *et al*., 1996; Dunshea *et al*., 1998; Mimbs *et al*., 2005). If confirmed through calculations, this benefit could further reduce the cropland requirements for equivalent pork production.

Furthermore, the use of ractopamine has been associated with reduced nitrogen and phosphate excretion per pig (DeCamp *et al*., 2001), resulting in potential environmental

benefits such as decreased nutrient runoff and reduced odour generation (Hankins *et al*., 2001). While the production benefits of ractopamine feeding have been extensively documented (Apple *et al*., 2007), the potential enhancements in resource utilisation efficiency and environmental advantages have yet to be fully determined.

2.4 Conclusion

From this literature review it is important to note the potential that beta-agonists have in terms of improving animal performance without the use of antibiotics. It is also important to note the vast advances made in pig genetic improvement, which focuses on similar production parameters, i.e. FCR and lean meat percentage, rather than beta-agonists. Many factors like gender and environment also affect these characteristics. For the animal to perform optimally all factors need to be considered. Economics is another important factor to note; lowering total dietary crude protein or removing expensive additives like beta-agonists are both ways to save the farmer money or improve animal performance to increase the return on investment.

Chapter 3: Materials and Methods

The trial was conducted at Baynesfield Swine Research Unit (BSRU), located on Baynesfield Estate in KwaZulu Natal province, South Africa. The environment is tropical and humid, with high summer rainfall between October and March. Average daily maximum temperatures range from 20℃ to 35℃.

3.1 Housing

All trial procedures were approved by the NAS and Animal Ethics Committee University of Pretoria (NAS128/2022).

The pig house had open sides with automatically controlled curtains that opened and closed according to temperature and wind speed. For the trial, a total of 440 grower pigs at 70 days of age were obtained from the weaner units at BSRU. The pig genetics used were Topigs TN70. The pigs were randomly allocated to 40 pens, each pen containing 11 pigs. The house consisted of 48 numbered group pens with 1 m²/pig, Feed and water were provided ad libitum by one TR2 feeder/pen and two water nipples per pen. The TR2 has two outlets that are 28 cm each in width. Boars and gilts were separated into pens according to sex. All pigs were tagged with coloured ear tags, where boars were numbered with uneven numbers starting from 001 and gilts with even-numbered ear tags starting from 002. The five treatments were colour-coded with the colours: red, green, orange, white, and yellow. The coloured ear tags matched the colour of the treatment the pigs were fed.

3.2 Experimental diets

All the pigs received the same feed with placement at 70 days of age until the end of the grower phase. Treatment diets were only given during the finisher phase from 120 days-of-age up to slaughter at 154 days-of-age.

The five treatments included in the trial were as follows:

1. Negative control (NC): No additives included (16% crude protein (CP) in finisher diet)
2. Positive control: Ractopamine HCl inclusion (6 mg/kg of feed) and current recommendation of 16% CP in the finisher diet.
3. Ractopamine HCl (6 mg/kg of feed), but only 13% CP in the finisher diet while dietary essential amino acid concentrations were similar to the positive control diet.

4. NC diet + salbutamol 10% at 6 mg/kg
5. NC diet + salbutamol 10% at 4 mg/kg

All treatment diets were similar in nutrient specifications except Treatment 3 with the lower CP concentration of 13%.

3.3 Feed Formulation

In Table 1 the formulated feed composition and nutrient concentrations used for all treatments through grower phases one, two and three are presented.

Table 1. Formulated feed composition and nutrient concentrations of the grower 1, 2 and 3 phases for the various treatments (g/kg)

Feed Ingredients	Grower 1	Grower 2	Grower 3
Maize	703.25	702.52	689.07
Wheat bran	89.77	100.00	130.00
Soya oil cake	132.20	115.49	102.93
Sunflower oil cake	38.78	50.00	50.00
Limestone	12.88	12.72	12.75
Mono-dicalcium phosphate	4.52	3.45	2.75
Salt	4.04	4.81	4.79
Lysine hydrochloride	6.79	5.24	3.62
Methionine	2.99	2.11	1.24
Threonine	2.16	1.33	0.78
Tryptophan	0.80	0.53	0.25
KZN grower premix	1.62	1.62	1.62
Axtraphy 10 000 TPT	0.1	0.1	0.1
Axtra XB	0.1	0.1	0.1

AxtraPHY 10000 TPT2 is a phytase feed enzyme
Axtra XB: Xylanase/ß-glucanase enzyme

In Table 2 the formulated nutrient concentrations of the various grower treatments are found.

Table 2. Formulated feed nutrient concentrations of the various grower treatments (g/kg)

Nutrient Concentration formulated	Grower 1	Grower 2	Grower 3
Net energy (MJ/kg)	9.70	9.60	9.55
Crude Protein	155	150	145
Fat	35.98	36.02	36.15
Fibre	34.65	37.60	40.01
Calcium	7.50	7.00	6.60
Sodium	2.00	2.30	2.30
Digestible P	3.20	3.00	2.90
Standardized ileal digestible lysine	10.90	9.40	7.90
Standardized ileal digestible lysine: Net energy	1.12	0.98	0.83

Table 3. shows the formulated feed composition for the various finisher treatments.

Table 3. Formulated feed composition of the finisher for the various treatments (g/kg)

Feed Ingredients	Positive control (Ractopamine; 16% crude protein)	Negative control (without ractopamine; 16% crude protein)	Ractopamine; 13% crude protein	Salbutamol at 6 mg/kg	Salbutamol at 4 mg/kg
Maize	718.5	718.5	750	718.5	718.5
Wheat bran	71.38	71.38	100	71.38	71.38
Soya oil cake	132.2	132.2	68	132.2	132.
Sunflower oil cake	50	50	50	50	50
Limestone	9.35	9.35	9.88	9.35	9.35
Mono-dicalcium phosphate	3.02	3.02	3.43	3.02	3.02
Salt	4.11	4.11	3.537	4.11	4.11
Lysine hydrochloride	5.45	5.45	7.34	5.45	5.45
Methionine	2.31	2.31	2.91	2.31	2.31
Threonine	1.53	1.53	2.39	1.53	1.53
Tryptophan	0.43	0.43	0.72	0.43	0.43
Ractopamine HCl*	0.006		0.006		
KZN grower premix	1.3	1.3	1.3	1.3	1.3
KZN finisher Premix	0.1	0.1	0.1	0.1	0.1
Axtraphy 10 000 TPT	0.1	0.1	0.1	0.1	0.1
Salbutamate				0.006	0.004

*Ractopamine HCl; Paylean, Elanco Animal Health, Greenfield, IN

AxtraPHY 10000 TPT2 is a phytase feed enzyme

Axtra XB: Xylanase/ß-glucanase enzyme

In Table 4 the formulated nutrient concentrations of the various finisher treatments are given.

Table 4. Formulated feed nutrient concentrations of the various finisher treatments (g/kg)

Nutrient Concentration	Positive control (Ractopamine; 16% crude protein)	Negative control (without ractopamine; 16% crude protein)	Ractopamine; 13% crude protein	Salbutamol at 6 mg/kg	Salbutamol at 4 mg/kg
Net energy (MJ/Kg)	9.8	9.8	9.8	9.8	9.8
Crude Protein	155	155	135	155	155
Fat	36.15	36.15	36.50	36.15	36.15
Fibre	35.52	35.52	36.60	35.52	35.52
Calcium	6	6	6.1	6	6
Sodium	2.02	2.02	1.8	2.02	2.02
Digestible P	2.9	2.9	2.9	2.9	2.9
Standardized ileal digestible lysine	9.9	9.9	9.9	9.9	9.9
Standardized ileal digestible lysine: Net energy	1.01	1.01	1.01	1.01	1.01

3.4 Trial procedures

During the trial, the performance of the pigs was measured at the end of each feeding phase (84, 98, 119, and 154 days-of-age). The following parameters were measured:

1. Feed intake—The average feed intake per pig for each pen was measured by weighing the amount of feed fed every week per pen and dividing by the number of animals per pen. Feed intake and body weight were measured on the same day once a week to accurately calculate the feed conversion ratio.
2. Body weight – All pigs were weighed individually once a week on a scale after they had been fed.
3. Feed conversion ratio per pen replicate – Calculated by dividing the feed intake of a pen over a period by the weight gain of the pigs in a pen over the same period. The feed conversion ratio was corrected for mortalities.
4. Calculated average daily gain per pig for each pen replicate.
5. Mortality was recorded throughout the trial.

Carcass characteristics were measured at the abattoir. Pigs were slaughtered at Frey's Food Brands abattoir, Cato Ridge, KwaZulu-Natal. The Hennessy Grading Probe (HGP) is a durable, handheld electronic and optical device connected to a computer system that uses reflectance spectroscopy to measure fat thickness and muscle depth. The probe's tip features a cutting blade that penetrates the carcass, allowing the insertion of a needle equipped with a light-emitting diode and a photo-sensitive diode. The light intensity reflected back to the photo-sensitive diode helps differentiate between adipose and muscle tissues. The probe then measures the distance travelled by the needle, recording fat and muscle thickness, and calculates the lean meat percentage (LM%) using the computer program.

The following parameters were measured to determine the carcass quality:

1. Warm carcass weight
2. Cold carcass weight (weight of carcass after 24 hours)
3. Carcass moisture loss (Warm carcass weight - cold carcass weight)
4. Lean meat %
5. Classification based on the PORCUS classification system used at the time of the trial (before implementation of amended regulation R3450 GG48654 on November 26, 2023).

3.5 Statistical analysis

Data was analysed statistically with the Proc Mixed model (Statistical Analysis System, 2021) for the average effects. Means and standard error were calculated, and the significance of the difference ($p<0.05$) between means was determined by Fischer's test (Samuels, 1989). Repeated Measures Analysis of Variance with the Mixed model was used for repeated week or period measures. The linear mix model used is described by the following equation:

$$Y_{ijk} = \mu + T_i + S_j + B_k + TS_{ij} + e_{ijk}$$

Where:

- Y_{ijk} = variable studied during the period
- μ = overall mean of the population
- T_i = effect of the i th treatment
- S_j = effect of the j th sex
- B_k = effect of the k th block
- TS_{ij} = effect of the ij th interaction between treatment and sex
- e_{ijk} = error associated with each Y

Data were analyzed statistically with the Proc Freq model (Statistical Analysis System, 2023) for the chi-square test, frequencies were calculated and significance of difference (P<0.05) determined by Fischers test (Samuels, 1989).

Chapter 4: Results

As shown in Table 5, in the finisher phase, the sows fed the negative control diet had significantly higher ($p<0.05$) feed intake when compared to the sows fed the low-concentration salbutamol and high-concentration salbutamol diets. The sows fed the high-concentration salbutamol diet had significantly lower feed intake when compared to the sows fed the positive control diet.

It was found that the boars that received the high-concentration salbutamol treatment had significantly lower ($p<0.05$) feed intakes when compared to the positive control and negative control.

Table 5. The effect of ractopamine HCl and salbutamol on total feed intake (kg) during the finisher phase

Treatments	Male	Female	Mean
Positive control (Ractopamine; 16% crude protein)	103.0^{ab}	106.2^{ab}	104.6 ^{ab}
Negative control (without ractopamine; 16% crude protein)	104.9^{ab}	109.2^{a}	107.1 ^{a}
Ractopamine; 13% crude protein	106.6^{a}	111.8^{a}	109.2 ^{a}
Salbutamol at 6 mg/kg	93.4^{c}	98.9^{c}	96.2 ^{c}
Salbutamol at 4 mg/kg	99.0^{bc}	100.5^{bc}	99.8 ^{bc}
SEM	±2.4	±2.4	±1.7

$^{a-c}$ Column means without a common superscript differ significantly ($p<0.05$).

SEM: standard error of the mean.

As seen in Table 6, the sows fed the low CP diet with ractopamine had a significantly poorer ($p<0.05$) FCR when compared to the females that were fed the high-concentration and low-concentration salbutamol diets.

Table 6. The effect of ractopamine HCl and salbutamol on feed conversion ratio during the finisher phase

Treatments	Male	Female	Mean
Positive control (Ractopamine; 16% crude protein)	2.51	2.72[ab]	2.62 [ab]
Negative control (without ractopamine; 16% crude protein)	2.56	2.73[ab]	2.64 [ab]
Ractopamine; 13% crude protein	2.66	2.82[a]	2.74 [a]
Salbutamol at 6 mg/kg	2.55	2.56[b]	2.55 [b]
Salbutamol at 4 mg/kg	2.50	2.52[b]	2.51 [b]
SEM	±0.075	±0.075	±0.053

[a,b] Column means without a common superscript differ significantly ($p<0.05$).

SEM: standard error of the mean.

As shown in Table 7, in the finisher phase the boars fed the positive and negative control diets had significantly higher body weight gain during the finisher period when compared to the boars fed the high-concentration salbutamol diet.

Table 7. The effect of ractopamine HCl and salbutamol on body weight gain (kg) during the finisher phase

Treatments	Male	Female	Mean
Positive control (Ractopamine; 16% crude protein)	41.19[a]	39.58	40.39 [ab]
Negative control (without ractopamine; 16% crude protein)	41.60[a]	40.65	41.13 [a]
Ractopamine; 13% crude protein	40.55[ab]	40.07	40.31 [ab]
Salbutamol at 6 mg/kg	37.51[b]	39.03	38.27 [b]
Salbutamol at 4 mg/kg	40.30[ab]	40.26	40.28 [ab]
SEM	±1.240	±1.240	±0.877

[a,b] Column means without a common superscript differ significantly ($p<0.05$).

SEM: standard error of the mean

As shown in Table 8 in the finisher phase of the boars, the positive and negative control diets had significantly higher ($p<0.05$) ADG when compared to the high-concentration salbutamol diet.

Table 8. The effect of ractopamine HCl and salbutamol on average daily gain (kg) during the finisher phase

Treatments	Male	Female	Mean
Positive control (Ractopamine; 16% crude protein)	1.18[a]	1.13	1.16 [ab]
Negative control (without ractopamine; 16% crude protein)	1.19[a]	1.16	1.18 [a]
Ractopamine; 13% crude protein	1.16[ab]	1.14	1.15 [ab]
Salbutamol at 6 mg/kg	1.07[b]	1.12	1.10 [b]
Salbutamol at 4 mg/kg	1.15[ab]	1.15	1.15 [ab]
SEM	±0.035	±0.035	±0.025

[a,b] Column means without a common superscript differ significantly ($p<0.05$).
SEM: standard error of the mean.

There were no significant differences between the body weights of the pigs in the different treatment groups at the start of the trial (Table 9).

Table 9. The starting body weight (kg) on day one of the finisher phase

Treatments	Male	Female	Mean
Positive control (Ractopamine; 16% crude protein)	72.42	75.12	73.77
Negative control (without ractopamine; 16% crude protein)	74.22	75.50	74.86
Ractopamine; 13% crude protein	73.40	76.69	75.05
Salbutamol at 6 mg/kg	76.05	76.02	76.03
Salbutamol at 4 mg/kg	72.36	75.11	73.73
SEM	±0.958	±0.958	±0.677

SEM: standard error of the mean

There were no significant differences between the final body weights of the pigs in the different treatment groups before slaughter (Table 10).

Table 10. The final body weight(kg) of the finisher phase before slaughter

Treatments	Male	Female	Mean
Positive control (Ractopamine; 16% crude protein)	113.2	114.7	114.0
Negative control (without ractopamine; 16% crude protein)	115.8	116.2	116.0
Ractopamine; 13% crude protein	114.0	116.8	115.4
Salbutamol at 6 mg/kg	113.3	115.6	114.5
Salbutamol at 4 mg/kg	112.7	115.4	114.0
SEM	±1.619	±1.619	±1.145

SEM: standard error of the mean

There were no significant differences between the cold carcass weights and warm carcass weights of the pigs in the different treatment groups after slaughter (Table 11).

Table 11. The effect of ractopamine HCl and salbutamol on warm carcass weight (kg) and cold carcass weight (kg)

Treatments	warm carcass weight		cold carcass weight	
	Male	Female	Male	Female
Positive control (Ractopamine; 16% crude protein)	87.91	91.45	84.85	87.95
Negative control (without ractopamine; 16% crude protein)	90.10	92.96	86.70	89.28
Ractopamine; 13% crude protein	88.46	93.49	85.24	89.99
Salbutamol at 6 mg/kg	88.61	93.49	85.34	89.98
Salbutamol at 4 mg/kg	88.36	93.46	85.27	90.23
SEM	±1.474	±1.474	±1.451	±1.451

SEM: standard error of the mean.

There were no significant differences between the dressing percentages of the pigs in different treatment groups after slaughter (Table 12).

Table 12. The effect of ractopamine HCl and salbutamol on dressing percentage

Treatments	Male	Female
Positive control (Ractopamine; 16% crude protein)	77.65	79.72
Negative control (without ractopamine; 16% crude protein)	77.83	80.03
Ractopamine; 13% crude protein	77.63	80.05
Salbutamol at 6 mg/kg	78.20	80.84
Salbutamol at 4 mg/kg	78.45	81.01
SEM	±0.490	±0.490

SEM: standard error of the mean.

As seen in Table 13, in the case of the gilts the high concentration salbutamol diet resulted in a significantly higher ($p<0.05$) lean percentage when compared to the negative control, while the positive control had a significantly higher lean percentage when compared with the low crude protein diet.

Table 13. The effect of ractopamine HCl and salbutamol on lean percentage

Treatments	Male	Female
Positive control (Ractopamine; 16% crude protein)	69.34	69.73^{ab}
Negative control (without ractopamine; 16% crude protein)	69.10	69.44^{bc}
Ractopamine; 13% crude protein	69.30	68.98^{c}
Salbutamol at 6 mg/kg	69.51	70.30^{a}
Salbutamol at 4 mg/kg	69.65	69.72^{ab}
SEM	±0.220	±0.220

$^{a-c}$ Column means without a common superscript differ significantly ($p<0.05$).

SEM: standard error of the mean.

As seen in Table 14, there was a significant difference ($p<0.05$) in the frequency of carcasses in specific carcass classifications. P and O are grouped, and R and C are grouped together as these classifications tend to get the same price per kilogram.

Table 14. Effect of beta-agonists on carcass classification frequency

Treatments	Frequency in class	
	P+O	R+C
Positive control (Ractopamine; 16% crude protein)	74	11
Negative control (without ractopamine; 16% crude protein)	68	19
Ractopamine; 13% crude protein	72	15
Salbutamol at 6 mg/kg	77	7
Salbutamol at 4 mg/kg	76	10

P: lean meat percentage ≥ 70%; O: lean meat percentage 68-69%; R: lean meat percentage 66-67%; C: lean meat percentage 64-65%.

P≤ 0.05, P=0.0016

In Table 15, the probability within row shows that when grouping the carcass classification together according to the payment received, the only significant difference found was when comparing the negative control (no ractopamine; 16% crude protein) and salbutamol at 6 mg/kg. Pigs fed salbutamol at 6 mg/kg had more carcasses classed in the P/O grouping than the pigs fed the negative control.

When comparing salbutamol at 4 mg/kg to the negative control the difference in frequency of P/O carcasses trends towards a significant difference ($P<0.1$).

It is worth noting that no significant difference was found when comparing the pigs fed the positive control diet to those fed a diet with less crude protein with the same inclusion of ractopamine HCl. It is also worth noting that the difference found between the positive control (Ractopamine; 16% crude protein) and salbutamol at 6 mg/kg was only numerical and not significant.

Table 15. Probability of difference between relevant treatments within rows.

Treatments		Probability
Positive control (Ractopamine; 16% crude protein)	Negative control (without ractopamine; 16% crude protein)	0.124
Positive control (Ractopamine; 16% crude protein)	Ractopamine; 13% crude protein	0.431
Positive control (Ractopamine; 16% crude protein)	Salbutamol at 6 mg/kg	0.332
Positive control (Ractopamine; 16% crude protein)	Salbutamol at 4 mg/kg	0.794
Negative control (without ractopamine; 16% crude protein)	Salbutamol at 6 mg/kg	0.014
Negative control (without ractopamine; 16% crude protein)	Salbutamol at 4 mg/kg	0.072
Salbutamol at 6 mg/kg	Salbutamol at 4 mg/kg	0.474

In Figure 4, high concentration of salbutamol, low concentration of salbutamol and the positive control had the lowest cost of feed. The low concentration of salbutamol provided the best return on investment (ROI) and the high concentration of salbutamol was a close second, R26.95 and R5.26 per pig more than the positive control. Low CP produced R50.38 per pig less than the positive control.

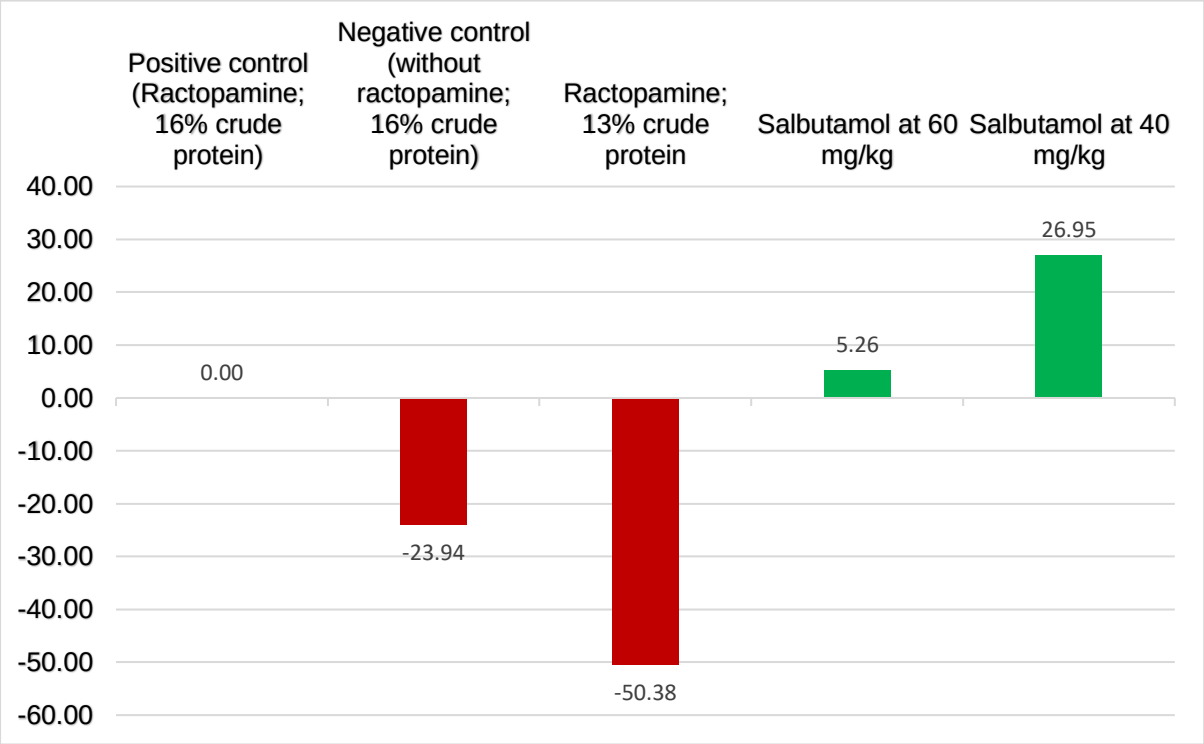

Figure 4: The effect of ractopamine HCl and salbutamol on return of investment

Chapter 5: Discussion

The aim of the study was to determine the effect of beta-adrenergic agonists ractopamine HCl and salbutamol, on animal performance and carcass characteristics. By comparing these performance enhancers with each other, and by comparing them with no performance enhancers (negative control). Secondarily, the trial also aimed to determine whether lowering crude protein percentage while meeting the essential amino acid requirement had an effect when using ractopamine HCl.

Dunshea et al. (1993) conducted a study to determine the protein requirements for pigs from 60 kg until slaughter at 90 kg, focusing on the effects of ractopamine. They estimated dietary protein requirements to be approximately 14.0% and 16.8% to support carcass protein accretion rates of 91 and 112 g/day for 0 and 20 ppm ractopamine, respectively. Carcass protein deposition rates did not increase with ractopamine at protein concentrations of 14% or lower, as the regression slope of protein intake on protein deposition was similar in both treatments. This suggests that the efficiency of dietary protein utilization was not improved. Therefore, an increase in protein deposition induced by ractopamine requires a proportional increase in dietary protein intake.

When comparing the positive control and Negative control diets. It was found that there were no significant differences across all monitored animal performance traits. It was expected that the positive control would have better FCR and P and O carcass percentages; however, this was not the case (Irshad *et al.,* 2013). Certain pig breeds or genetic lines may inherently possess traits that predispose them to enhanced muscle growth and lean tissue deposition. Beta-adrenergic agonists like ractopamine HCl and salbutamol work by stimulating beta-adrenergic receptors, which can promote muscle growth and reduce fat deposition. However, the extent to which these agonists influence muscle growth may vary depending on the genetic makeup of the pigs. Some genetic lines may already exhibit optimized muscle growth characteristics, making them less responsive to the effects of beta-adrenergic agonists. Hence, this could be responsible for the non-significant result obtained from this study.

There was no significant difference in feed intake of pigs fed the positive control diet (Ractopamine; 16% crude protein) when compared with those fed a diet with less crude protein and having the same inclusion of ractopamine HCl. It could be assumed that ractopamine HCl, which is known to improve feed efficiency and promote lean tissue deposition in pigs by redirecting nutrients towards muscle growth, might have enhanced nutrient utilization and

growth efficiency in pigs fed both the positive control and lower protein diets, resulting in similar feed intake despite differences in dietary composition.

The data showed that pigs fed salbutamol in high concentrations had significantly lower feed intake when compared to pigs fed the negative control diet and positive control diet. Salbutamol, like ractopamine HCl, is a beta-adrenergic agonist that acts on adrenergic receptors to promote lean tissue deposition and improve feed efficiency. However, high concentrations of salbutamol may elicit stronger metabolic responses, including increased metabolic rate and altered nutrient partitioning, which could increased feed intake as pigs prioritize energy expenditure towards growth and maintenance functions. Also, Beta-adrenergic agonists have been associated with appetite suppression in livestock animals. High concentrations of salbutamol may exert greater suppressive effects on appetite, leading to reduced feed intake in pigs and leaner carcasses. This appetite suppression could be mediated by central nervous system pathways or peripheral mechanisms affecting hunger and satiety signals. This decreased feed intake obtained is in line with those of Marchant-Forde et al. (2012); the decrease was linked to the high concentration of salbutamol in the diet.

Pigs fed salbutamol at 6 mg/kg had significantly more carcasses classed in the P/O grouping in comparison to pigs fed no beta-agonist. Comparing salbutamol at 4 mg/kg to the negative control the difference trends towards a significant difference ($P<0.1$). This could be due to the fact that salbutamol shifts nutrient partitioning in favour of lean tissue deposition over fat accumulation. Salbutamol stimulates lipolysis, the breakdown of stored fat reserves, and inhibits lipogenesis which is the synthesis of new fat molecules. As a result, pigs supplemented with salbutamol exhibit reduced fat deposition and improved carcass composition, with a greater proportion of lean muscle tissue relative to fat.

There was no significant difference in the FCR of the boars between the treatments when compared to the negative control; however, some studies suggested that FCR is improved when animals were fed the performance enhancers (Marchant-Forde *et al.,* 2012).

Pigs fed the positive and negative control diets had significantly higher ADG and overall gain compared to the pigs fed thehigh concentration salbutamol diet, which indicated that high concentration salbutamol did not perform as expected. This could be due to a dose-dependent effect, where optimal benefits are achieved at specific concentrations, and higher doses may not provide additional advantages. The salbutamol lean % shows that the performance enhancer had a significant effect when compared to the negative control.

According to Ying *et al. (*2011), pigs fed ractopamine had heavier warm carcass weights, although in this trial, no significant difference was found when comparing all treatments to the negative control. This may be due to the lipolytic effect of the beta-adrenergic agonist.

There was no significant difference in the dressing percentage of pigs in the treatment groups when compared with those of the negative control during the trial. Nevertheless, Watkins (1990) reported ractopamine improved the dressing percentage of pigs. The discrepancy obtained in our study was assumed to be due to an improvement in the genetic make-up of the pigs as earlier discussed.

The low concentration salbutamol provided a higher return on investment than the high concentration salbutamol. This was based on the relatively low feed costs and high revenue obtained during the study.

The economic analysis revealed unexpected results regarding the cost-effectiveness of different treatments. While low concentration salbutamol emerged as the most economically viable option, the reasons behind this outcome may involve complex interactions between feed costs, performance outcomes, market prices, and production efficiencies. Factors such as feed intake, growth rates, and carcass composition contribute to the overall economic performance of each treatment group, and variations in these parameters can influence cost-effectiveness.

Chapter 6: Conclusion

In summary, this study has successfully demonstrated that the beta-adrenergic agonists ractopamine hydrochloride and salbutamol can significantly enhance the performance and carcass characteristics of finisher pigs.

The administration of ractopamine HCl at 6 mg/kg of feed, even with a reduced crude protein (CP) diet, resulted in notable improvements in live weight gain, feed conversion ratio (FCR), and lean meat percentage. This suggests that ractopamine HCl is effective in enhancing growth performance and carcass quality, even when the dietary CP is lowered to 13%. The potential cost savings from reducing protein content in feed could be economically beneficial for producers, particularly given the high cost of protein sources.

Similarly, salbutamol, administered at both 6 mg/kg and 4 mg/kg, showed significant positive effects on performance indicators. The leaner carcasses and improved dressing percentages observed in salbutamol-treated groups highlight its viability as an alternative to ractopamine HCl.

An important aspect of this study was the economic analysis, which revealed a higher return on investment (ROI) for pigs fed with beta-agonists. This is a crucial consideration for producers aiming to maximize profitability while maintaining high standards of animal welfare and product quality. The findings suggest that the strategic use of beta-agonists can enhance production efficiency and economic returns, supporting their continued use in commercial pigs operations.

The study underscores the need for further research to validate these findings across different genetic lines, production systems, and environmental conditions. Future studies should explore the long-term effects of beta-agonist use on meat quality attributes such as tenderness, juiciness, and flavour. Additionally, investigating the environmental impacts of reduced nitrogen and phosphate excretion associated with beta-agonist use could provide valuable insights into sustainable livestock production practices.

In conclusion, the use of ractopamine HCl and salbutamol in finisher pigs presents a viable strategy for improving growth performance and carcass quality. The economic benefits, coupled with the potential for enhanced production efficiency, make beta-agonists a valuable tool for pig producers. Nevertheless, it is imperative to balance these advantages with considerations of human health, animal welfare, and environmental sustainability. By addressing these aspects, the industry can ensure the responsible and effective use of beta-agonists in pig production.

Chapter 7: Critical Review and Recommendation

Ensure that samples are kept safe or immediately submitted for analysis, as some of the samples were stolen in Johannesburg before analysis could be done. This could have been prevented if the feed samples were immediately couriered to the lab or if a lab closer to where the trial was held was used.

Larger groups of pigs per treatment could lead to more accurate data, however, it was not an easy task to weigh the pigs individually. It is recommended that if the number of pigs were increased, making use of group weighing would be easier than individually weighing the pigs but could diversly affect your statistics by decreasing degrees of freedom. Other than that, the experimental trial proceeded well and without other incidents, the fact that brand new well maintained private facilities were used played a major role in the trial continuing without any major problems.

It is also recommend running a trial where the different beta-agonists used are added to a ration that has low crude protein in order to compare how beta-agonists perform when the feed is not formulated for the requirements of the beta-agonist to perform optimally. It is also recommend running a trial to see how different breeds of pigs perform when beta-agonists are used.

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