THE EFFECT OF DIETARY CONJUGATED LINOLEIC ACID SUPPLEMENTATION ON PRODUCTION EFFICIENCY AND MEAT QUALITY OF PIGS

by

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DECLARATION

I hereby declare that the thesis, **The effect of dietary conjugated linoleic acid supplementation on production efficiency and meat quality of pigs**, hereby handed in for the qualification of **Philosophiae Doctor** at the University of the Free State, is my own work and that I have not previously submitted the same work for a qualification at another University or faculty. I hereby concede copyright of this thesis to the University of the Free State

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31 January 2014

Opgedra aan my Ouers, Neil en Jacoba

“Dankie vir die geleenthede en ondersteuning wat julle my gebied het, vir alles wat julle my geleer het van eerlikheid, opregtheid en deursettingsvermoë”

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GLOSSARY OF ABBREVIATIONS

*a**	Colour coordinate – redness value
@	At
ADG	Average daily gain
ADF	Acid detergent fibre
AI	Atherogenicity index
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
AOCS	American Oils Chemist's Society
ARC	Agricultural Research Council
ASTM	American Society of Testing Materials
*b**	Colour coordinate – yellowness value
BFAP	Bureau of Food and Agriculture Policy
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
c	*cis*
CF	Crude fibre
CLA	Conjugated linoleic acid
cm	Centimeter
CP	Crude protein
DAFF	Department of Agriculture, Forestry and Fisheries
DBI	Double bond index
℃	Degrees Celsius
Δ	Delta
DE	Digestible energy
DHA	Docosahexaenoic acid
DM	Dry matter
DPA	Docosapentaenoic acid
EDTA	Ethylene diamino tetra-acetic acid
EFC	Extractable fat content
EPA	Eicosapentaenoic acid
FAME	Fatty acid methyl ester/s

Individual FAME:

Abbreviation	*Common name*	*Complete formula*	*Systematic (IUPAC) name*
C12:0	Lauric	C12:0	Dodecanoic
C14:0	Myristic	C14:0	Tetradecanoic
C15:0	Pentadecylic	C15:0	Pentadecanoic
C16:0	Palmitic	C16:0	Hexadecanoic
C16:1	Palmitoleic	C16:1*c*9	*cis*-9-Hexadecenoic
C17:0	Margaric	C17:0	Heptadecanoic

C17:1	Heptadecenoic	C17:1*c*10	*cis*-10-Heptadecenoic
C18:0	Stearic	C18:0	Octadecanoic
C18:1*c*7	Vaccenic	C18:1*c*7	*cis*-7-Octadecenoic
C18:1*t*7	Octadecenoic	C18:1*t*7	*trans*-7-Octadecenoic
C18:1*c*9	Oleic	C18:1*c*9	*cis*-9-Octadecenoic
C18:1*t*9	Elaidic	C18:1*t*9	*trans*-9-Octadecenoic
C18:2	Linoleic	C18:2*c*9,12(*n*-6)	*cis*-9,12-Octadecadienoic
C18:3*n*-3	α-Linolenic	C18:3*c*9,12,15(*n*-3)	*cis*-9,12,15-Octadecatrienoic
C18:3*n*-6	λ-Linolenic	C18:3*c*6,9,12(*n*-6)	*cis*-6,9,12-Octadecatrienoic
C19:0	Nonadecanoic	C19:0	Nonadecanoic
C20:0	Arachidic	C20:0	Eicosanoic
C20:1	Eicosenoic	C20:1*c*11	*cis*-11-Eicosenoic
C20:2	Eicosadienoic	C20:2*c*11,14(*n*-6)	*cis*-11,14-Eicosadienoic
C20:3*n*-3	Eicosatrienoic	C20:3*c*11,14,17(*n*-3)	*cis*-11,14,17-Eicosatrienoic
C20:3*n*-6	Eicosatrienoic	C20:3*c*8,11,14(*n*-6)	*cis*-8,11,14-Eicosatrienoic
C20:4	Arachidonic	C20:4*c*5,8,11,14(*n*-6)	*cis*-5,8,11,14-Eicosatetraenoic
C20:5	Eicosapentaenoic	C20:5*c*5,8,11,14,17(*n*-3)	*cis*-5,8,11,14,17-Eicosapentanoic
C22:0	Behenic	C22:0	Docosanoic
C22:1	Erucic	C22:1*c*13	*cis*-13-Docosenoic
C22:2	Docosadienoic	C22:2*c*13,16(*n*-6)	*cis*-13,16-Docosadienoic
C22:5	Docosapentaenoic	C22:5*c*7,10,13,16,19(*n*-3)	*cis*-4,7,10,13,16-Docosapentaenoic
C22:6	Docosahexaenoic	C22:6*c*4,7,10,13,16,19(*n*-3)	*cis*-4,7,10,13,16,19-Docosahexanoic
C24:0	Lignoceric	C24:0	Tetracosanoic
C24:1	Nervonic	C24:1*c*15	*cis*-15-Tetracosenoic
FCR	Feed conversion ratio		
FFA	Free fatty acids		
FDA	Food and Drug Administration		
FFDM	Fat free dry matter		
FHM	Fat hardness measurement		
FS	Fat score		
g	Gram		
g/day	Gram/day		
GC	Gas chromatograph		
GRAS	Generally regarded as safe		
HOSF	High-oleic sunflower oil		
Hz	Hertz		
i.e.	That is		
IMF	Intramuscular fat		
IV	Iodine value		
kg	Kilogram		
L	Litre		
*L**	Colour coordinate – lightness value		

LMC	Lean meat content
m	Meter
µmol/L	micromole per liter
mg	Milligram
mg/day	Milligram/dag
mg/g	Milligram/gram
MJ/kg	Megajoule per kilogram
mM	Millimolar
mm	Millimeter
ml	Milliliter
MUFA	Monounsaturated fatty acid/s
MFL	Myofibrillar fragment length/s
N	Normal
NaCl	Sodium chloride (salt)
n-3	Omega-3 fatty acid/s
n-6	Omega-6 fatty acid/s
ND	Not determined / detected
NDF	Neutral detergent fibre
NIRS	Near infrared spectroscopy
NS	Not significant
NSA	Not statistically analysed
OOO	Oleic-oleic-oleic
OOL	Oleic-oleic-linoleic
OSI	Oxidative stability index
p	Significance level
%	Percentage
PCA	Principle component analysis
pH_{45min}	pH value 45 minutes post mortem
$pH_{24hours}$	pH value 24 hours post mortem
PI	Peroxidizability index
ppm	Part per million (mg/kg)
POL	Palmitic-oleic-linoleic
PPO	Palmitic-palmtic-oleic
PSE	Pale, soft and exudative
PSO	Palmitic-stearic-oleic
PSL	Palmitic-stearic-linoleic
PUFA	Polyunsaturated fatty acid/s
PV	Peroxide value
PVC	Polyvinyl chloride
R	Rand
RDA	Recommended daily allowance
rH	Relative humidity

rpm	revolutions per minute
SFA	Saturated fatty acid/s
SPO	Stearic-palmitic-oleic
t	*trans*
TA	Titratable acidity
TBARS	Thiobarbituric acid reactive substances
TBHQ	Tertiary-butylatedhydroxyquinone
Tr	Trace amounts
UFA	Unsaturated fatty acid/s
UK	United Kingdom
µl	Microlitre
µM	Micromolar
USA	United States of America
USDA	United States Department of Agriculture
UV	Ultra-violet
V	Volts
vs.	Versus
a_w	Water activity
WHC	Water-holding capacity
<	Less than
>	More than

CHAPTER 1

INTRODUCTION

Archaeological records, according to Berg (2006), revealed that pigs were already domesticated and utilized as a food source for humans, approximately 9000 years ago! Over the last several decades, consumers have become more aware of a healthy lifestyle and are presently more concerned about the impact of diet on their health than ever in the past (Verbeke, Van Oeckel, Warnants, Viaene, & Boucqué, 1999; Morel, Leong, Nuijten, Purchas, & Wilkinson, 2013). Pork was often avoided, as consumers considered it to contain an excess of fat, saturated fatty acids (SFA) and cholesterol (Hernández, Navarro, & Toldrá, 1998). Health conscious consumers prefer pork with high levels of polyunsaturated fatty acids (PUFA) (Morel et al., 2013). This increased health-consciousness among consumers led to significant changes in pig carcass attributes (Scheffler, & Gerrard, 2007).

The main response of the global meat industry to meet consumer demands for healthier pork was to start producing leaner pigs. They achieved this by aggressively adopting new pig production technologies to increase both efficiency and production (Blanchard, 1995; Liu, Ipharraguerre, & Pettigrew, 2013). One such an approach, adopted by pig producers, was selection to improve lean growth and carcass yield (Scheffler et al., 2007). This response of the meat industry to meet consumer demands for healthier pork had certain implications. As pigs become leaner, their fat tends to become softer and more unsaturated (Sather, Jones, Robertson, & Zawadski, 1995). This is good news for the health conscious consumer but may cause serious problems for the meat processor. The increased content of PUFA may have detrimental effects on the sensory and technological quality as well as the overall acceptability of meat products (Houben, & Krol, 1983; Stiebing, Kühne, & Rodel, 1993; Warnants, Van Oeckel, & Boucqué, 1998; Teye, Sheard, Whittington, Nute, Stewart, & Wood, 2006).

It is well known that in pigs and other monogastric animals, the fatty acid composition of the fat tissue triglycerides can be changed by altering the fatty acid composition of the diet. Dietary fats are absorbed intact from the small intestine and incorporated directly into the fat tissue of the pig (Rhee, Davidson, Cross, & Zirpin, 1990). Adding different lipid products to an animal's diet can, therefore, successfully alter the fatty acid profile of the tissue of that animal (Wood, Sheard, Enser, Nute, Richardson, & Gill, 1999; Scheerder, Gläser, Eichenberger, & Wenk, 2000; Morel et al., 2013). Scientific evidence for this dates back at least to 1926 (Ellis, & Isbell, 1926).

There has, therefore, been great interest in the manipulation of the fatty acid composition of muscle and fat tissues in recent years, in order to produce meat with desirable nutritional and technological qualities (Teye et al., 2006). Fresh pork and pork products manufactured from such meat can be described as "designer" or "functional" foods (Jiménez-Colmenero, Carballo, & Cofrades, 2001; Arihara, 2006). Such pork products can then be marketed as nutraceuticals, which

is food with perceived medicinal or health benefits that may prevent, ameliorate or cure a disease (Arihara, 2006). One such an approach to improve pork quality is dietary supplementation with naturally occurring feed additives, such as conjugated linoleic acid (CLA), in the growing-finishing diet (Wiegand, Sparks, Parrish, & Zimmerman, 2002).

Conjugated linoleic acid is a collective term indicating a group of octadecadienoic acids that are geometric and positional conjugated isomers of linoleic acid (C18:2). These substances occur naturally in animal products, predominantly in beef, meat of other ruminants and in dairy products, but are present in lower amounts in pork and in meat from other non-ruminant species (Dugan, Aalhus, & Lien, 2001). Numerous positional and geometric isomers of CLA have been reported as components of naturally occurring foods (Lo Fiego, Macchioni, Santoro, Pastorelli, & Corino, 2005a). The *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers appear to be the most biologically active (Kennedy, Martinez, Schmidt, Mandrup, LaPoint, & McIntosh, 2010). Conjugated linoleic acid isomers found in meat and dairy products of ruminants, consist mainly of 90% of the *cis*-9, *trans*-11 isomer and 10% of the *trans*-10, *cis*-12 isomer. Commercial preparations of CLA are made from the C18:2 of safflower or sunflower oils under alkaline conditions. This type of processing yields a CLA mixture containing approximately 40% of the *cis*-9, *trans*-11 isomer and 44% of the *trans*-10, *cis*-12 isomer (Kennedy et al., 2010).

Experiments on laboratory animals in human medicine indicated that dietary CLA supplementation has beneficial effects on improving the immune function, preventing cancer, reducing the incidence of heart disease, improving blood sugar level, decreasing blood cholesterol and reducing body weight (Migdal, Pasciak, Wojtysiak, Barowicz, Pieszka, & Pietras, 2004; Larsen, Wiegand, Parrish, Swan, & Sparks, 2009). Feeding of CLA to laboratory animals improved rate and efficiency of gain and decreased fat deposition (O'Quinn, Smith, Nelssen, Tokach, Goodband, & Smith, 1998). Published studies and preliminary reports of pig trials indicate that feeding CLA supplemented diets may provide several advantages. Dietary CLA supplementation of pigs has been shown to improve performance and reduce fat deposition as well as increase lean meat content (LMC) (Swan, Parrish, Wiegand, Larsen, Baas, & Berg, 2001; Wiegand, Parrish, Swan, Larsen, & Baas, 2001; D'Souza, & Mullan, 2002). Pigs fed CLA had less backfat, more carcass lean, bigger loin muscle area and a better feed conversion (Eggert, Belury, & Schinckel, 1998; Ostrowska, Muralitharan, Cross, Bauman, & Dunshea, 1999; Larsen et al., 2009; Jiang, Zhong, Zheng, Lin, Yang & Jiang, 2010; Migdal et al., 2004). With respect to meat quality, CLA increased the saturated/unsaturated fat ratio in adipose tissue and intramuscular fat (IMF) and improved belly firmness (Dugan, Aalhus, Jeremiah, Kramer, & Schaerfer, 1999; Eggert, Stahl, Latour, Richert, Gerrard, Forrest, Bowker, Wynveen, Hammelman, & Schinckel, 1999; Eggert, Belury, Kempa-Steczko, Mills, & Schinckel, 2001; Wiegand et al., 2001; Joo, Lee, Ha, & Park, 2002). Limited information is available on the effect of dietary CLA supplementation on other technological properties of fresh meat such as water holding capacity (WHC) and colour. A positive effect of CLA supplementation was reported for WHC and colour of fresh meat (Migdal et al., 2004; Szymczyk,

2005; Bee Jacot, Guex, & Biolley, 2008; Jiang et al., 2010). No data has yet been reported on the effect of CLA supplementation on technological properties such as WHC and colour of processed meat and meat products. This lack of data opens up a whole new, practically pristine, research field. Some researchers (Dugan et al., 1999; Wiegand et al., 2002; Corino, Magni, Pastorelli, Rossi, & Mourot, 2003) found no detrimental effect of CLA supplementation on the eating and sensory quality of pork. D'Souza et al. (2002), however, found inferior eating quality, i.e. flavour, tenderness, juiciness and overall acceptability, as a result of feeding CLA. As pork-processing plants become increasingly mechanised, CLA may provide a nutritional solution to fat firmness problems that may enhance the overall value of extremely lean carcasses (Eggert et al., 1998).

Substantial work on CLA supplementation was done in North America and Europe where animals are fed to the very heavy slaughter weight of ± 130 kg (Lauridsen, Mu, & Henckel, 2005; Martin, Muriel, Antequera, Andres, & Ruiz, 2009; Cordero, Isabel, Menoyo, Daza, Morales, Piñeiro, & López-Bote, 2010). In South Africa slaughter weights of 70 kg for porkers and 90 kg for baconers are most common (Vervoort, 1997; Pieterse, Loots, & Viljoen, 2000). Little is known about the effect of CLA supplementation on animals slaughtered at lower slaughter weights. No information could be found on the effect of dietary CLA supplementation on animal performance, carcass composition and meat quality of pigs from the three gender groups (boars, barrows and gilts). This study was therefore designed to investigate the effect of dietary supplementation of CLA on both slaughter weight and gender.

The first aim of this study was to determine possible differences between the digestibility of CLA and sunflower oil (SFO) supplemented feed.

The following hypothesis was formulated:

The major difference between the fatty acid compositions of CLA and SFO is the C18:2 content. Linoleic acid from SFO is converted to CLA isomers under alkaline conditions (Kennedy et al., 2010). The CLA used in this trial was manufactured from SFO. The null hypothesis would be that there would be no differences in the digestibility of CLA and SFO in pigs.

The second aim of the study was to assess the effect of a 0.5% inclusion of commercial CLA in diets on pig production efficiency.

The following hypothesis was formulated:

Conjugated linoleic acid can be included at levels of 0.5 - 1% in complete pig feeds and received GRAS status in the USA in 2004 (Dr R Ruehle, BASF, Personal Communication, 30 September 2013). Conflicting results regarding the effect of dietary CLA supplementation on production efficiency of pigs was reported in literature (Ostrowska et al., 1999; Ramsay, Evock-Clover, Steele, & Azain, 2001). The null hypothesis for production efficiency would

therefore be that feeding a CLA supplemented diet, in the growing-finishing period of pigs, will have no effect on pig production efficiency.

The third aim of this study was to determine the effect of a 0.5% inclusion of a commercial CLA preparation in the diet on carcass quality of lighter vs. heavier (70 kg vs. 90 kg) pigs as well as pigs from different gender groups (boars, barrows and gilts).

The following hypothesis was formulated:

Supplementing pig diets with CLA will result in a reduction of backfat thickness and an increase in the area of *M. longissimus thoracis* (Eggert et al., 1998; Ostrowska et al., 1999; Migdal et al., 2004; Larsen et al., 2009; Jiang et al., 2010). The null hypothesis for carcass quality would be that feeding a CLA supplemented diet in the growing-finishing period of pigs under commercial production conditions, will have a positive effect on carcass quality of lighter and heavier pigs as well as pigs from different gender groups.

The fourth aim of this study was to determine the effect of a 0.5% inclusion of a commercial CLA preparation in the diet on health and nutritional implications and the technological properties of pork fat tissue of lighter vs. heavier (70 kg vs. 90 kg) pigs as well as pigs from different gender groups (boars, barrows and gilts).

The following hypothesis was formulated:

A CLA supplemented diet, in the growing-finishing period of pigs, has shown positive results towards nutritional and health implications as well as the technological properties of pork fat tissue (Ramsay et al., 2001; Averette Gatlin et al., 2006; Larsen et al., 2009). The null hypothesis for nutritional and health implications and technological properties would therefore be that a 0.5% inclusion of CLA would improve nutritional and health properties of subcutaneous and IMF. At the same time the technological properties of subcutaneous and IMF fat of younger and lighter pigs from the three different gender groups will improve.

The fifth aim of this study was to determine the oxidative stability of fresh and processed meat products manufactured from CLA supplemented pork.

The following hypothesis was formulated:

Conjugated linoleic acid possesses certain antioxidant properties (Ha, Storkson, & Pariza, 1990) that will be transferred to the fat component of processed meat products, which is susceptible to oxidation. However, with an increase in CLA concentration in the processed products, Flintoff-Dye, & Omaye (2005) suggested that CLA it is reverted to a pro-oxidant due to oxidative reactions, causing destruction of the conjugated double-bond system of CLA. The null hypothesis for oxidative stability would thus be that a 0.5% inclusion of CLA in pig diets would have no effect on fat oxidation in processed meat products manufactured from pork from such treatment.

CHAPTER 2

LITERATURE REVIEW

2.1. HISTORICAL BACKGROUND

Based on archaeological records, the domestic pig (*Sus scrofa domesticus*) originated from the Eurasian wild boar (*Sus scrofa*) (Giuffra, Kijas, Amarger, Carlborg, Jeon, & Anderson, 2000). Pigs are one of the oldest and most successfully domesticated mammals (Rowley-Conwy, Albarella, & Dobney, 2012). This can be attributed to the adaptable nature and omnivorous diet of pigs (Anonymous, 2005). Although pigs were first utilised as a human food source approximately 9000 years ago, very little information is available on exactly how pigs were utilised (Berg, 2006). During the 14th and 15th century, pork could be found on the menus of extravagant celebrations (Strong, 2002). In 1368, “two gilded suckling-pigs spitting fire” were served as the first of seven courses at a wedding, while at the coronation banquet of Henry VI in 1429, the menu included “boars’ heads in castles of gold” (Strong, 2002).

During approximately this same time, French tradesmen in the food production industry produced a range of cooked, salted and/or dried meats (Courtine, 1994). Pork was mostly utilized and the method of preparation varied from region to region. This led to the development of a new branch of cookery, named charcuterie (Courtine, 1994). Products included bacon, ham, sausage, terrines (pork cooked in a deep dish with straight sides), galantines (a dish made from lean pork emulsified with fat and mixed with eggs, spices and various other ingredients and pressed into a symmetrical shape, after which it was cooked in an aspic stock and served cold), pâtés (a meat, game or fish preparation put into a dish (terrine) lined with bacon, cooked in the oven and served cold), confit (a piece of pork cooked in its own fat and stored in a pot, covered in the same fat to preserve it), rillettes (a preparation of pork cooked in lard, pounded to a smooth paste, potted and served cold), trotters and head cheese/brawn (Courtine, 1994). Originally, the development of meat or processed meat products was the result of the need to preserve meat before the advent of refrigeration (Courtine, 1994; Vandendriessche, 2008).

2.2. GLOBAL CONSUMPTION PATTERNS OF MEAT IN GENERAL AND PORK SPECIFICALLY

Meat consumption is influenced by social, technological, economic, and political factors (Andersen, 2000; Vinnari, 2008). Social factors that could contribute to increased meat consumption include the increased occurrence of obese people, increasing portion size and the increasing number of households keeping meat eating pets (Vinnari, 2008). The technological factors that could have an effect on meat consumption include the development of less energy dense meat products and the development of more user-friendly meat products (i.e. products with reduced cooking times) (Vinnari, 2008). The economic factors that could have an impact on increasing meat consumption

include more efficient production methods and a general increase in income levels in society (Vinnari, 2008; Font-i-Furnols, Realini, Montossi, Sañudo, Campo, Oliver, Nute, & Guerrero, 2012). The political factors that could have an impact on increasing meat consumption include liberalisation of market policies, enabling cheaper meat products to be imported from other countries (Vinnari, 2008).

Worldwide, there has been a considerable increase in meat consumption, with developing countries showing the largest increase (Kearney, 2010). The demand and consumption of meat in developing countries is due to the fact that meat is a high-value product, which is highly valued by consumers in these countries (Priento, Roehe, Lavín, Batten, & Andrés, 2009). Convenience is the biggest driver of consumption of meat and processed meat products (Vandendriessche, 2008). Products such as sausages, burgers, pork pies, etc. account for almost half of all the meat consumed in developed countries (Kearney, 2010). The Food and Agricultural Organisation of the United Nations (FAO) estimated that this increased consumption of livestock products will continue in developed countries into the following decades (Vinnari, 2008). It is estimated that meat consumption in developed countries will be as high as 100 kg per person per year by 2030 (Vinnari, 2008).

Increased meat consumption resulted in meat becoming the subject of controversies relating to: increased health risks (several forms of cancer, cardiovascular and metabolic diseases), safety, environmental and animal welfare issues (Grunert, 2006; Latvala, Niva, Mäkelä, Pouta, Heikkilä, Kotro, & Forsman-Hugg, 2012; Capper, 2013; Pereira et al., 2013). Increased health risks resulted in more emphasis being placed on the nutritional properties of meat, i.e. the quality and quantity of animal fat (Olsson, & Pickova, 2005). Society became concerned about the importance of meat and overall fat content of meat in the diet, therefore, the demand for healthier meat, with less SFA increased (Olsson et al., 2005; Mas, Llavall, Coll, Roca, Díaz, Oliver, Gispert, & Realini, 2011). Dietary fat is one of the three major energy providing macronutrient groups (Nürnberg, Wegner, & Ender, 1998) and also contains fat soluble vitamins (A, D, E and K) (Nürnberg et al., 1998). Dietary guidelines recommend the reduction of fat consumption to 25-30% of daily caloric intake. Dietary guidelines also recommend the fat component to consist of 33% each of SFA, monounsaturated fatty acid (MUFA) and PUFA. The omega-3 fatty acid (*n*-3) and omega-6 (*n*-6) fatty acid requirements of young adults are 1.5 g/day and 10 g/day respectively (Nürnberg et al., 1998).

Pork is consumed on all continents and plays an important role in the economies of many countries (Ngapo, Martin, & Dransfield, 2007). According to the Foreign Agricultural Service of the United States Department of Agriculture (USDA) (2013), global pork production reached a record of 107.41 million tons in 2012 and the total global pork consumption reached 106.68 million tons (Table 2.1). Mass production and enhancement of pork started in the 20th century in Europe and North America (Rosenvold, & Andersen, 2003a). Rosenvold et al. (2003a) stated that the significance of factors that influence the quality aspects of pork has been investigated over the last century.

Table 2.1: Worldwide pig production and consumption (1000 metric tonnes, Carcass weight equivalent) (USDA, Foreign Agriculture Service, 2013)

	2009	2010	2011	2012	2013Apr
Production:					
China	48 905	51 070	49 500	52 350	53 800
EU-27*	22 434	22 571	22 866	22 630	22 550
Brazil	3 130	3 195	3 227	3 330	3 370
Russia	1 844	1 920	2 000	2 075	2 150
Vietnam	1 910	1 930	1 960	2 000	2 025
Canada	1 788	1 771	1 797	1 820	1 795
Philippines	1 234	1 247	1 275	1 382	1 420
Japan	1 310	1 292	1 267	1 297	1 305
Mexico	1 162	1 175	1 202	1 227	1 270
Korea South	1 062	1 110	837	1 086	1 240
Others	5 346	5 501	5 753	5 768	5 818
Subtotal	90 125	92 782	91 684	94 965	96 743
United States	10 442	10 186	10 331	10 554	10 669
World Total	**100 567**	**102 968**	**102 015**	**105 519**	**107 412**
Domestic consumption:					
China	48 823	51 157	50 004	52 725	54 225
EU-27*	21 057	20 842	20 680	20 423	20 310
Russia	2 719	2 835	2 971	3 145	3 230
Brazil	2 423	2 577	2 644	2 670	2 751
Japan	2 467	2 488	2 522	2 557	2 533
Vietnam	1 891	1 912	1 940	1 980	2 005
Mexico	1 770	1 784	1 710	1 838	1 930
Korea South	1 480	1 539	1 487	1 546	1 628
Philippines	1 344	1 405	1 419	1 518	1 556
Taiwan	925	901	919	893	891
Others	6 512	6 677	6 974	7 196	7 260
Subtotal	91 411	94 117	93 270	96 491	98 319
United States	9 013	8 653	8 340	8 438	8 659
World Total	**100 424**	**102 770**	**101 610**	**104 929**	**106 978**

* = European Union of 27 member states

These aspects include genotype, feeding, production systems, fasting, pre-slaughter handling, stunning methods and slaughter procedures (Rosenvold et al., 2003a).

As early as 1920 to 1930, studies in the United States already showed the dramatic effects of the fatty acid composition of dietary fat on the fatty acid composition and quality of body fat in the pig (Ellis et al., 1926). Today, pork can even be considered as being a nutraceutical, with the incorporation of CLA into the feed (Wood, Enser, Fisher, Nute, Richardson, & Sheard, 1999; Averette Gatlin, See, Larick, Lin, & Odle, 2002).

2.3. SOUTH AFRICAN PORK CONSUMPTION

South Africa contributes about 0.2% of the world pig population (Muchenje, & Ndou, 2010). The South African pig industry is relatively small in terms of the total South African agricultural sector,

as it contributes only about 2.15% to the primary agricultural sector (DAFF, 2012). In 2011, pig production increased to more than 185 000 tons (Figure 2.1) as a result of better prices being paid for pigs. This increase in production was the result of a 12% increase in annual pork consumption. Consumption declined slightly in 2012, in response to the decreasing beef price. A gradual increase in pig production is expected over the next few years (Figure 2.1). The expected growth of 41% in production, from 2013 to 2020, will outpace the projected 38% growth in consumption. As a result, pork imports will only increase to approximately 35 000 tons by 2020 (BFAP, 2012). According to the Department of Agriculture, Forestry and Fisheries (2013), 2 651 000 pigs were slaughtered from the 1st of July 2011 to the 31st of June 2012. For the same period, 208 200 tonnes of pork was produced and the per capita consumption of pork in South Africa was 4.7 kg/year. Compared to poultry (35.79 kg/year), beef/veal (16.60 kg/year) and lamb (3.20 kg/year), pork was the third most consumed meat in South Africa during this period (DAFF, 2013).

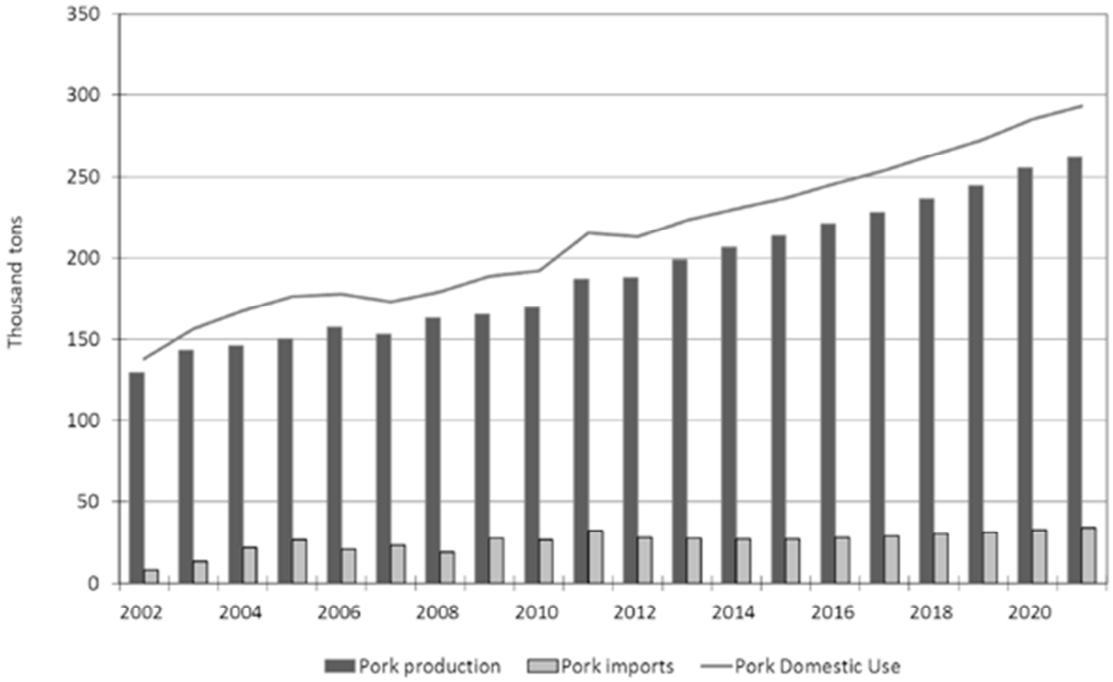


Figure 2.1: South African pork production, imports and domestic use (BFAP, 2012)

It is estimated that about half of all South African pork is utilized by the meat processing industry to manufacture bacon, sausages, hams and other meat products. This pork is produced by 400 commercial producers, in an industry that employs 10 000 people. There are around 4 000 non-commercial producers who slaughter 350 000 pigs annually. The remaining 50% of the commercial production is used as fresh pork in products such as pork chops, roasts and gammons. The market is estimated to be worth in excess of R1.5 billion annually, with volumes of around 120 000 tons. Polonies and viennas hold a market share of 40% and 30% of the processed meat market, respectively, with the balance being made up by bacon,

sausages, hams, spreads and meat rolls (Eskort, 2013).

2.4. PORK QUALITY

According to Andersen (2000), the concept “pork quality” includes, besides the composition and size of pigs, also eating, nutritional, technological, health, hygienic and ethical quality. Pork quality is the result of peri-mortem muscle metabolism, which is influenced by farm management conditions, transport, pre-slaughter handling, stunning, processing, carcass cooling rate, muscle structure, chemical composition, chemical environment, interaction of chemical constituents, post-mortem changes in muscle tissue and microbial numbers and populations on carcasses (Kapper, Klont, Verdonk, & Urlings, 2012; Joo, Kim, Hwang, & Ryu, 2013).

The term pork quality has different meanings to different people. For the modern pig producer, pork quality entails those properties which raise the most favourable price when selling the pig to the abattoir. Pig producers therefore prefer to rear pigs with increased lean growth, yielding more lean cuts in carcasses at minimum production cost (Lonergan, Huff-Lonergan, Rowe, Kuhlers, & Jungst, 2001; Fortin, Robertson, & Tong, 2005; Scheffler et al., 2007). For the abattoir operator and meat processing industry the main parameters for the evaluation of pork quality include the absence of pathogens, water-holding capacity (WHC), composition of the meat, meat to bone ratio, microbial load, presence/absence of residues and contaminants, as well as specific physical/chemical properties of value in processing (Fortin et al., 2005). Finally, the consumer can only differentiate between sensory quality parameters, such as tenderness, juiciness, flavour and the absence of off-flavours in the heated/processed product (Fortin et al., 2005).

There is a constant increase in consumer’s demands for high quality meat (Joo et al., 2013). The meat industry is therefore obligated to consistently produce and supply meat and meat products that are both safe and healthy (Joo et al., 2013). To achieve this, the meat industry needs to obtain reliable information on meat quality throughout the production process, which could ultimately provide guaranteed quality of meat and meat products (Damez, & Clerjon, 2008).

2.4.1. The role of muscle structure in meat quality

Muscle fibres are a major component (75-90%) of skeletal muscle (Lefaucheur, 2010; Joo et al., 2013) and are directly related to meat quality (Estellé, Gil, Vázquez, Latorre, Ramírez, Barragán, Folch, Noguera, Toro, & Pérez-Enciso, 2008; Joo et al., 2013).

Variation in pig muscle fibres can be explained by breed, genetic selection, gender, hormones, growth performance, muscle location, age and nutrition (Migdal et al., 2004; Joo et al., 2013). Pig skeletal muscle fibres have routinely been characterised into three major fibre types, designated type I, IIA and IIB (Estellé et al., 2008). Type I muscle fibres has the smallest diameter and are also known as red or oxidative fibres. Type IIA fibres are intermediate in size and are also known as intermediate fibres. Type IIB fibres have the largest diameter and are also known as white or glycolytic muscle fibres (Klont, Brocks, & Eikelenboom, 1998). Muscle fibre characteristics

such as total number of fibres, cross-sectional area of fibres and fibre type composition are the major determining factors of muscle mass as well as meat quality (Joo et al., 2013). It is well known that total number of fibres, cross-sectional area of fibres and fibre type composition are closely related (Ryu, & Kim, 2005). Identifying the specific relationships between these muscle fibre characteristics and meat quality remains difficult (Lefaucheur, 2010). It is widely reported that increasing the cross-sectional area of muscle fibres would be detrimental for meat quality, in particular for colour, WHC and tenderness (Lefaucheur, 2010). Increasing the total number of muscle fibres could be a good strategy to simultaneously increase LMC and preserve meat quality by reducing the cross-sectional area of muscle fibres (Lefaucheur, 2010).

Animals possessing a higher amount of muscle fibres and muscle fibres with an increased cross-sectional area have an increased growth rate and greater muscle mass (Miller, Garwood, & Judge, 1975; Te Pas, Soumillion, Harders, Verburg, Van Den Bosch, Galesloot, & Meuwissen, 1999). Increased muscle growth rate, age and carcass weight can lead to changes in histochemical muscle properties such as a decrease in the proportion of oxidative fibres and an increase in the proportion of glycolytic fibres which can result in less tender and less red meat (Migdal et al., 2004).

Fibre type composition in muscle is related to the rate of post-mortem pH decline. Increasing the proportion of glycolytic muscle fibres in pork *longissimus* muscle has been shown to increase the rate and extent of post-mortem pH decline (Kim, Ryu, Jeong, Yang, & Joo, 2013). Oxidative muscle fibres are susceptible to cold temperatures and thus, rapid post-mortem temperature decline could increase muscle shortening, especially if the muscle contains a high amount of oxidative fibres (Huff-Lonergan, Zhang, & Lonergan, 2010). Colour stability is decreased when the proportion of oxidative muscle fibres are increased (Kim et al., 2013). The composition of fast-twitch glycolytic muscle fibres in pork muscle is related to higher lightness (*L**) and WHC (Joo et al., 2013).

2.4.2. The role of lipids in meat quality

The total fat content of pig carcasses range typically between 24% and 29% (Realini, Duran-Montgé, Lizardo, Gispert, Oliver, & Esteve-Garcia, 2010), while the fat content of lean meat is ± 1% (Wood, Enser, Fisher, Nute, Sheard, Richardson, Hughes, & Whittington, 2008; Lakshmanan, Koch, Brand, Männicke, Wicke, Mörlein, & Raum, 2012). The association between animal fats and cardiovascular disease has been extensively studied and recommendations have ranged from excluding fats altogether, to a moderate consumption of fats, due to their essential role in the body (Webb, & O'Neill, 2008). Recently, the emphasis has shifted away from fat quantity to fat quality (Webb et al., 2008). Lipid quality plays an important role in the production of meat products (Miklos, Xu, & Lametsch, 2011). The specific role of fat differs between types of products and affects the rheological and structural properties of the product, besides contributing to succulence, flavour and texture (Miklos et al., 2011). Wood (1984) defined good quality fat in pigs

as firm and white and poor quality fat as soft, oily, wet, grey and floppy. Fat quality was therefore defined in terms of firmness and cohesiveness of the subcutaneous fat (Wood, Jones, Bayntun, & Dransfield, 1985). Santoro (1983) reported that poor fat quality is exhibited by soft fat which is not sufficiently mature, resulting in structural defects in the connective tissue. Products manufactured from poor quality fats will exhibit a granular surface on cutting and not the desired smooth surface associated with good quality processed meats (Santoro, 1983). Poor quality fat has a greater tendency to oxidise and to develop rancid flavours and odours (Barton-Gade, 1983; Santoro, 1983). With poor quality fat, the rancid flavour is transmitted to the meat (Santoro, 1983). During storage of poor quality fat, the colour of the fat turns from normal light yellow to an intense brownish orange (Santoro, 1983).

Pertinent cut-off point values for fat quality parameters are subject to great variation, because of the great interdependence with factors such as pig genotype, sex, age, feeding conditions, commercial quality grade and fatty tissue localisation within the carcass (Fischer, 1989a). Meat products containing soft fat show quality defects, such as insufficient drying, oily appearance, rancidity development and lack of cohesiveness between muscle and adipose tissue on cutting (Gandemer, 2002; Maw, Fowler, Hamilton, & Petchey, 2003). Barton-Gade (1983) indicated that iodine value (IV) is used as an indicator of soft fat and that a maximum IV of 70 would produce firm fat. Iodine value determination has the disadvantage that it is expensive and time-consuming (Andersen, Borggaard, Nishida, & Rasmussen, 1999). Refraction index (RI) is another measurement of fat quality. The corresponding limit for RI in terms of fat quality is RI < 1.4598 (Hart, according to Houben et al., 1983). Refraction index measurement has the advantage that it is rapid, but fat still has to be extracted, which can be a lengthy process. A new method has been introduced to determine the fat score (FS) by using near-infrared spectroscopy (NIRS) (Müller, Wenk, & Schreeder, 2008). In large Swiss abattoirs, fat quality is characterised by this FS, which is a measure of the number of double bonds in the outer layer of the backfat (Prabucki, 1991). A FS < 62 was recommended for good fat quality (Prabucki, 1991).

The content of individual fatty acids, combinations of fatty acids and ratios of fatty acids has been used extensively to predict fat quality (Muchenje, Dzama, Chimonyo, Strydom, Hugo, & Raats, 2009). Increased PUFA levels are associated with a higher occurrence of oxidation and rancidity and together with MUFA, a soft, greasy and oily texture of the fat (Hadorn, Eberhard, Guggisberg, Piccinali, & Schlichtherle-Cerny, 2008). Various maximum levels of PUFA had been proposed for good quality fat, ranging from < 15% (Houben et al., 1983), to even < 12% (Prabucki, as cited by Houben et al., 1983). Other fatty acid parameters include: > 41% SFA content (Häuser, & Prabucki, 1990); > 12% stearic acid (C18:0) content (Lizardo, van Milgen, Mourot, Noblet, & Bonneau, 2002); < 59% unsaturated fatty acid (UFA) content (Prabucki, 1991); < 57% MUFA; 12-15% linoleic acid (C18:2) content (Lizardo et al., 2002); 11% C18:2 content in salami and fermented sausages (Fischer, 1989b); < 15% C18:2 content in bacon (Enser, 1983); and < 12% to < 15% C18:2 in meat (Houben et al., 1983). The ratio of C18:0/C18:2 is the best measure of fat

softness and were recommended to be less than 1.2 or 1.47 for bacon (Honkavaara, 1989; Enser, Dransfield, Jolley, Jones, & Leedham, 1984). Double bond index (DBI) is another fatty acid related fat quality parameter. For good quality fat a DBI < 80 is required (Häuser et al., 1990).

Combinations of fatty acids such as C16:0 + C18:0 and C16:0/C18:2 have been associated with fat firmness (Enser, 1984). Cameron, Warriss, Porter, & Enser (1990) reported a positive correlation of fat firmness with C16:0 + C18:0 and C16:0/C18:2. Lea, Swoboda, & Gatherum (1970) suggested that the MUFA/SFA ratio (C16:1 + C18:1/C16:0 + C18:0) may also be a measure of fat firmness and melting point, which may be independent of carcass fatness. According to Cameron et al. (1990), the (C16:1 + C18:1/C16:0 + C18:0) ratio was not correlated with carcass weight and was negatively correlated with fat firmness. Häuser et al. (1990) also proposed the following additional quality criteria for good quality fat. A dienoic fatty acid content of < 10%; a trienoic fatty acid content of < 1%; a tetraenoic fatty acid content of < 0.5% and a pentaenoic + hexaenoic fatty acid content of < 1%. From a health and nutritional point of view, Enser (2000) proposed a PUFA/SFA ratio of 0.4-1.0 and *n*-6/*n*-3 ratio of < 4. From a medical point of view, Simopoulos (2008) proposed an *n*-6/*n*-3 ratio of between 1 and 5.

Another important physical quality parameter for fat is colour. Consumers, butchers and meat processors prefer pork fat to be white and yellow discolouration, caused by rancidity (Barton-Gade, 1983), will be rejected. Colour measurement equipment, like the Minolta chromometer or Hunter Labscan, may be used to determine fat colour *L**, redness (*a**) and yellowness (*b**) values (Tischendorf, Schöne, Kirchheim, & Jahreis, 2002).

Variation in fat quality may have serious implications for the end product specifications, which manufacturers of meat products have to face (Hugo, & Roodt, 2007; Miklos et al., 2011).

2.4.3. Technological quality

Technological quality is a complex and multivariate property of meat (Rosenvold et al., 2003a) and it describes the suitability of raw material for further processing (Olsson et al., 2005). Technological quality attributes of meat include its ultimate pH ($pH_{24hours}$), WHC, colour, texture and chemical composition (Olsson et al., 2005). These parameters are influenced by multiple interacting factors including: breed, genotype, feeding, pre-slaughter handling, stunning, slaughter method, chilling and storage conditions (Rosenvold et al., 2003a; Olsson et al., 2005). Water-holding capacity and colour are affected by almost all of the above factors (Rosenvold et al., 2003a).

Water-holding capacity can be defined as the ability of meat to retain inherent water during storage, processing and cooking (Honikel, 1998; Olsson et al., 2005). The pH and temperature development, early post mortem, are especially critical for the WHC of pork (Olsson et al., 2005). A higher WHC will increase the value of pork for use in highly processed pork products (Andersen, 2000). Water loss results in either a product with a less attractive appearance for the consumer (i.e. higher drip loss, higher cooking loss, lower juiciness and lower tenderness) (Sheard, Nute, Richardson, & Wood, 2005; Muchenje et al., 2009; Muchenje et al., 2010) or inferior technological

quality (Olsson et al., 2005). Both these defects have economic consequences for the meat industry (Olsson et al., 2005). Water content is also related to the physical properties of meat, because it is linked with juiciness and pale, soft and exudative (PSE) as well as dark, firm and dry (DFD) defects (Damez et al., 2008).

Pale soft and exudative meat syndrome in pork was first recognised and described during the 1950s (Cassens, 2000). The problem continues to exist today to approximately the same extent as when it was discovered (Cassens, 2000). Certain highly muscled breeds of pigs (Landrace and Pietrain) are highly predisposed to PSE and have much higher incidences of PSE (Cassens, 2000). Stress susceptible pigs are very excitable and sensitive to environmental, social and transportation conditions and meat from such pigs have a very high incidence of PSE (Cassens, 2000). In a well-fed and unstressed pig, the pH value typically falls from about 7.2 in the live animal to an ultimate post mortem pH of about 5.5 (Olsson et al., 2005). The PSE meat syndrome occurs in pork when the pH decreased to about 5.4 while muscle temperature is above 25 ℃ (Cassens, 2000) 45 minutes after slaughter (A dzitey, & Nurul, 2011) and when rigor mortis onset occurs at a pH below 5.9 at a temperature above 35 ℃ (Cassens, 2000).

Pale, soft and exudative meat has an undesirable greyish pink appearance, lack of firmness due to excessive drip loss (Qiao, Ngadi, Wang, Gariépy, & Prasher, 2007) and lower emulsifying capacity during processing (Cassens, 2000). Dry firm and dark meat have a dark purplish red appearance, a firm and sticky surface with a high WHC, very little or no drip loss and very high pH (Qiao et al., 2007).

When poor meat colour is not associated with other defects, such as poor WHC, toughness or microbial contamination; meat colour is less important in meat processing, as meat from different origins are mixed with other ingredients that enable some colour correction (Van Oeckel, Warnants, & Boucqué, 1999).

2.4.4. Consumer quality

From the consumers' perspective, fresh meat quality should be defined by consumer preferences that are determined by appearance quality traits, eating quality traits and reliance quality traits (Joo et al., 2013). Appearance quality traits are strongly influenced by the consumers' decisions to select good quality meat at the point of purchase (Rosenvold, & Andersen, 2003b; Grunert, Bredahl, & Brunsø, 2004). Eating quality traits are used by the consumer to determine the actual meat quality at the point of purchase (Joo et al., 2013). Reliance quality traits are extrinsic factors that consumers use to determine meat quality (Joo et al., 2013).

The appearance of meat is of primary concern in modern marketing, as most consumers "buy by the eye" (Rosenvold et al., 2003b). The consumers' decision to purchase good quality meat is strongly influenced by the appearance of fresh meat (Bryhni, Byrne, Rødbotten, Claudi-Magnussen, Agerhem, Johansson, Lea, & Martens, 2002; Fortomaris, Arsenos, Georgiadis, Banos, Stamataris, & Zygoyiannis, 2006). The appearance of meat is determined by meat and fat

colour of packaged meat, amount and distribution of fat, amount of drip on the surface of the meat, purge in the tray and texture of the meat (Joo et al., 2013). Meat colour is the most important appearance quality trait, because it is the first factor seen by the consumer and is used as an indicator of freshness and wholesomeness (Rosenvold et al., 2003b; Tikk, Lindahl, Karlsson, & Andersen, 2008; Joo et al., 2013).

At the point of consumption, consumers determine the actual meat quality by eating traits (Bryhni et al., 2002; Fortomaris et al., 2006). Sensory attributes like odour, flavour, juiciness and tenderness are associated with eating quality traits (Wojtysiak, & Migdal, 2007; Omana, Goddard, Plastow, Janz, Ma, Anders, Moore, & Bruce, 2014). The more important sensory attributes during consumption are tenderness, flavour and juiciness (Joo et al., 2013). Tenderness is the most important eating quality trait of meat and it strongly influences consumers' perception of acceptability (Wojtysiak et al., 2007; Lee, Choe, Choi, Jung, Rhee, Hong, Lee, Ryu, & Kim, 2012). Meat tenderness is mainly affected by the amount and solubility of connective tissue, the composition and contractile state of muscle fibres and the extent of proteolysis in rigor muscle (Lee et al., 2012). Pigs are slaughtered young, thus the immature connective tissue does not significantly influence pork tenderness (Olsson et al., 2005). Tenderness is more important for red meat such as beef and lamb because of a higher composition of red muscle fibres and connective tissue compared to pork (Joo et al., 2013). Flavour is another important eating quality attribute, because people expect certain attributes such as savouriness in meat (Mottram, 1998; Calkins, & Hodgen, 2007). Meat flavour is affected by species, sex, age, stress level, amount of fat and diet of the animal (Joo et al., 2013). Beef, lamb, pork and poultry have distinctive flavour characteristics due to variation of the flavour precursors between and within species (Joo et al., 2013). The flavour precursors are normally occurring in the fat tissue (Joo et al., 2013). The effect of gender on meat flavour is mostly related to testosterone and skatole, that are produced in intact males and females respectively. Boar taint in pork from intact males is an unpleasant urine-like and sweaty odour that is related to the presence of androstenone and skatole (Bonneau, 1998).

Juiciness is a more important eating quality trait for pork, because pork consumers place a higher premium on juiciness than on tenderness or flavour (Joo et al., 2013). A lack of juiciness in pork is a major quality issue, pork muscle that lacks IMF exhibits a lack of juiciness (Fortin et al., 2005). It is generally accepted that an increased level of IMF has a positive influence on sensory attributes of pork (Fernandez, Monin, Talmat, Mourot, & Lebret, 1999). An IMF content of between 2-4% was suggested for improved juiciness (Fortin et al., 2005; Shi-Zeng, & Su-Mei, 2009). The minimum level of 2% reflects the minimum eating satisfaction requirements and the maximum level of 4% the health concerns associated with excessive fat (Fortin et al., 2005).

2.5. FAT DEPOSITION IN THE PIG

Fat deposition is the difference between fat synthesis (lipogenesis) and fat mobilisation (lipolysis) and depends upon energy intake of essential nutrients (Madsen, Jakobsen, & Mortensen, 1992).

Both processes are substantially influenced by hormones such as adrenalin, glucagon, insulin and thyroid hormones (Müller, 1983). The hormones involved in the control of lypolytic activity in the adipose tissue have glycogenolytic effects in the muscle (Müller, 1983).

Carcass fat deposition is affected by breed, sex and nutrition (Turk, & Smith, 2009). Fat deposition can be characterised chemically by the continual accretion of lipids, primarily in the form of triacylglycerols and morphologically by adipocyte differentiation and hypertrophy (Nürnberg et al., 1998). Nutrients in excess of requirements for function of life and protein production will be deposited as fat in the body (Kühne, 1983).

Porcine carcass fat is deposited in four depots with different anatomical locations namely: visceral (internal), subcutaneous, intermuscular (between muscle) and intramuscular (within muscles) (Monziols, Bonneau, Davenel, & Kouba, 2007; Webb et al., 2008; Joo et al., 2013). Considerable fatty acid variations exist between the different anatomical locations in the pig (Monziols et al., 2007). It has been suggested that not all adipose tissue are similar, but each shows specific development and metabolism (Monziols et al., 2007).

Fat firstly accumulates in the subcutaneous and intermuscular sites, which provide insulation for muscles against the effects of temperature (Shi-Zeng et al., 2009) and secondly inside the muscle in the perimysial connective tissue (Shi-Zeng et al., 2009). The subcutaneous depot of pigs is the most important site of deposition, with about 62% of the total fat tissue at slaughter, followed by the intermuscular fat with about 24% and the visceral fat with about 13% of total fat (Nürnberg et al., 1998). Intermuscular fat is described as earlier maturing tissue than subcutaneous adipose tissue and consequently would be expected to have a higher concentration of lipids (Fortin, Wood, & Whelehan, 1985). Intramuscular fat has been reduced to below 1% in modern pigs (Wood et al., 2008).

Total lipid content does not differ significantly between the two layers of subcutaneous adipose tissue (66.8-67.8%) (Monziols et al., 2007). There is greater unsaturation and a higher deposition of C18:2 in the outer layer than in the inner layer of subcutaneous adipose tissue, suggesting that lipid metabolism is lower in the outer layer than in the inner (Christie, Jenkinson, & Moore, 1972). The inner layer exhibits larger *de novo* lipogenesis, with the result that PUFAs (particularly C18:2) are diluted with more endogenous fatty acids in the inner layer than in the outer layer (Christie et al., 1972). A difference in composition between the fat layers could be due to an adaptation of adipose tissue to temperature, trying to maintain the physical fluidity of the lipids in the different tissues (Dean, & Hilditch, 1933).

The degree of saturation of the fat depots in the pig follows a negative gradient from outside inward. The outer layer is more unsaturated, than the middle layer, the inner layer and the perirenal fat. Intermuscular adipose tissue also fits the pattern, its degree of unsaturation being lower than subcutaneous, but higher than in flare fat (Villegas, Hedrick, Veum, McFate, & Bailey, 1973). There is also a difference in the MUFA content between the different adipose tissues, along a gradient, with the highest concentration in the outer layer of the subcutaneous adipose tissue,

than the inner layer, the IMF and the flare fat (Bee, Gebert, & Messikommer, 2002; Monziols et al., 2007).

Oleic acid and C18:0 are the most abundant fatty acids and comprise more than 60% of the total fatty acids in all anatomical locations and occurs predominantly in the triacylglycerol fraction (Webb et al., 2008). The concentration of C18:2 (exclusively from exogenous origin) are higher in lean pigs (Kouba, Mourot, & Peiniau, 1997). This could be explained by the fact that the *de novo* lipogenesis is lower in lean pigs, with therefore less endogenous fatty acids, resulting in less dilution of exogenous C18:2. This could be the reason why contemporary pigs, selected against fatness, present a high C18:2 content (Monziols et al., 2007). Saturated fatty acids and MUFA are synthesised *de novo* in the animal body from carbohydrates and proteins and excess energy is converted to these fatty acids (Okuyama, & Ikemoto, 1999). Pigs, like other mammals, cannot synthesise C18:2 and C18:3*n*-3 (Okuyama, & Ikemoto, 1999). These fatty acids must be supplied in the diet (Okuyama, & Ikemoto, 1999). Linoleic acid is essential for the maintenance of growth, reproductive physiology, maintenance of the brain and retinal functions, but the essential amount (1%) is relatively small (Okuyama, & Ikemoto, 1999). The proportion of C18:2 in pig adipose tissue declines as fat deposition proceeds and is an index of fatness (Wood et al., 2008). From these parent fatty acids, other essential fatty acids, belonging to the *n*-6 and *n*-3 family respectively, may be synthesised in the organism by desaturation and chain elongation reactions as follows: C18:3*n*-3 → C18:4*n*-3 → C20:4*n*-3 → C20:5*n*-3 → C22:5*n*-3 (DPA; Docosapentaenoic) → C22:6*n*-3 (DHA; Docosahexaenoic) (Jakobsen, 1995).

Kouba, & Bonneau (2009) reported that kidney fat from Large White X Landrace castrated males, grew more rapidly than subcutaneous adipose tissue or IMF. In the shoulder and loin, about one third of the total adipose tissue is in the intermuscular fraction. In the belly area of pigs weighing 30-110 kg the intermuscular fat and subcutaneous adipose tissue occurred at the same level. In pigs weighing more than 140 kg, the belly area contained more intermuscular fat than subcutaneous adipose tissue. The intermuscular fraction of adipose tissue in the ham area grew slower than the subcutaneous fraction, so that it represented less than 25% of total ham adipose tissue in 140 kg body weight pigs. Intermuscular adipose tissue exhibited lower lipid content than the subcutaneous adipose tissue, whatever the body weight, but the differences in lipid content between the adipose tissues decreased with increasing weight (Kouba, & Bonneau, 2009).

2.6. FAT COMPOSITION OF THE PIG

2.6.1. Fatty acid composition of adipose tissue and muscle in pigs

Lipid composition of pork varies depending on the type of muscle and muscle fibre composition and is influenced by many factors, such as animal species, genotype, rearing and feeding (Cardenia, Rodriguez-Estrada, Cumella, Sardi, Della Casa, & Lercker, 2011). On average, the subcutaneous fatty acid composition of industrial pigs is: 36% SFA, 44%, MUFA and 12% PUFA (Gandemer, 2002).

Table 2.2 indicates the approximate fatty acid composition of pig subcutaneous adipose tissue compared to IMF (Enser, Hallet, Hewitt, Fursey, & Wood, 1996). Pigs have high proportions of the major PUFA, C18:2 in both adipose and muscle tissue (Wood et al., 2008). The proportion of C18:2 can be similar for adipose tissue and muscle (Table 2.2) or adipose tissue can have a higher proportion than muscle (Enser et al., 1996; Wood et al., 2008). Linoleic acid is derived entirely from the diet, as it passes unchanged through the pig's stomach and is then absorbed into the pig's blood stream in the small intestine and incorporated into the adipose and muscle tissue (Wood et al., 2008). The second most important PUFA is C18:3*n*-3. It is present in many concentrated feed ingredients but at a lower level than C18:2 (Wood et al., 2008). In pigs, the proportion of C18:3*n*-3 is higher in adipose tissue than in muscle tissue (Table 2.2) (Wood et al., 2008).

Table 2.2: Fatty acid composition and content (g/100 g total FA) in subcutaneous adipose tissue and muscle of loin chops in pigs (Enser et al., 1996)

Fatty acid	**Adipose tissue**	**Muscle**
C14:0	1.6[a]	1.3[a]
C16:0	23.9[a]	23.2[a]
C16:1*cis*-9	2.4[a]	2.7b
C18:0	12.8[a]	12.2[a]
C18:1*cis-9*	35.8[b]	32.8[a]
C18:2*n*-6	14.3[a]	14.2[a]
C18:3*n*-3	1.4[b]	0.95[a]
C20:4*n*-6	0.2	2.21
C20:5*n*-3	ND*	0.31
Ratio *n*-6/*n*-3	7.6	7.2
P:S**	0.61	0.58
Total ***	**65.3**	**2.2**

Means with different superscripts in the same row are significantly different ($p<0.05$)

* = not determined; ** = polyunsaturated:saturated; *** = fatty acid content

Muscle lipids are composed mainly of triacylglycerols in the adipocytes that are located along the muscle fibres and in the interfascicular area (De Smet, Raes, & Demeyer, 2004). Triacylglycerols from muscle are characterised by a high percentage of MUFA (59-62%), a low percentage of PUFA (4-6%) and a SFA proportion that varies between 32-37% (Tejeda, Gandemer, Antequera, Viau, & García, 2002).

Muscle contains significant proportions of long chain (C20-C22) PUFA, which are formed from C18:2 and C18:3*n*-3 (Wood et al., 2008). Long chain *n*-3 and *n*-6 PUFA are mainly found in phospholipids, but are also detected in neutral lipids of pigs (Wood et al., 2008). Muscle phospholipid content is relatively independent of the total fat content and varies between 0.2-1% of total muscle weight (De Smet et al., 2004).

2.6.2. Fatty acid composition of triacylglycerols and phospholipids

Lipids consist mainly of at least 99% triacylglycerols, with a small amount of cholesterol and degradation products of triacylglycerols (diacyl- and monoacylglycerols) and FFA (Gandemer, 2002). The main triacylglycerols in subcutaneous adipose tissue of industrial pigs, where P, S, O and L are palmitic (C16:0), stearic (C18:0), oleic (C18:1*c*9) and linoleic (C18:2) acids respectively, are POO (38%), PSO (24%), POL (13%) and OOO, PSL, PPO, OOL (3% each) (Gandemer, 2002).

In muscle a significant proportion is phospholipid, which has a much higher PUFA content, in order to perform its function as a constituent of cellular membranes (Wood et al., 2008). Table 2.3 indicates that C18:1*c*9, the major fatty acid in meat, is more predominant in the triacylglycerol fraction. Oleic acid is formed from C18:0 by the enzyme stearoyl Co-A desaturase, a major lipogenic enzyme (Wood et al., 2008). Linoleic acid was found at a much higher proportion in phospholipid fractions than in neutral lipid fractions (Wood et al., 2008). The proportion of C18:3*n*-3 was slightly higher in the neutral lipid fraction compared to the phospholipid fractions (Wood et al., 2008).

Table 2.3: Fatty acid composition of *longissimus* muscle triacylglycerol (neutral) and phospholipid in pigs (Wood et al., 2008)

Fatty acids	Neutral lipid (%)	Phospholipid (%)
C14:0	1.6	0.3
C16:0	23.8	16.6
C16:1*cis*	2.6	0.8
C18:0	15.6	12.1
C18:1*cis*-9	36.2	9.4
C18:2*n*-6	12.0	31.4
C18:3*n*-3	1.0	0.6
C20:4*n*-6	0.2	10.5
C20:5*n*-3	ND	1.0

ND = Not determined

2.6.3. Effect of fat content on fatty acid composition

As the fat content of the animal and its meat increases from early life to time of slaughter, the proportions of individual fatty acids change (Wood et al., 2008). In pig subcutaneous adipose tissue, the C18 fatty acids, namely, C18:0 and C18:1*c*9 increased, while C18:2 decreased with maturation (Wood et al., 2008). This could be ascribed to increased *de novo* tissue synthesis of SFA and MUFA and a decline in the direct incorporation of C18:2 from the diet (Kouba, Enser, Whittington, Nute, & Wood, 2003; Wood et al., 2008).

An inverse relationship between the proportions of C18:2 in subcutaneous adipose tissue and the amount of fat, or an index of it, such as backfat thickness, has been observed by Wood et al. (2008). A correlation exists between the proportions of C18:2 in the inner layer of subcutaneous adipose tissue and fat thickness in Large White pigs, selected for fast growth and low fat thickness

(Wood et al., 2008). These pigs had a higher amount of C18:2 (Wood et al., 2008). Similarly, in pigs with 8 mm, 12 mm and 16 mm backfat thickness, the average C18:2 content in adipose tissue declined from 14.9% to 12.4% to 10.6% (Wood et al., 2008).

The overall fat content of the animal and muscle have an important impact on the proportionate fatty acid composition, because of the different fatty acid compositions of neutral- and phospholipids (Wood, Nute, Richardson, Whittington, Southwood, Plastow, Mansbridge, Da Costa, & Chang, 2004). Phospholipids are essential components of cell membranes, with the amount remaining fairly constant or increasing little as the pig fattens. In young lean, genetically lean or animals fed a low energy diet, the lower C18:1*c*9 and higher C18:2 contents of phospholipid have a major influence on total muscle fatty acid composition (Kouba et al., 2003; Wood et al., 2008). As body fat increases, neutral lipids predominate the overall fatty acid composition (Kouba et al., 2003; Wood et al., 2008).

Age has a significant effect on total lipid, neutral lipid and fatty acid proportions (Kouba et al., 2003). There is an increase in the proportion of C18:1*c*9 and a decrease in the proportion of C18:2 in the neutral lipids of older animals, due to the increasingly important role of stearoyl Co-A desaturase. The importance of dietary fat, as a source of muscle fatty acids, declined as fat deposition accelerated in the muscle triacylglycerol and adipose tissue (Kouba et al., 2003).

2.6.4. The effect of gender on fatty acid composition

Gender of animals also has an important effect on fatty acid composition, because of its effect on carcass fatness (Nürnberg, et al., 1998). When animals are fed to the same fatness level and slaughter weight, castration influences the fatty acid composition of IMF (Nürnberg et al., 1998; Webb et al., 2008). Intact males are leaner and deposit less fat throughout the body and within the muscle than females, in turn females are leaner than castrated males (Nürnberg et al., 1998; Joo et al., 2013).

The relative concentration of C18:2 and PUFA in backfat decreased, in the order of males > females > castrated males, while the SFA increased (Nürnberg et al., 1998). This is mainly due to the decreased backfat thickness of intact males (Wood et al., 2008). Even at the same backfat thickness as females, intact males, however, had a higher proportion of C18:2 and a lower proportion of C18:1*c*9 in subcutaneous adipose tissue. At the same backfat thickness as females, intact males also contained a higher proportion of water and a lower proportion of lipid, signifying less mature tissue. This helps to explain why fat content tends to be lower in intact male pigs than females and castrated males (Wood et al., 2008).

The fatty acid composition of IMF of the female pig was more unsaturated than those of castrated males (Högberg, Pickova, Andersson, & Lundström, 2003). Muscle phospholipid fatty acid composition does not seem to differ between females and castrated males, but higher PUFA concentrations have been found in total lipid or triacylglycerols of females (Nürnberg et al., 1998).

This can be an indication of differences in lipid metabolism between genders (Högberg et al., 2003).

2.6.5. The effect of slaughter weight on fatty acid composition

In South Africa the usual carcass weight is 50-55 kg (porkers) or 70-75 kg (baconers) with a maximum of 85 kg (Vervoort, 1997). Bruwer (1991) indicated that South African pigs weighing less than 20 kg are classified as suckling pigs, while those weighing more than 90 kg are known as sausage pigs. Pieterse et al. (2000) stated that the average slaughter weight of pigs in South Africa is 70 kg. Hugo, Osthoff, & Jooste (1999) indicated that the low slaughter weight of pigs in South Africa results in low backfat thickness.

According to Wood, Enser, Whittington, Moncrieff, & Kempster (1989), pigs with a heavier slaughter weight had a physiologically more mature fat that is more saturated compared to pigs with a lighter slaughter weight. The accumulation of SFA in adipose tissues increases with age and growth of animals (Wood et al., 1989). This more mature and saturated fat, as a result of age and a heavier slaughter weight, could result in an improvement of pork quality (Candek-Potokar, Zlender, Lefaucheur, & Bonneau, 1998; Lebret, Noblet, & Bonneau, 1999). Consumer demand for leaner pigs resulted in a reduction in age and slaughter weight of pigs (Kühne, 1983). Increasing carcass weight concomitantly increases age (Beattie, Weatherup, Moss, & Walker, 1999) and the amount of adipose tissue at slaughter (Nürnberg et al., 1998). The chemical fat content of backfat increased with growth of pigs (Nürnberg et al., 1998). It was found that deposition of fat in the period from 70-220 days of life; caused an increase in adipocyte diameter of both backfat layers (Nürnberg et al., 1998). The rapid adipose tissue growth in pigs from 100-180 days of age is followed by a phase when adipocyte growth is minimal from 180-220 days of age. The relative percentage of UFA decreased with growth up to 180 days of age (Nürnberg et al., 1998). No change in fatty acid composition was observed after 180 days of age (Nürnberg et al., 1998). According to Osterhoff (1988), when pigs age and if they are slaughtered at 100 kg live weight, they would have deposited all their fat tissues, including IMF. Younger pigs deposit more unsaturated lipids and fat tends to be softer, while older pigs have harder, firmer, more saturated fat, which is preferred by butchers and processors (Bruwer et al., 1991).

The effect of age on fatty acid profiles is also related to body fatness (Nürnberg et al., 1998). During growth, the proportion of energy available for fat deposition in pigs increases, so that the rate of *de novo* fatty acid synthesis is increased. This resulted in increased synthesis of mainly C16:0, C18:0 and C18:1*c*9 and a reduction in C18:2 and C18:3*n*-3 contents (Nürnberg et al., 1998). It was reported by Beattie et al. (1999) that increased slaughter weight resulted in increased eye muscle area as well as subcutaneous fat content resulting in a decrease in total LMC. Increasing slaughter weight significantly improved fat quality (García-Macías, Gispert, Oliver, Diestre, Alonso, Muñoz-Luna, Siggens, & Cuthbert-Heavens, 1996).

When slaughtering occurs at a lower live weight, the lower cohesiveness of fat becomes increasingly important, especially in boars (Metz, 1985). Adipose tissue of pigs weighing less than 160 kg showed a higher percentage of water and smaller percentage of lipids compared to adipose tissue of heavier pigs (Lo Fiego, Santoro, Macchioni, & De Leonibus, 2005b). The increase of adipose tissue depots that occurs during growth is associated with an increase in lipid content (Lo Fiego et al., 2005b). Santoro (1983) stated that slaughter weight and age should be high when pigs are to be used for cured and seasoned uncooked products. Cisneros, Ellis, McKeith, McCaw, & Fernando (1996) indicated that belly yields increased with slaughter weight.

2.6.6. The effect of genotype on fatty acid composition

During recent decades, breeding strategies were aimed at increasing the lean meat to fat ratio in pig carcasses (Hadorn et al., 2008). Breed comparisons are often confounded by other effects like fat level, live weight or age at slaughter and production system (De Smet et al., 2004). Breed effects may be influenced by segregation of major genes, i.e. the stress sensitivity gene in pigs is well known (De Smet et al., 2004). It is sometimes difficult to assess the real contribution of genetics to differences in fatty acid composition (De Smet et al., 2004).

Breeds or genetic types with a low concentration of total lipid in muscle, in which phospholipid will make up a high proportion of the total lipid, will have higher proportions of PUFA in the total lipid fraction (Wood et al., 2008). In pigs, IMF content appears to be highly heritable (Nürnberg et al., 1998; Joo et al., 2013), while the fatty acid composition of muscle lipid is moderately to highly heritable (Nürnberg et al., 1998). Intramuscular fat of Duroc pigs had higher concentrations of SFA, MUFA and lower PUFA content than Landrace pigs (Nürnberg et al., 1998). The adipocyte diameter of backfat, intermuscular fat and IMF in Pietrain pigs is lower than in obese phenotypes (Nürnberg et al., 1998). Such pigs with a genetic predisposition for less subcutaneous fat can also be expected to produce carcasses with more UFA (Larsen et al., 2009).

The Duroc pig breed is noteworthy in having a higher IMF content relative to subcutaneous fat when compared to other breeds (Wood et al., 2008). According to Wood et al. (2008), traditional pig breeds (Berkshire and Tamworth) grow slower and were lighter and fatter than the modern breeds (Duroc and Large White). The amount of phospholipid in *longissimus* muscle was similar between the breeds but the amounts of triacylglycerols and total lipid were higher in Berkshire and Duroc compared to Large White and Tamworth (Wood et al., 2008). Duroc pigs had the highest ratio of muscle lipid to subcutaneous fat thickness (Wood et al., 2008). The proportion of phospholipid in total lipid was 18.8%, 23.8%, 38.9% and 31.7% in Berkshire, Duroc, Large White and Tamworth respectively (Wood et al., 2008). Values for the proportions of C18:1*c*9 and C18:2 in the total lipid were the same for all breeds, except for Duroc, where the proportion of C18:1*c*9 was lower and the proportion of C18:2 was higher than expected. A possible explanation for this is the slightly higher proportion of phospholipids in the Duroc *longissimus* muscle, which is also associated with its ”redder” muscle fibre type profile, in comparison with the other breeds (Chang,

Da Costa, Blackley, Southwood, Evans, & Plastow, 2003). The FA profile would thus be expected to be closer to the *psoas* muscle than the *longissimus* muscle, with a higher C18:2 and a lower C18:1*c*9 proportion (Wood *et al*., 2004).

2.6.7. The effect of diet on fatty acid composition

As previously mentioned, several factors exist that could have an effect on subcutaneous and IMF fatty acid composition, but diet in general is the most important factor (Högberg, Pickova, Babol, Andersson, & Dutta, 2002). Pigs, being monogastric animals are particularly susceptible to changes in the fatty acid composition of adipose tissue and muscle (Nürnberg et al., 1998; Scollan, Hocquette, Nuernberg, Dannenberger, Richardson, & Moloney, 2006; Vicente, Isabel, Cordero, & Lopez-Bote, 2013). Extensive changes can be brought about by altered feeding strategies i.e. feeding diets containing oils and fats with different fatty acid compositions (Doreau, & Chillard, 1997; Wood, Richardson, Nute, Fischer, Campo, Kasapidou, Sheard, & Enser, 2003; De Smet et al., 2004; Mas et al., 2011, Vicente et al., 2013). It is assumed that all digested fatty acids are equally useful for metabolic purposes and consequently a wide range of dietary fatty acids are used in practical pig nutrition (Vicente et al., 2013).

Fats and oils have traditionally been used as high-energy feedstuffs for pigs to maintain feed intake in warm climates and to reduce dust levels in feed and pig facilities (Aalhus, & Dugan, 2001; Azain, 2004; Duran-Montgé, Lizardo, Torrallardona, & Esteve-Garcia, 2007; Rossi, Pastorelli, Cannata, & Corino, 2010). Dietary fat supplementation decreases the endogenous fat synthesis and increases the deposition of the dietary fat into the fatty tissues of the pig (De Wilde, 1983). Depending on the protein source, the lipid content of conventional pig diets can vary, but rarely exceeds 3-4% (Farnworth, & Kramer, 1987). Metz (1985) indicated that with leaner pigs, the level of fat in the rations should be kept very low or feed should have a very saturated profile in order to produce good quality fat.

Pork fat has been modified by feeding diets containing fat sources high in PUFA such as full fat soybeans or linseed or diets high in MUFA, such as canola oil or high-oleic sunflower oil (Mas et al., 2011). Dietary incorporation of MUFA in pork fat is less pronounced, because MUFA is the predominant fatty acid in pigs and therefore MUFA from endogenous origin plays an important role (Verbeke et al., 1999).

Lipids in pork are relatively unsaturated and attempts to further increase concentrations of PUFA may increase the risk of lipid oxidation, leading to off-odours and flavours and colour changes (Wood et al., 2003; Mas et al., 2011). Oxidation can be inhibited by adding vitamin E to the diet (Dorreau et al., 1997). Vitamin E administered in the feed, is incorporated in cell membranes and thereby prevents oxidation of the unsaturated triacylglycerols and phospholipids (Verbeke et al., 1999). High levels of PUFA may also have an adverse effect on pork and bacon quality (Mas et al., 2011). Diets high in MUFA provide meats with a more favourable nutritional

profile and are positively correlated with pork flavour and less susceptible to oxidation compared to meats from animals fed diets rich in PUFA (Mas et al., 2011).

Spectacular results can be achieved using diets with high levels of C18:2, which is a common fatty acid in grains and oilseeds. In general, the proportion of this fatty acid in tissues increases linearly as the dietary intake increases (Doreau et al., 1997; Wood et al., 2008). In early studies by Ellis et al. (1926), the proportion of C18:2 in subcutaneous adipose tissue increased from 1.9% on a low fat diet to over 30% in diets containing a high level of soyabeans (Wood et al., 2008). Inclusion of maize in diets resulted in an increased C18:2 content in fat deposits (Bas, & Morand-Fehr, 2000). Fat is softer and more unsaturated as a result of increased C18:2 content (Dorreau et al., 1997). Linoleic acid content in muscle was lower than in adipose tissue and the dietary effect was smaller (Wood et al., 2008). Linoleic acid and other long chain fatty acids compete for insertion into phospholipid molecules in muscle (Wood et al., 2008).

Other dietary lipid sources containing specific fatty acids can be used to influence meat fatty acid composition (Wood et al., 2008). Examples are diets containing added palm kernel oil [high in lauric acid (C12:0), myristic acid (C14:0) and C18:0], palm oil [high in C16:0 and palmitoleic acid (C16:1)] and soybean oil (high in C18:2 and C18:3*n*-3). The greatest dietary impact of these oils in adipose tissue and muscle was on the content of C12:0, C14:0 and C18:2, with the C16 and C18 SFA and MUFA hardly affected by oil type (Wood et al., 2008). These results can be explained by the fact that C12:0 and C14:0 are mainly derived from the diet (Wood et al., 2008). Conversely, the C16 and C18 SFA and MUFA are mainly the products of synthesis in the animal and interconversions between them limit the impact of dietary addition (Wood et al., 2008).

Due to human health concerns, pig feed can be formulated with a higher content of natural sources of UFA (vegetable oils i.e. SFO or soybean oil or corn oil) and healthy oils, such as *n*-3 series or CLA (Cardenia et al., 2011; Mas et al., 2011). Meat from such pigs can be considered a healthy and a natural source of essential fatty acids (Olsson et al., 2005). Pork naturally has a high *n*-6/*n*-3 fatty acid ratio and supplementing pig diets with fish oil/meal, linseed oil and/or forage, which are rich in *n*-3 fatty acids, leads to a decrease in *n*-6 fatty acids, resulting in a pork product with a better *n*-6/*n*-3 ratio that is more beneficial to human health (Verbeke et al., 1999; Wood et al., 2008). Little or no effect was however observed on PUFA/SFA ratios (Webb et al., 2008). The extent of dietary PUFA and MUFA enrichment of IMF is demonstrated in Table 2.4. By incorporating oilseeds in pig feed, the dietary guideline of PUFA/SFA of 0.6-0.7 for backfat can easily be achieved (Verbeke et al., 1999). This was not the case for IMF, where this ratio stays well below the recommended values (Table 2.4) (Verbeke et al., 1999).

Dietary supplementation of CLA in pig diets has received attention in recent years, due to the positive effects on carcass and meat quality characteristics (Dugan, Aalhus, Schaefer, & Kramer, 1997; Ostrowska et al., 1999; Thiel-Cooper, Parrish, Sparks, Wiegand, & Ewan, 2001) and for nutritional interest in CLA-enriched meat (Martín, Antequera, Muriel, Andres, & Ruiz, 2008; Larsen et al., 2009).

Table 2.4: PUFA and MUFA enrichment of pork loin by PUFA/MUFA rich fat sources in the pig diet (Verbeke et al., 1999).

Main fat source	Feed fatty acid content			IMF					
	C18:1%	C18:2%	C18:3%	C18:1%	C18:2%	C18:3%	MUFA/ SFA	PUFA/ SFA	(n-6)/ (n-3)
Tallow	1.1	1.1	0.13	44.06	10.36	0.52	1.3	0.3	19.92
Rapeseed	2.58	1.47	0.33	46.55	10.54	1.11	1.39	0.32	9.5
Soybeans	1.4	2.47	0.31	38.75	14.98	1.04	1.01	0.37	14.4
Linseed	1.42	1.27	1.55	38.17	10.68	4.41	1.02	0.36	2.42
HOSO[a]	8.61	1.92	0.09	52.72	12.72	n.d.	1.88	0.54	-
Safflower oil	6.49	1.75	n.d.	48.8	10.4	1.4	1.53	0.34	7.43
Dietary guidelines							≥ 1	0.6-0.7	≤ 6

[a]HOSO = High-oleic sunflower oil; n.d. = not detectable

2.7. WHAT IS CONJUGATED LINOLEIC ACID?

Conjugated linoleic acid is the best-known isomer of C18:2 (Webb et al., 2008) and is a non specific collective term that refers to the group of octadecadienoic acids that is a mixture of geometric and positional isomers of C18:2 (O'Quinn, Nelssen, Goodband, & Tokach, 2000; Lo Fiego et al., 2005a; Pompeu, Wiegand, Evans, Rickard, Gerlemann, Hinson, Carr, Ritter, Boyd, & Allee, 2013; Tous, Lizardo, Vilà, Gispert, Font-i-Furnols, & Esteve-Garcia, 2013). The conjugated double bonds with *cis* and/or *trans* configuration are located in the region of carbon atoms 8-13. The predominant configurations in CLA occur at carbon positions 9 and 11 or 10 and 12 (Figure 2.2) (Müller, Kirchgessner, Roth, & Stangl, 2000; O'Quinn et al., 2000; Wiegand et al., 2002; Lo Fiego et al., 2005a). The main CLA isomer found in foods of animal origin is the *cis*-9, *trans*-11 isomer (Lo Fiego et al., 2005a).

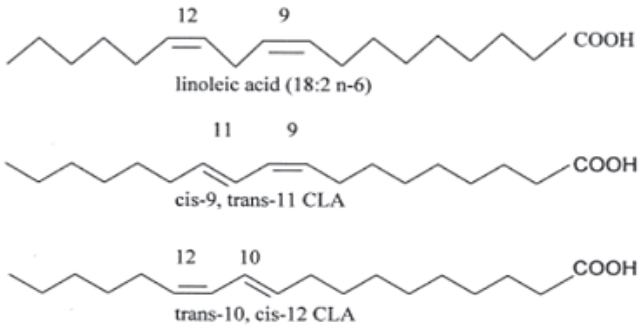


Figure 2.2: Structure of C18:2 (top), *cis*-9, *trans*-11 CLA isomer (middle) and *trans*-10, *cis*-12 CLA isomer (bottom) (Evans et al., 2002)

The *cis*-9, *trans*-11 isomer was thought to be the only biologically active form of CLA, because it was the only isomer found in the phospholipid portion of tissue (Wiegand et al., 2002). Khanal, & Dhiman (2004) reported that CLA configurations with one *trans* double bond is biologically active. The *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers appear to be the most biologically active (Kennedy et al., 2010) and of primary physiological importance (Crumb, 2011).

The *cis*-9, *trans*-11 isomer is thought to play an active anticarcinogenic role (Lo Fiego et al., 2005a), whereas the *trans*-10, *cis*-12 isomer is specifically responsible for the antiobesity effects (Kennedy et al., 2010) by decreasing body fat deposition, inhibiting pre-adipocyte differentiation and proliferation (Lo Fiego, et al., 2005a).

These substances occurs naturally in animal products, predominantly in beef, meat of other ruminants and in dairy products at 0.5-1.5% of the total fatty acids according to Dugan et al. (1999) and 0.2-2.0% of the total fatty acids according to Crumb (2011). Conjugated linoleic acid from animal fats usually consists of 90% of the *cis*-9, *trans*-11 isomer and 10% of the *trans*-10, *cis*-12 isomer (Kennedy et al., 2010). Conjugated linoleic acid is present in lower amounts in pork and in meat from other monogastric species (0.1-0.2% of the total fatty acids) (Dugan et al., 1999; Lo Fiego et al., 2005a).

2.7.1. Background to conjugated linoleic acid

Conjugated fatty acids were first identified in the 1930's in the milk from grazing cattle (Crumb, 2011). In 1978 it was identified in raw and cooked meat (Pariza, Ashoor, Chu, & Lund, 1979). Since the initial discovery of naturally occurring CLA in meat in 1978, it has been identified in many different meat and dairy products (O'Quinn et al., 2009). Conjugated linoleic acid was first identified as an anti-carcinogen by Kennedy et al. (2010). The discovery of CLA has drawn much attention to the variety of its biological activities (Park, & Pariza, 2007). With the approval of CLA as generally regarded as safe (GRAS) for use in certain types of food in 2004, the consumption of CLA increased (Dilzer, & Park, 2012). Increased CLA consumption led to the development of CLA fortified foods and stimulated research on the health benefits of CLA (Crumb, 2011; Giua, Blasi, Simonetti, & Cossignani, 2013).

Conjugated linoleic acid research revealed many promising health benefits for humans (Crumb, 2011). Many *in vitro* and *in vivo*, animal studies indicate that CLA could have beneficial effects as an anti-mutagen, antioxidant (Crumb, 2011), anti-carcinogen (Lo Fiego et al., 2005a; Larsen et al., 2009; Crumb, 2011, Dilzer et al., 2012; Matak et al., 2013) and anti-atherosclerotic agent (Kennedy et al., 2010; Dilzer al., 2012). It has been shown that CLA reduces LDL cholesterol, the incidence of heart disease, modulate lipid metabolism (Crumb, 2011) and modulate immune- (Pariza, 2004; Larsen et al., 2009; Crumb, 2011; Dilzer et al., 2012) and inflammatory responses (Pariza, 2004; Crumb, 2011). Dietary supplementation with CLA also has positive effects on growth, osteoporosis (Dilzer et al., 2012) and diabetes (Matak et al., 2013). One of the main interests in CLA has been in its ability to control body fat in animals and humans (Pariza, 2004; Dilzer et al., 2012; Matak et al., 2013). If CLA is supplemented over time, weight reduction progresses linearly for a period of 6 months, but become unresponsive after approximately 2 years (Dilzer et al., 2012). Due to the substantial increase in obesity prevalence the past 30 years, interest in CLA as a weight loss treatment has been increasing (Kennedy et al., 2010).

Lower efficacy in human studies, compared to animal studies, may be related to differences in the dose administered, supplementation period, differences amongst metabolic rates and differences in experimental protocol (Dilzer et al., 2012). Most human studies used CLA doses ranging between 0.7-6.8 g per day, which is much lower than what is used for animal studies (Dilzer et al., 2012). Supplementation periods in human studies could be too short, since less than 4-weeks supplementation in humans did not provide positive effects by CLA on body fat reduction (Dilzer et al., 2012). After 6 months of supplementation, greater efficacy of CLA on body fat modulation could be observed (Dilzer et al., 2012). Differences in metabolism between humans and animals may also have contributed to the differing effects (Dilzer et al., 2012). It is also possible that CLA may mainly be effective at reducing fat mass gain during a weight gain period (Dilzer et al., 2012).

2.7.2. Origin of conjugated linoleic acids in the human diet

Diet is the major source of CLA for incorporation into human tissue (Ritzenthaler, McGuire, Falen, Shultz, Dasgupta, & McGuire, 2001). The primary dietary sources of CLA for humans are foods derived from ruminants, including meat, fat, milk, cheese, yoghurt and butter (Crumb, 2011). Dairy products, followed by ruminant meats are the richest sources of natural CLA, while tissue from monogastric animals has the lowest natural levels of CLA (O'Quinn et al., 2000). Several factors has been identified that affect CLA concentration in animals (Crumb, 2011). These factors include: season, breed, diet and nutritional status as well as age (Kennedy et al., 2010). Diet tends to have the greatest overall effect of all the factors on CLA content in both milk and meat fat (Crumb, 2011). This led research to focus on methods to increase overall CLA concentration in animal products meant for human consumption (Crumb, 2011).

The recommended therapeutic intake of CLA for humans ranges from 1.5 to 3.5 g/day (Crumb, 2011). It was estimated that a 70 kg human should consume 3.0 g CLA/day to obtain the beneficial effects from CLA (Hur, Park, & Joo, 2007). The CLA dose that resulted in a significant reduction in fat mass was 3.2 g/day (Dilzer et al., 2012). Human serum levels range from 10-70 µmol/L (Kennedy et al., 2010). The average intake of CLA from natural sources (primarily the *cis*-9, *trans*-11 isomer) is estimated between 97.5 to 212 mg/day (Dilzer et al., 2012). Conjugated linoleic acid concentrations in beef range from 1.2 to 12.5 mg/g of fat (Crumb, 2011).

2.7.3. Biosynthesis of CLA

2.7.3.1. Biosynthesis of CLA in ruminant animals

Conjugated linoleic acid is a naturally occurring fatty acid (Evans, Brown, & McIntosh, 2002), which is produced via two biosynthetic processes. These processes are carried out primarily in ruminants and to a lesser extent in monogastrics (Crumb, 2011). The first process occurs in the rumen and the second process occurs endogenously in the tissues (Khanal et al., 2004; Crumb, 2011).

The first process, known as biohydrogenation, is where several bacterial species in the gastrointestinal tract converts C18:2 to numerous isomers of CLA (Wallace, McKain, Shingfield, & Devillard, 2007; Kennedy et al., 2010; Crumb, 2011). Various CLA isomers are formed as intermediates during biohydrogenation of C18:2 to C18:0 in the rumen by *Butyrivibrio fibrisolvens* and other rumen bacteria (Khanal et al., 2004). These isomers have been known to induce physiological effects in the host ruminant (Wallace et al., 2007). The biohydrogenation process changes the position and configuration of the double bonds in C18:2 (Kennedy et al., 2010). This results in the isomerisation of C18:2, where the double bond at the carbon-12 position is transferred to the carbon-11 position (Khanal et al., 2004). A single bond occurs between one or both of the two double bonds, forming the *cis*-9, *trans*-11 or *trans*-10, *cis*-12 CLA isomers (Kennedy et al., 2010). This is followed by the rapid hydrogenation of the *cis*-9 bond resulting in *trans* vaccenic acid (Khanal et al., 2004).

Butyrivibrio fibrisolvens was the first reported ruminal bacterium to produce the *cis*-9, *trans*-11 CLA isomer. The specific activity for *cis*-9, *trans*-11 CLA production from C18:2 are several folds higher in *Butyrivibrio*-related ruminal bacteria, compared to the production of the *cis*-9, *trans*-11 CLA isomer of C18:2 in monogastric species (Wallace et al., 2007). The *cis*-9, *trans*-11 isomer is typically the most abundant CLA isomer (Wallace et al., 2007). The synthesis of the *cis*-9, *trans*-11 CLA isomer from C18:2 by ruminal bacteria occurs via a different biochemical mechanism than the formation of the *trans*-10, *cis*-12 CLA isomer from C18:2 in the rumen (Wallace et al., 2007). Fewer bacterial species are known to synthesise *trans*-10, *cis*-12 from C18:2 (Wallace et al., 2007). While the formation of CLA from C18:2 by *Butyrivibrio fibrisolvens* in the rumen was accepted, it was not sufficient to account for all the CLA present in milk and meat of ruminants (Khanal et al., 2004). Ruminal synthesis of CLA is only marginal, indicating that CLA formed during the biohydrogenation of C18:2 in the rumen is not the only source of CLA synthesis (Khanal et al., 2004).

The second source of CLA in ruminants is the endogenous synthesis via $^{\Delta}9$ desaturase of *trans* vaccenic acid (Evans et al., 2002; Khanal et al., 2004). *Trans* vaccenic acid is a major *trans* fatty acid, which is a biohydrogenation product of C18:2 (Wood et al., 2008). This fatty acid is converted to CLA in adipose tissue by the action of stearoyl Co-A desaturase, the same enzyme responsible for the production of C18:1*c*9 from C18:0 (Wood et al., 2008). It is estimated that over 86% of the *cis*-9, *trans*-11 CLA isomer in beef fat originates from the desaturation of *trans* vaccenic acid (Khanal et al., 2004). It could be speculated that endogenous synthesis of body fat is similar to that of milk fat because *trans* vaccenic acid and $^{\Delta}9$ desaturase are the two primary prerequisites (Khanal et al., 2004).

2.7.3.2. Biosynthesis of CLA in monogastric animals

Synthesis of CLA from *trans* vaccenic acid has been shown to occur in humans (Duffy, Quinn, Roche, & Evans, 2006). Several species of bacteria derived from the human intestine can

synthesise CLA (Khanal et al., 2004). The amount of CLA synthesised endogenously or from intestinal bacteria has not yet been estimated in humans or other monogastric animals (Khanal et al., 2004). The fact that humans or other monogastric animals do not have any appreciable amounts of these specific bacteria in their digestive systems, needed for CLA synthesis, is an indication that endogenous synthesis could be the only appreciable source of CLA in these animals (Khanal et al., 2004). Synthesis of CLA in other monogastric herbivores has also not been reported (Khanal et al., 2004). As mentioned before, investigators have detected very little or no CLA in chickens and pigs (Khanal et al., 2004). It needs to be verified whether the small amounts of CLA found in poultry and pigs are merely the result of feeding ruminant products, such as meat meal, bone meal and blood meal, or whether they actually can synthesis CLA (Khanal et al., 2004).

When pure *trans* vaccenic acid is fed to mice it is desaturated to CLA (Khanal et al., 2004). This conversion occurs presumably in the adipose tissue, even though the liver is the site of fat synthesis in monogastrics (Khanal et al., 2004). In rats, the endogenous synthesis of CLA occurs using *trans* vaccenic acid as the precursor (Khanal et al., 2004). Greater concentrations of CLA in mammary tissue and milk fat of lactating mice fed *trans* vaccenic acid, might have been related to increased $^{\Delta}9$ desaturase activity in the mammary tissue and not the liver (Khanal et al., 2004). This suggests that, adipose tissue is the major site for the bioconversion of CLA from *trans* vaccenic acid (Khanal et al., 2004).

Propionibacterium freudenreichii subspecies *freudenreichi, a* bacterium in monogastric animals, mainly forms the 9,11 geometric isomers of CLA from C18:2 (Wallace et al., 2007). The synthesis of *cis*-9, *trans*-11 from C18:2 is also associated with *Bifidobacterium* species as well as some human intestinal *Roseburia* (Wallace et al., 2007). Among the human intestinal isolates, the *Bifidobacterium* produced trace amounts of the *trans*-10, *cis*-12 CLA isomer. *Lactobacillus casei* produced the *trans*-10, *cis*-12 CLA isomer as a minor component during C18:2 metabolism (Wallace et al., 2007).

2.7.4. Chemical synthesis of CLA

Conjugated linoleic acid is manufactured by many chemical suppliers (O'Quinn et al., 2000). Commercial preparations of CLA are made from the C18:2 fraction of safflower or SFO under alkaline conditions (Banni, Petroni, Blasevich, Carta, Cordeddu, Murru, Melis, Mahon, & Belury, 2004; Kennedy et al., 2010). Synthetically prepared mixtures of CLA predominantly contain the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers (Ma, Wierzbicki, Field, & Clandinin, 1999). Alkaline isomerisation of C18:2 yields a CLA mixture containing approximately 40% of the *cis*-9, *trans*-11 isomer and 44% of the *trans*-10, *cis*-12 isomer (Kennedy et al., 2010). Mixtures of these two isomers are found in most CLA supplements available in the market and are consequently the most readily available for research (Banni et al., 2004). Synthetically prepared CLA has been extensively used for most animal and human studies (O'Quinn et al., 2000; Dilzer et al., 2012). It

has been suggested that the overall effects of CLA are the results of interactions between the two major CLA isomers (Dilzer et al., 2012).

2.8. CONJUGATED LINOLEIC ACID AND PORK RESEARCH

Monogastric animals incorporate CLA into their tissues through the consumption of dietary CLA and from small amounts of bacterial isomerisation of C18:2 (O'Quinn et al., 2000). The introduction of commercial processing facilities for CLA, led to the use of CLA in pig studies becoming more feasible (O'Quinn et al., 2000). The inclusion of feed additives like CLA could be considered a strategy to improve pork quality (Matak et al., 2013).

Dietary CLA supplementation of pig diets has been used over a wide range of supplementation periods ranging from 45-93 days and at inclusion levels ranging from 0.12-5% (O'Quinn et al., 2000; Jiang et al., 2010). The primary focus has been on improved health (Hur et al,. 2007), growth performance (average daily gain; ADG) and feed efficiency (feed conversion ratio; FCR) (O'Quinn et al., 2000; Migdal et al., 2004; Hur et al., 2007), less backfat (O'Quinn et al., 2000; Hur et al., 2007), more carcass lean and bigger loin muscle area (O'Quinn et al., 2000; Migdal et al., 2004), an overall reduction of body fat percentage (O'Quinn et al., 2000; Ritzenhaler et al., 2001), belly fat firmness (O'Quinn et al., 2000; Eggert et al., 2001) and increased meat quality (O'Quinn et al., 2000; Hur et al., 2007). Enrichment of pork with CLA can be enhanced when CLA is fed with additional dietary fat, such as tallow, to further increase the SFA content (Averette Gatlin et al., 2006). Conjugated linoleic acid proved to be most effective in reducing fat mass and increasing lean mass when combined with enhanced physical activity (Pariza, 2004). Reductions in fat cell size, rather than fat cell number, are indicated as the reason for the decrease of fat deposition (Wang, & Jones, 2004).

Dietary CLA supplementation is an effective strategy of producing CLA-enriched meat and meat products with the potential health benefits of CLA consumption for humans (Szymczyk, 2005; Hur et al., 2007; Martin et al., 2008; Han, Feng, Yu, Tang, Bamikole, Tan, Zeng, Zhou, & Wang, 2011). As mentioned in the introduction, most of the work on CLA supplementation has been done on animals fed to the very heavy slaughter weight of ± 130 kg used in Europe and North America (Lauridsen et al., 2005; Martin et al., 2009; Cordero et al., 2010). In South Africa, slaughter weights of 70 kg for porkers and 90 kg for baconers are most common (Vervoort, 1997; Pieterse et al., 2000). Little is known on the effect of CLA supplementation on animals slaughtered at lower slaughter weights. No information could be found on the effect of dietary CLA supplementation on animal performance, carcass composition and meat quality of pigs from the three gender groups (boars, barrows and gilts).

2.8.1. Animal performance

Migdal et al. (2004) supplemented pig diets with 2% CLA and found better results for daily gain and feed conversion, compared to the control diet with 2% SFO, although these results were not

statistically significant. Jiang et al. (2010) supplemented pig diets with 1.25% and 2.5% CLA and found no statistically significant effect on fat percentage, dressing percentage and ADG, compared to the control with 2.5% SFO. Although not statistically significant, dietary CLA supplementation reduced average daily feed intake by 3.4% for the 1.25% CLA diet and by 7.6% for the 2.5% CLA diet, compared to the control supplemented with 2.5% SFO. CLA supplementation increased the lean percentage by 3.5% for the 1.25% CLA and by 4.7% for the 2.5% CLA diet (Jiang et al., 2010). Ostrowska et al. (1999) fed six dietary treatments containing (0%, 0.125%, 0.25%, 0.5%, 0.75% and 1.0% CLA) to pigs and found no statistically significant effect on ADG or feed intake, but reported an increased gain to feed ratio of 6.3% for pigs supplemented with 0.5% CLA. Ramsay et al. (2001) fed diets supplemented with 0%, 0.25%, 0.5%, 1.0% and 2.0% CLA to gilts and barrows. Dietary CLA did not affect total gain or the number of days in the experiment. Dietary CLA supplementation had no effect on ADG or feed efficiency. Ramsay et al. (2001) reported that gilts had lower feed efficiency than barrows. Warm carcass weight, carcass length, dressing percentage and weight of the liver, head or kidneys were unaffected by dietary CLA (Ramsay et al., 2001).

Conjugated linoleic acid is thought to have an effect on body composition regulation and energy retention (Müller et al., 2000; Wang et al., 2004). In trials with pigs, a negative effect on body fat accumulation, coupled with an increase in lean body mass was observed (Müller et al., 2000; Wang et al., 2004). Ramsay et al. (2001) reported that low levels of dietary CLA (0.25% and 0.5%) resulted in increased 10^{th} rib backfat thickness. Bee et al. (2008) reported that a 1% CLA fortified diet reduced the backfat thickness at the 10^{th} rib level. The reduction of fat deposition, as a result of feeding CLA, was confirmed by several studies conducted during the latter growth phase (50-100 kg) of pigs (Mersmann, 2002). Wang et al. (2004) reported that increasing dietary CLA from 0.07% to 0.55% linearly reduced fat deposition. That confirmed the findings of Mersmann (2000) that reduction in fat deposition is related to the dose of dietary CLA. Mersmann (2002) postulated that dietary CLA supplementation would be more effective in reducing fat deposition in genetically obese pigs, compared to leaner genotypes. This can be ascribed to the fact that further reduction of backfat thickness of leaner genotypes could possibly interfere with important metabolic functions of adipose tissue (Mersmann, 2002). It can also be expected that the response to CLA would differ between species because the patterns of lipid metabolism are species-specific (Mersmann, 2002). This variability may includes sites of *de novo* fatty acid synthesis, composition of lipids and lipoproteins, concentration and dynamics of individual lipoproteins, endocrine, and genetic regulation of lipid metabolism and depot sites for fat deposition (Mersmann, 2002).

Experimental diets containing 1% or 3% dietary CLA had no effect on feed digestibility, compared with a control diet containing SFO instead of CLA (Müller et al., 2000). Dietary nutrient interactions may also play a role in the response of animals to CLA administration, although definitive conclusions on this aspect could not yet be made (Müller et al., 2000). Müller et al. (2000) reported that sows fed an exactly isoenergetic diet containing 0.5-1.5% CLA, that was close to their

maintenance level, demonstrated no effect on heat production and energy retention. Some studies have shown that CLA feeding reduces food or energy intake (Wang et al., 2004). The reductions were marginal and cannot fully account for the marked decrease in fat deposition (Wang et al., 2004). Other reports have shown no effect on food or energy intake, even when large decreases in body fat mass were observed after CLA supplementation (Wang et al., 2004). Unknown mechanisms may also play a role in CLA-induced fat reduction (Wang et al., 2004).

2.8.2. Carcass characteristics

Dietary inclusion of 0.5% CLA in pig diets is recommended during the last 4 weeks of fattening (Dr R Ruehle, BASF, Personal Communication, 30 September 2013). In many animal models dietary CLA induces substantial reductions in body fat without substantially reducing body weight (Pariza, 2004). In most animal models the reduction in body fat appears to be due to reductions in body fat accretion and not reductions in body fat that had already accumulated before the initiation of the experiment (Pariza, 2004). The effect of CLA on body weight was investigated in various animal models (Wang et al., 2004). Most animal studies have shown that CLA reduced body fat and reduced subcutaneous fat accumulation (Ostrowska et al., 1999). That resulted in a differential effect on intra- and intermuscular fat content (Ostrowska et al., 1999), thereby increasing the percentage of carcass lean in finishing pigs (Ramsay et al., 2001; Larsen et al., 2009). Contrary to the findings of Ostrowska et al. (1999), Bee et al. (2008) reported that a 1% inclusion of dietary CLA did not affect overall subcutaneous fat deposition. The effect of CLA on body weight depends on the amount and isomer composition of the CLA mixture (Mersmann, 2000; Wang et al., 2004). When animals were supplemented with ≤ 0.5% dietary CLA, containing approximately equal amounts of *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers, body weights were not affected (Wang et al., 2004). Conjugated linoleic acid has been shown to increase live weight gain and improve feed efficiency and decrease carcass fat content in pigs (Wang et al., 2004).

Dietary supplementation with 0.12-5% CLA increased the contents of *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA isomers in lean and fat tissues (Ostrowska et al., 1999). The enhancement was greater in the fat tissue than in the lean tissue (Ostrowska et al., 1999). The effects of dietary CLA on fat content varied between backfat and IMF (Ostrowska et al., 1999). The estimated transfer efficiency of dietary CLA isomers to backfat is 41-52% (Hur et al., 2007). Based on these findings, it was hypothesised that the different effects of CLA on backfat and IMF accumulation may result from different concentrations of CLA in these tissues (Ostrowska et al., 1999). Different amounts of CLA are known to regulate expression of genes and proteins related to adipocyte proliferation and differentiation, which would lead to different fat depositions in backfat and *longissimus* muscle tissue (Jiang et al., 2010).

Dietary CLA reduces fat accretion in finishing pigs by reducing lipogenesis from preformed fatty acids and by increasing lipolysis (Ramsay et al., 2001). Alternatively, carcass fat may be reduced by CLA-induced apoptosis and subsequent lipodystrophy within the adipose tissue

(Ramsay et al., 2001). Grower pigs deposit fat at a lower proportion of total gain than lean tissue (Ramsay et al., 2001). Animals may need to accumulate fat at a higher rate than that of the grower pig to permit detection of an effect of dietary CLA treatment on fat accretion (Ramsay et al., 2001). Pigs should be in the finisher phase of growth to obtain the maximal beneficial effects of CLA supplementation on carcass composition (Ramsay et al., 2001).

Larger *longissimus* muscle and lower fat content were observed in pigs supplemented with 2% CLA (Migdal et al., 2004). The decrease in backfat depth is CLA dose-dependent (Ostrowska et al., 1999). Backfat depth at the 1st and 10th rib was reduced by between 16.6% and 12.9% respectively, when diets were supplemented with 2.5% and 1.25% CLA (Jiang et al., 2010). Backfat depth and ADG decreased quadratic with increasing amount of CLA (Jiang et al., 2010). Jiang et al. (2010) reported that, at the 2.5% CLA supplementation level, the overall carcass fat content was decreased by approximately 20%. Bothma, Hugo, Osthoff, Joubert, Swarts, & de Kock (2014) supplemented pig diets with 0%, 0.25%, 0.5% and 1% CLA and reported no significant decrease in backfat thickness between the different treatment groups. Although not statistically significant, carcass water composition and protein content increased linearly with increasing dietary CLA supplementation (Jiang et al., 2010). As a result of this, the ratio of fat to lean in the carcass was decreased in pigs fed CLA (Ostrowska et al., 1999). The fat to protein ratio in the carcass decreased linearly with increasing dietary CLA (Ostrowska et al., 1999). Carcass water deposition increased with increasing dietary CLA, reaching a maximum at 0.5% dietary CLA (Ostrowska et al., 1999) Protein deposition and lean tissue deposition were maximised at 0.5% dietary CLA (Ostrowska et al., 1999). Carcass fat deposition decreased linearly with increasing CLA supplementation rates (Ostrowska et al., 1999).

2.8.3. Effect of CLA supplementation on pork quality and stability

It was reported that dietary CLA supplementation improves the physiochemical characteristics of pork (Szymczyk, 2005). The appearance of lean meat and its technological characteristics are often related (Migdal et al., 2004). The meat from animals on a CLA supplemented diet was characterised by a slightly greater *a** and *b** and a higher coefficient of *L**, regardless of sex of the animals (Szymczyk, 2005). Szymczyk (2005) supplemented pig diets with, 0%, 0.1%, 0.2%, 0.4% and 0.6% CLA and found that the highest inclusion level had a significant effect on the *L** and *b** values of the meat. Meat from pigs supplemented with 0.6% CLA was considerably lighter, this was confirmed by the higher *L** and *b** values. These lighter colour values of muscle from CLA supplemented pigs could possibly be explained by increased number and diameter of white muscle fibres (Migdal et al., 2004). This increase in white muscle fibres resulted in a reduction in the number and diameter of red muscle fibres (Migdal et al., 2004; Kim et al., 2013). In contrast, Joo et al. (2002) reported that dietary CLA levels of 1%, 2% and 5% had no effect on *L**-value of pork. Jiang et al. (2010) also reported that supplementing pig diets with 1.25% and 2.5% CLA, had no effect on *L**, *a** and *b** values in the *longissimus* muscle. Matak et al. (2013) reported a similar

finding with 1% CLA diet. Joo et al. (2002) supplemented pig diets with 1%, 2% and 5% and found no effect on final pH. Jiang et al. (2010) also reported that supplementing pig diets with 1.25% and 2.5% CLA, had no effect on pH value of the *longissimus* muscle. Matak et al. (2013) reported a similar finding with 1% dietary CLA supplementation. Szymczyk (2005) and Bee et al. (2008) reported a reduction in the pH of the *longissimus* muscle of pigs after dietary supplementation of pigs at the 0.1%, 0.2%, 0.4%, 0.6% and 1% level.

Dietary CLA supplementation increased the IMF content of pork by 53.8% for the 1.25% CLA inclusion level and 57.2% for the 2.5% CLA inclusion level (Jiang et al., 2010). Joo et al. (2002) also reported that a 5% inclusion of CLA resulted in increased IMF content. The shear force of meat increased by 24.2% for the 1.25% CLA diet and 28.3% for the 2.5% CLA diet (Jiang et al., 2010). Contradictory findings were reported by Matak et al. (2013) who found that a 1% CLA diet reduced the shear force value of meat. Dietary CLA supplementation resulted in decreased purge loss in pork loin (Hur et al., 2007). Joo et al. (2002) reported that inclusion of 1%, 2.5% and 5% CLA had no significant effect on WHC.

From these inconsistent findings it is clear that further research is needed to determine the effect of dietary CLA supplementation on the physiochemical quality of pork.

The antioxidant activity of CLA was first recognised in 1990 from *in vitro* studies. The antioxidant properties of CLA are controversial, since there is still disagreement among researchers on CLA's ability to act as an antioxidant in animal products (Hur et al., 2007). According to Ha, Strokson, & Pariza (1990) CLA is an effective antioxidant that is more potent than α-tocopherol and almost as effective as butylated hydroxytoluene (BHT). The antioxidant effect of CLA might be partially responsible for the anticarcinogenic effect of CLA (Hur et al., 2007). Szymczyk (2005) suggested that the CLA isomers are incorporated into the phospholipid fraction. This results in decreased phospholipid oxidation susceptibility by the reduction of C18:2 and arachidonic (C20:4) acid and the concurrent increase in the SFA content. According to Hur et al. (2007) CLA does not participate in oxidation processes in meat, because no structural changes could be detected in CLA during storage of meat.

Since dietary CLA reduces C18:2, C20:4 and C18:1 content in fat and shifts the whole fatty acid composition to the more saturated side (Hur et al., 2007), meats from animals fed CLA may be less susceptible to lipid oxidation, colour changes and volatile production (Hur et al., 2007).

It was reported that dietary CLA supplementation improved the colour stability of patties, through the inhibition of lipid and oxymyoglobin oxidation (Hur et al., 2007). As dietary CLA levels increased, the TBARS values and hexanal content of meat patties, after storage under aerobic conditions, decreased (Hur et al., 2007). The TBARS values of loins from pigs fed CLA did not increase rapidly during storage (Hur et al., 2007). The lack of changes in CLA content during storage could be due to the greater stability of CLA if compared with other PUFA (Hur et al., 2007). The gradual decrease in meat malonaldehyde (TBARS), together with an increased level of CLA in feed, is a highly desirable change and implies the increased oxidative stability of pork enriched with

CLA (Szymczyk, 2005). Szymczyk (2005) attributed the decreased susceptibility of CLA enriched meat to oxidation to the higher SFA content of fat as well as the greater oxidative stability of CLA isomers compared to other PUFA.

Cooking and storage of meat had no effect on the CLA content of meat (Hur et al., 2007). Normally, unsaturated tissue lipids affect the storage stability of the carcass through oxidative breakdown, resulting in the development of peroxides and rancidity (Bee et al., 2008). Lipid peroxidation is a major cause of deterioration in the quality of muscle foods and can directly affect many meat characteristics such as flavour, colour, texture, nutritive value and food safety (Bee et al., 2008). The balance between antioxidants and pro-oxidants and the composition of skeletal muscle influences the susceptibility of muscle lipids to oxidation (Bee et al., 2008). When oxidative stress was increased by cooking and subsequent storage for 4 days at 4 ℃, oxidation was lower in CLA fortified meat (Bee et al., 2008). Inclusion of CLA had a protective effect on lipid oxidation when oxidative stress was elevated (Bee et al., 2008). Strong antioxidant properties have been shown by *trans*-10, *cis*-12 CLA isomers, regardless of its concentration while oxidation was accelerated by the *cis*-9, *trans*-11 CLA isomer at concentrations above 200 µM (Szymczyk, 2005).

Hur et al. (2007) indicated that CLA functions more as a pro-oxidant and that CLA is not as an effective radical scavenger as vitamin E or BHT. Pariza (2004) attributed the pro-oxidant properties of CLA to the enhancement of oxygen consumption and energy expenditure. According to Wang et al. (2004) several studies demonstrated CLA's ability to increase fatty acid oxidation and that the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers were oxidised to a much greater extent than C18:2. This literature study demonstrated that there is a need for further research on the antioxidative properties of CLA.

2.8.4. Effect of CLA supplementation on fatty acid composition

As previously mentioned, the fatty acid composition of intramuscular and adipose tissues of pigs can be efficiently manipulated by dietary intervention (Bee et al., 2008). By changing the pig's diet, the pig industry can change the fatty acid profile of pork according to the recommendations from nutritionists with respect to the most beneficial fatty acid profile for the human diet (Bee et al., 2008). Based on evidence derived from epidemiological, clinical and biochemical studies, the low *n*-3 fatty acid content of Western diets (Bee et al., 2008) is one of the major concerns today. It is recommended that the *n*-6/*n*-3 ratio must be less than 4:1 (Bee et al., 2008). The *n*-6/*n*-3 ratio reaches values of 12:1 in tissue lipids of pigs fed standard grower-finisher diets in countries like Switzerland (Bee et al., 2008). The main concern of increasing the *n*-3 fatty acids in tissue is the higher susceptibility to lipid oxidation (Bee et al., 2008). Increasing the saturation level of tissue lipids by the dietary inclusion of CLA might prevent oxidation (Bee et al., 2008). Feeding pigs diets fortified with CLA has been proven to be effective in lowering the MUFA/PUFA ratio and by that, lowering the susceptibility to lipid oxidation (Bee et al., 2008). Interestingly, supplementation of pig diets with CLA, a PUFA, has been shown to increase SFA content (Averette Gatlin et al., 2006).

This increase in the SFA content led to a significant decrease in the PUFA content (Averette Gatlin et al., 2006). As a result of this, the *n*-6/*n*-3 ratio was decreased in the direction advisable for human nutrition (Migdal et al., 2004). The effect of CLA on fatty acid metabolism is one of the main research interests to animal scientists, because dietary CLA may induce the changes of fatty acid composition in animals (Wang et al., 2004).

The apparent inhibition of desaturase activity may contribute to the relative increase in the proportion of SFA/UFA (Migdal et al., 2004). This inhibition may be through a PUFA responsive element in the promoter region of stearoyl-CoA desaturase (Migdal et al., 2004). Stearoyl-CoA desaturase enzyme activity has been detected in porcine adipose tissue and the relative level of desaturase activity was dependent on copper content in pig diets (Ramsay et al., 2001). The significance of a stearoyl Co-A desaturase reduction lies in the fact the stearoyl Co-A desaturase is the rate-limiting enzyme in the synthesis of MUFA, where a double bond is added at the carbon-9 position (Larsen et al., 2009). Research suggests that feeding isomers of CLA decreased the $^{\Delta}9$ desaturase index and stearoyl Co-A desaturase activity in pigs (Migdal, et al., 2004; Larsen et al., 2009). A decrease in $^{\Delta}9$ desaturase index and inhibition of stearoyl Co-A desaturase activity was reported when 1% CLA (Averette Gatlin et al., 2002), 1.5% CLA (Smith, Hively, Cortese, Han, Chung, Casteñada, Gilbert, Adams, & Mersmann, 2002), 1.75% CLA (Larsen et al., 2009) and 1.25% and 2.5% CLA (Jiang et al., 2010) was fed to pigs. It would therefore be a reasonable assumption that feeding CLA causes an increase in SFA (Averette Gatlin et al., 2002; Smith et al., 2002; Larsen et al., 2009; Jiang et al., 2010). Pigs fed 1-5% mixed CLA isomers had increased levels of SFA and decreased levels of UFA (Hur et al., 2007). Sows fed mixed CLA isomers for 35 days had more C16:0 and less C18:1 in their backfat (Hur et al., 2007). These fatty acid changes are the main reason for increased SFA and decreased MUFA (Hur et al., 2007).

Animal studies have shown that CLA supplementation inhibits lipogenesis (Migdal et al., 2004) and triacylglyceride esterification through the disruption in the fatty acid desaturation process (Hur er al., 2007). The inhibition of lipogenesis in adipocytes by CLA is an isomer-specific effect (Migdal et al., 2004). Cells treated with the *trans*-10, *cis*-12 CLA isomer exhibited smaller lipid droplets and reduced amounts of the major MUFAs, C16:1 and C18:1*c*9 (Wang et al., 2004).

A linear relationship exists between the content of CLA in feed and the CLA level in IMF or adipose tissue (Migdal et al., 2004; Szymczyk, 2005). Dietary CLA supplementation resulted in the incorporation of the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers into the subcutaneous adipose tissue and IMF (Bee et al., 2008). Linoleic acid content in the *longissimus* muscle was reduced by as little as 0.25% dietary CLA supplementation (Ramsay et al., 2001). Elevated CLA levels exerted a strong influence on the fatty acid composition of the *longissimus* muscle and backfat (Szymczyk, 2005). For the *longissimus* muscle, a significant increase in SFA was accompanied by a decrease in MUFA (Szymczyk, 2005). Although the fatty acid content of backfat generally showed similar tendencies as the *longissimus* muscle (Szymczyk, 2005), the fatty acid composition of adipose tissue was generally more sensitive to dietary CLA substitution than skeletal muscle (Ramsay et

al., 2001). This may simply be the consequence of the metabolic function of adipose tissue to accumulate fatty acids vs. oxidation in skeletal muscle (Ramsay et al., 2001). The incorporation of both the CLA isomers was more effective in backfat, while the *cis*-9, *trans*-11 isomer was more effectively incorporated into the *longissimus* muscle than the *trans*-10, *cis*-12 isomer (Szymczyk, 2005). The composition of fatty acids within subcutaneous adipose tissue, following CLA supplementation, differed from that in muscle (Szymczyk, 2005). The adipose tissue of barrows on a 2% linseed and 1% CLA supplemented diet was more saturated than the subcutaneous fat from barrows supplemented with 2% linseed, 3% linseed and 2% linseed and 1% tallow (Bee et al., 2008). Although dietary CLA supplementation resulted in incorporation of the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA isomer into adipose tissue, these isomers did not inhibit the desaturation of C18:2 (Bee et al., 2008). Intramuscular fat from barrows, supplemented with 2% linseed and 1% CLA, had higher levels of eicosapentaenoic (EPA, C20:5), C22:5 (DPA) and C22:6 (DHA) compared to the IMF of barrows supplemented with 2% linseed, 3% linseed and 2% linseed and 1% tallow (Bee et al., 2008).

Soft bellies are a problem in bacon production, because they have decreased yields, poor sliceability and potentially decreased shelf life (Larsen et al., 2009). Leaner genetic lines of pigs tend to have leaner bellies and deposit more unsaturated fat, compared to genetically fatter pigs (Larsen et al., 2009). Belly softness can also be attributed to the variety of unsaturated lipids fed to pigs (Larsen et al., 2009). They hypothesised that dietary CLA supplementation could produce firmer and higher quality bellies. The increase of firmness in such bellies will be the result of a shift to a more SFA profile in pork tissues after incorporation of dietary CLA. Dietary CLA has in fact been associated with increased firmness of bellies from finishing pigs, suggesting an increased SFA content (Ramsay et al., 2001). In addition to improved bacon composition and quality, another potential benefit of feeding CLA is the increased incorporation of CLA in bacon, which opens the possibility of marketing bacon as a CLA-fortified food (Larsen et al., 2009).

2.8.5. Effect of CLA supplementation on sensory properties

Consumer response is an important consideration in evaluating the success of CLA enriched meat and meat products (Crumb, 2011). Limited research has been done on the effect of different concentrations of CLA on the eating quality of pork (Dugan et al., 1999; Thiel-Cooper, Wiegand, Parrish, & Love, 1999; Wiegand, Parish, & Sparks, 1999; Weber, Schinckel, Houseknecht, & Richert, 2001; Wiegand et al., 2001; D'Souza et al., 2002; Tischendorf et al., 2002; Martin et al., 2009) and results from these studies showed great contradictions.

According to Crumb (2011), meat with increased concentrations of CLA received better retail acceptability scores, while the tenderness and palatability score of the CLA enriched meat were not affected. In general, greater concentrations of SFA and MUFA were associated with higher sensory panel scores for overall acceptability as well as tenderness, juiciness and flavour (Swan et al., 2001). Poorer scores for these traits resulted from pork with higher concentrations of PUFA. It

is expected that changes in carcass composition, fatty acid composition or both may lead to differences in palatability and acceptance of pork products (Averette Gatlin et al., 2006).

Averette Gatlin et al. (2006) reported that a 1% inclusion of CLA resulted in a slight increase of the fat aroma of loin samples. According to Migdal et al. (2004), the eating quality of CLA supplemented pork was not significantly influenced, although the flavour was significantly influenced. The difference in flavour can be caused by some changes in the fatty acid composition in the IMF, especially in C18:1*c*9, C18:2 and C20:4, which were significantly lower and in C16:1, which was significantly higher in meat from CLA supplemented pigs.

Dietary treatment, containing 1 and 2% CLA, did not affect the cooking losses, lipid oxidation, volatile profile and sensory traits of cooked loin, evaluated by 17 trained assessors (Martin et al., 2009). They did, however, find that the content of the CLA isomers of the fresh meat decreased after the cooking process (Martin et al., 2009). Supplementing the diets of barrows with 0.75% CLA had no effect on tenderness, juiciness and flavour intensity (Wiegand et al., 2001). These results were verified in previous studies, in which no differences were observed in sensory characteristics with CLA supplementation (Dugan et al., 1999; Thiel-Cooper et al., 1999; Wiegand et al., 1999). D'Souza et al. (2002) evaluated the effect of a 0.5% inclusion of CLA and found that pigs on the control diet tended to have better flavour, tenderness, juiciness and overall acceptability, compared to pork from CLA fed pigs (D'Souza et al., 2002). When pig diets were supplemented with 2% CLA and evaluated for tenderness, juiciness and flavour, Tischendorf et al. (2002) found that the added CLA had no effect on these sensory attributes.

2.9. CONCLUSIONS

Modern consumers demand leaner and healthier pork. The global pork industry responded by producing leaner pigs by utilising modern breeding, feeding and management techniques. These leaner pigs led to softer and more unsaturated fat. For the health conscious consumer, this is good news, but unfortunately soft, unsaturated fat resulted in technological problems during the manufacturing and storage of processed meat products.

Poor technological properties may be improved by dietary manipulation. The problem with this approach is that an increase in SFA will result in improved technological properties, but deterioration in health properties. By increasing the PUFA content the health properties will be improved, but the technological properties will deteriorate. This illustrates the great dilemma between technological properties and human health that meat producers and the meat industry have to deal with. This inverse relationship between health and technological properties can possibly be solved by supplementing pig diets with naturally occurring additives, such as CLA. A linear relationship exists between dietary CLA and the amount of CLA deposited in subcutaneous and IMF. This dietary intervention of supplementing pig diets with CLA may be one way of designing functional pork products with superior health and good technological properties that can be marketed as a nutraceutical.

The feeding of CLA-supplemented diets may provide a strategy to improve the health, growth performance, feed efficiency, carcass leanness, belly fat firmness and meat quality of pigs. Backfat can be decreased, percentage lean can be increased, loin muscle area can be increased and an overall body fat reduction can take place. The decreased fat content, as a result of CLA supplementation, may result in an increased protein content. The *cis*-9, *trans*-11 isomer is more effectively incorporated into *longissimus* muscle. The physiochemical characteristics of pork may be positively influenced by CLA supplementation. Meat from CLA supplemented pigs may have increased colour and lipid stability, increased WHC, less purge loss and increased IMF content. Supplementing pig diets with CLA may increase both the number and diameter of white muscle fibres and correspondingly reduce the number and diameter of red fibres. These improvements could result in improved profitability of pork production systems. Feeding CLA to pigs will inhibit lipogenesis. The *trans*-10, *cis*-12 isomer may be responsible for the reduction in adipocyte cell size. The reduction in adipocyte cell size will result in decreased carcass fat content and leaner carcasses. The *cis*-9, *trans*-11 isomer may be responsible for the anticarcinogenic effect of CLA.

To summarize, literature indicate that no differences exist between the digestibility of SFO and CLA (Müller et al., 2000). Dietary CLA altered lipid metabolism by decreasing the effect of the desaturase enzymes, producing higher concentrations of SFA and lower concentrations of MUFA and PUFA. The change in fatty acid profile, as a result of CLA supplementation, enhanced the technological properties of subcutaneous and IMF. Conjugated linoleic acid had an enormous effect on increased belly firmness this is of practical significance since this will increase the sliceability of lean bellies during bacon manufacturing. Saturated and MUFA content are positively correlated to overall acceptability of pork and CLA supplementation may result in a slight increase in aroma of pork fat. The numerous health benefits of CLA may provide a possible solution against the negative association meat and fat has towards health.

CHAPTER 3

MATERIALS AND METHODS

3.1. Digestibility study

3.1.1. Animals

Six Landrace x Large White crossbred male pigs, with an average weight of ± 44 kg, were penned individually into metabolism crates. They were fed at twice the maintenance rate of the control and experimental diets. The control diet was supplemented with 1.0% SFO and for the experimental diet 0.5% SFO was supplemented with 0.5% CLA. A crossover design was used. This entailed three animals and two periods (adaptation to feed and collection of faecal matter). Pigs were randomly assigned to the experimental treatments. Each experimental period comprised eleven days, i.e. seven days for adaptation and four days for collection of faecal matter, before each animal was submitted to the next treatment. The seven day adaption period could be seen as a rest period. Animals that finished daily feed were fed an additional 10% feed. Refusals of feed were analysed by weighing and subtraction from the feed offered. Faecal matter was collected three times per day at 08:00, 12:00 and 16:00 and immediately stored at -20 ℃, pending chemical analysis. At the end of the trial, faecal samples were thawed and dried at 60 ℃ for 24 hours. The faecal samples taken from each animal, on its specific diet, at the three different times, were mixed together as one sample. This represented the specific animal's daily faecal sample. This sample was sub-sampled and analysed.

3.1.2. Faecal matter analyses

A representive faecal matter sample that had been ground through a 1 mm sieve was chemically analysed for dry matter (DM; AOAC, 2005; method nr. 934.01), crude protein (CP; AOAC, 2005; method nr. 976.05), crude fibre (CF; AOAC, 2005; method nr. 978.10), neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Van Soest, 1963). Digestibility coefficients were determined by division [(Nutrient intake – Faecal nutrient)/Nutrient intake].

3.2. Animal production study

3.2.1. Animals

One hundred and fourty four Landrace x Large White crossbred pigs, with an average weight of ± 30 kg, were randomly divided into three gender groups (boars, barrows and gilts) comprising of fourty eight pigs each. Within each gender group pigs were randomly assigned to one of two dietary treatments of twenty four pigs each. These treatments comprised of a control diet, supplemented with 1.0% SFO and an experimental diet, where 0.5% SFO was supplemented with 0.5% CLA. Each gender group was further divided into two slaughter weight groups (70 kg and 90 kg), consisting of twelve pigs each (Annexure 1). Each group of twelve pigs can be considered as

an experimental group. The experimental design can therefore be described as a 2 X 3 X 2 factorial design. The pigs were housed in groups of twelve pigs per pen. Pigs were provided *ad libitum* access to feed and water. The pigs' weights were recorded weekly. Pigs were fed until the average live weight was ± 70 kg for the porkers and ± 90 kg for the baconers.

3.2.2. Diets

The formulation and nutrient composition of the diets are shown in Tables 3.1 and 3.2. Diets were formulated to be isocaloric and isonitrogenous (Table 3.2). Sunflower oil, in 20 litre containers, was obtained from Chipkins, Bloemfontein, South Africa. Luta-CLA® 60, manufactured by BASF Pty Ltd, was imported by Advit, Johannesburg, South Africa, in a 175 kg container. The CLA and SFO containers were transported to Meadow Feeds, where the two diets were mixed in 3000 kg batches. The control diet contained 1.0% SFO and the experimental diet was comprised of 0.5% SFO plus 0.5% CLA (Table 3.1). Conjugated linoleic acid can safely be included at levels of 0.5 - 1% in complete pig feeds and received GRAS status in the USA in 2004 (Dr R Ruehle, BASF, Personal Communication, 30 September 2013). Feed was packaged in 50 kg bags and stored in the dark, at room temperature, until used.

Table 3.1: Composition of the experimental diets on an air dry basis

Component	**SFO Diet Inclusion (%)**	**CLA Diet Inclusion (%)**
Yellow maize	68.06	68.06
Gluten 20	3.00	3.00
Sunflower oil	1.00	0.50
Luta-CLA 60	0.00	0.50
Fishmeal	2.00	2.00
Soya oilcake	20.00	20.00
Sunflower oilcake	3.00	3.00
Lysine	0.137	0.137
Threonine	0.0149	0.0149
Monocalcium phosphate	0.47	0.47
Limestone	1.45	1.45
Salt	0.42	0.42
Phyzime Phytase Pig Premix	0.05	0.05
Mycosorb	0.10	0.10
Pig Starter	0.30	0.30
Total	100.00	100.00

3.2.3. Oil and Feed analysis

Proximate analysis on feed was performed by the laboratories of Meadow Feeds. Lipid stability tests on feed samples were performed on samples from twelve randomly selected bags of feed from each treatment at the start and end of the trial. Lipids from feed samples were extracted with diethyl ether, using the Soxhlet extraction method (AOAC, 2005; method nr. 2003.06). Feed was chemically analyzed for peroxide value (PV; AOAC, 2005; method nr. 965.33), free fatty acid value

Table 3.2: Nutrient composition of the experimental diets on an air dry basis

	Unit	SFO Diet	CLA Diet
Moisture	%	10.99	10.99
Protein	%	17.25	17.25
Fibre	%	3.60	3.60
Fat	%	3.58	3.58
Calcium	%	0.91	0.91
Phosphorous	%	0.61	0.61
Digestible Energy	MJ/kg	13.79	13.79

(FFA) (Pearson, 1973), 2-thiobarbituric acid reactive substances (TBARS) (Raharjo, Sofos, & Schmidt, 1992) and fatty acid methyl esters (FAME) (Park, Albright, Cai, & Pariza, 2001).

3.2.4. Slaughter and carcass measurements

Pigs were slaughtered, after a 41 and 68 day feeding period, when the average live weights reached 70 kg and 90 kg, respectively. Pigs were weighed and feed was removed approximately 12 hours before slaughter. Pigs were transported to the abattoir where they were humanely slaughtered. All pigs were electrically stunned (220 V @ 60Hz for 7 seconds), stuck, scalded (60 ºC) and dressed, following commercial procedures.

To identify the pale, soft and exudative (PSE) and dry, firm and dark (DFD) condition in the pigs, pH values were measured 45 minutes (pH_{45min}) as well as 24 hours ($pH_{24hours}$) post mortem in the *M. longissimus thoracis* muscle with a portable pH-meter (Eutech instruments Pty Ltd, Singapore) with a glass body, gel-filled, spear tip probe, with BNC connector. In this study a pH_{45min} value of ≤ 6.00 was used to differentiate PSE from normal pork. A $pH_{24hours}$ value of ≥ 6.00 indicated whether the DFD condition existed in the carcasses. The Hennessy Grading Probe was used to measure backfat thickness and the thickness of the *M. longissimus thoracis* muscle, 45 mm off the carcass midline, between the second and third last rib. The percentage lean meat content in each carcass was calculated according to the formula currently used by the South African meat industry (Bruwer, 1992): Percentage lean meat content was calculated as (LMC) = 72.5114 – 0.4618V + 0.0547S [V = fat thickness (mm) and S = muscle thickness (mm) at 45 mm from the carcass midline, between the second and third last rib]. Commercial warm carcass weights were also obtained at this time. Growth rate was expressed as average daily gain (ADG) and calculated as live weight gain at the end of the trial, divided by days in the trial. After hanging in a cold room at ± 1 ºC for 24 hours, commercial cold carcass weights and carcass measurements were obtained. Carcass measurements consisted out of carcass length, shoulder circumference and buttock circumference.

3.2.5. Fat sampling

A core sample of both layers of subcutaneous fat was taken from all carcasses, 45 mm from the carcass midline, at the same place where the Hennessy Grading Probe was inserted. It is known

that the lipid saturation between backfat layers differ (McDonald, & Hamilton, 1976). Since both layers of backfat are used in processed meat products and because the emphasis of this work was on the technological properties of fat, it was decided to use the combined fat layers. Samples for lipid extraction were stored in Nunc cryotubes (AEC-Amersham, Johannesburg, South Africa) at -20 ℃ pending lipid extraction. Backfat quality was determined on all 144 carcasses obtained from the animal production study.

3.3. Backfat quality

3.3.1. Lipid extraction and fractionation

Extraction of total lipids from backfat (± 1.50 g) was performed quantitatively according to Folch, Lees, & Sloane-Stanley (1957), using chloroform and methanol in a ratio of 2:1. Buthylated hydroxytoluene (BHT) was added as an antioxidant, at a concentration of 0.001%. The extracts were dried under vacuum in a rotary evaporator and further dried in a vacuum oven at 50 ºC overnight with phosphorous pentoxide as moisture adsorbent. Total extractable fat content (EFC) was determined by weighing and expressed as % fat (w/w) per 100 g tissue. The fat free dry matter (FFDM) content was determined by weighting the residue on a pre-weighed filter paper, used for Folch extraction, after drying. By determining the difference in weight, the FFDM could be expressed as % FFDM (w/w) per 100 g tissue. The moisture content of the backfat was determined by subtraction (100% – % lipid – % FFDM) and expressed as % moisture (w/w) per 100 g tissue. The extracted backfat samples was stored in a polytop (glass tube, with push-in top) under a blanket of nitrogen (N_2) and frozen at -20 ºC pending chemical and fatty acid analysis.

Extracted lipid from CLA supplemented gilts were subjected to silicic acid column chromatography according to Bossio, & Scow (1997). Extracted lipid (± 10 mg) was dissolved in chloroform (2 x 300 µl) and fractionated by using a Varian Vac ELUT SPS 24 solid phase extraction system, using silica-bonded NH_2 columns with a 500 mg bed mass, 3 ml capacity and 40 µm mesh size obtained from Agilent (Part no. 12102041, MFG code 204107). Columns were activated with chloroform (2 ml). Successive application of chloroform (5 ml), acetone (10 ml) and methanol (5 ml) produced fractions containing, neutral lipids (triacylglycerols), glycolipids plus sphingolipids (referred to as glycolipids) and polar lipids (phospholipids), respectively. The extracts were subsequently dried under N_2 at 50 ℃ and stored at -20 ℃, pending fatty acid analysis.

3.3.2. Iodine value and refraction index determination

A sample of 0.5 g lipid, extracted by the Folch et al. (1957) method, was used to determine the Hanus iodine value (IV; AOAC, 2005; method nr. 920.158). Iodine value was expressed as the number of grams iodine absorbed by 100 g fat, which indicates the unsaturation of the fat. Extracted fat was also used to determine the refraction index value (RI; AOAC, 2005; method nr. 921.08), with an Atago 5000α Refractometer (Atago Co. Ltd, Japan). Three drops of extracted fat (from Folch extraction) were placed on the glass surface in the sample chamber by means of a

disposable glass pasteur pipette. Triplicate readings of RI-values were made at a temperature of 40 ºC and an average value was obtained for each sample.

3.3.3. Fatty acid analysis

Total lipid (± 25 mg), extracted by the Folch et al. (1957) method, was converted to methyl esters by base-catalysed transesterification, in order to avoid CLA isomerisation, with sodium methoxide (0.5 M solution in anhydrous methanol) during 2 h at 30 ℃, as proposed by Park et al. (2001). Fatty acid methyl esters were quantified using a Varian 430-GC flame ionization GC, with a fused silica capillary column, (Chrompack CPSIL 88, 100 m length, 0.25 mm ID, 0.2 µm film thicknesses). Analysis was performed by using an initial isothermic period (40 ℃ for 2 minutes). The temperature was thereafter increased at a rate of 4 ℃/minute to 230 ℃. Finally an isothermic period of 230 ℃ for 10 minutes followed. Fatty acid methyl esters in *n*-hexane (1 µl) were injected into the column using a Varian CP-8400 Autosampler. The injection port and detector were both maintained at 250 ℃. Hydrogen, at 45 psi, functioned as the carrier gas and N_2 was employed as the makeup gas. Galaxy Chromatography Data System Software recorded the chromatograms. Identification of sample FAME was made by comparing the relative retention times of FAME peaks from samples with those of standards obtained from Supelco (Supelco 37 Component Fame Mix 47885-U, Sigma-Aldrich Aston Manor, Pretoria, South Africa). Conjugated linoleic acid standards were obtained from Matreya Inc. (Pleasant Gap, United States). These standards included: *cis*-9, *trans*-11; *cis*-9, *cis*-11; *trans*-9, *trans*-11 and *trans*-10, *cis*-12 C18:2 isomers. Nonadecanoic acid (C19:0) (SIGMA N553377-1G) was used as the internal standard to improve quantitative FAME estimation. Neutral-, glyco- and phospholipid fractions were converted to methyl esters by base-catalysed transesterification as described above.

Fatty acid data was used to calculate the following ratios of fatty acids: C16:0 + C18:0; (C16:1+C18:1*c*9)/(C16:0 + C18:0); C16:0/C18:2; C18:0/C18:2; total MUFA; total di-, tri-, tetra-penta- and hexaenoic fatty acids; total pentaenoic + total hexaenoic fatty acids; total SFA; total PUFA; total UFA; MUFA/SFA; PUFA/SFA; $^{\Delta}$9 desaturase index (C18:1*c*9/C18:0) and the ratio of omega-6 to omega-3 (*n*-6)/(*n*-3) fatty acids. Double bond index (DBI) was calculated as: DBI = Σ% of UFA x number of double bonds of each UFA (Alam, & Alam, 1986). Peroxidizability index (PI) was calculated as: PI = [(% Monoenoic x 0.025) + (% Dienoic x 1) + (% Trienoic x 2) + (% Tetraenoic x 4) + (% Pentaenoic x 6) + (% Hexaenoic x 8)] (Pamplona, Portero-Otín, Riba, Ruiz, Prat, Bellmut, & Barja, 1998). Atherogenicity index (AI) was calculated as: AI = (C12:0 + 4 x C14:0 + C16:0)/(MUFA + PUFA) (Chilliard, Ferlay, Rouel, & Lambere, 2003).

3.4. Advanced meat quality work

3.4.1. Animals

Fourty gilts from the animal production part of the trial, 20 per slaughter weight (70 kg and 90 kg) and 20 per dietary treatment (0.5% CLA and 0.5% SFO) were selected for advanced meat quality work (i.e., ten 70 kg gilts supplemented with 0.5% SFO, ten 70 kg gilts supplemented with 0.5%

CLA, ten 90 kg gilts supplemented with 0.5% SFO and ten 90 kg gilts supplemented with 0.5% CLA (Annexure 1). Each group of ten pigs can be considered as an experimental group.Gilts were selected for this work, since the meat quality and fat deposition of gilts are intermediate between boars and barrows (Barton-Gade, 1987; Babol, & Squires, 1995; Xue, Dial, & Pettigrew, 1997).

3.4.2. Carcass preparation

After a 24 hour storage period at approximately 1 °C, the heads were removed and the carcasses were split. The left side rib, belly and loin were selected for sensory analysis, shear force measurements and meat quality analysis. The left side loin was cut into 30 mm thick chops, vacuum-packed and stored at -18 ℃ for sensory anal ysis. The right side thick rib, rib, loin and belly were selected for meat processing work. The right side thick rib and rib were deboned and minced through a kidney plate, vacuum-packed and stored at -18 ℃ for the manufacturing of patties and salami. The bellies were also vacuum-packed and stored at -18 ℃ for the manufacturing of bacon.

3.4.3. Backfat, belly fat and M. longissimus thoracis colour

Backfat, belly fat and muscle (*M. longissimus thoracis*) colour (*L**-, *a**- and *b**-values) was determined after 30 min bloom time with a Minolta CR-400 chromameter (Konica Minolta Sensing Inc., Osaka, Japan) using a 11mm port size, illuminant D65 and 2° standard observer. This instrument was calibrated with a white reference tile and a D65 illuminant source before the measurements. The CIE *L***a***b** colour scale was used for comparison where *L** represents lightness, *a** represents redness and *b** represents yellowness. The *a** and *b** values was used for the calculation of Chroma $\sqrt{a*^2 + b*^2}$ and Hue angle, [$\tan^{-1}$(*b**/*a**)] (Ripoll, Joy, & Muñoz, 2011).

3.4.4. Muscle sampling from M. longissimus thoracis for fat quality measurements

Twenty four hours post-mortem, a core sample of *M. longissimus thoracis* (± 5 g) was taken, approximately 45 mm from the mid-dorsal line, between the second and third last rib on the right side of the carcass. Samples intended for lipid extraction and fractionation were stored in Nunc cryotubes (AEC-Amersham, Johannesburg, South Africa) at -20 ℃.

3.4.5. Fat sampling

A core sample of both layers of subcutaneous fat was taken from the right side bellies of all 40 gilts. Samples for lipid extraction were stored in Nunc cryotubes (AEC-Amersham, Johannesburg, South Africa) at -20 ℃.

3.5. Backfat and Belly fat quality

3.5.1. Lipid extraction and fractionation

Extraction of total lipids from belly fat (± 1.50 g) of all pigs and lipid fractionation of belly fat (± 10

mg) from CLA supplemented pigs were performed as described in Section 3.3.1.

3.5.2. Fat hardness

The rib and belly from the left side were used to measure fat hardness. Backfat hardness was measured on the cross sectional fat surface of the left loin, between the second and third last rib, after the fat was shaved and smoothed. A Bristol fat hardness meter MK2 was used for fat hardness measurements. Fat hardness values were obtained from the average of three readings, adjusted to 1 ℃, using the equation: Fat hardness measurement (FHM) = [M – 18(1 ℃ – T ℃)], with FHM being the temperature-corrected meter reading, M the actual reading and T the actual fat temperature (Sather et al., 1995).

3.5.3. Iodine value and refraction index determination

Iodine value and RI of extracted belly fat lipids were determined according to the method described in Section 3.3.2

3.5.4. Fatty acid analysis

Fatty acid analysis of extracted lipid and lipid fractions from belly fat were determined according to the method describe in Section 3.3.3.

3.6. Physical and chemical properties of *M. longissimus thoracis*

3.6.1. M. longissimus thoracis and backfat area measurements

The eye muscle area and backfat from *M. longissimus thoracis* chops were traced onto paper. The areas were measured by means of a Video Image Analyser (VIA) (analySIS Life Science system). The composition of chops was expressed as % lean and % fat.

3.6.2. Drip loss of M. longissimus thoracis

Drip loss of pork was measured in duplicate. Fifty grams of fresh meat (24 h post mortem) was sliced into cubes of 10 mm x 10 mm x 20 mm. Each cube was hung onto a pin, secured to the cap, inside a sample bottle (200 ml), ensuring that the meat did not touch the sides of the bottle. The samples were stored for 3 days at 4 ℃ ± 1 ℃. The amount of drip loss was measured as the difference between the sample mass before and after. Drip loss was expressed as a percentage of the starting mass.

3.6.3. Water-holding capacity of M. longissimus thoracis

A 400-600 mg meat sample was placed on a filter paper (Whatman 4, Whatman International Limited, Maidstone, England), sandwiched between two perspex plates and pressed at constant pressure for 5 min, according to the method described by Grau, & Hamm (1953). The WHC was determined by calculating the ratio of meat area to liquid area after pressing. The areas were

measured by means of a VIA (analySIS Life Science system), described by Irie, Izumo, & Mohri (1996). The WHC was expressed as the area of the meat, divided by the area of the moisture (including meat area).

3.7. Intramuscular fat quality

3.7.1. Lipid extraction and fractionation

Extraction of the IMF from *M. longissimus thoracis* (± 5 g) and fractionation of the IMF from CLA supplemented pigs (± 10 mg) were performed as described above in Section 3.3.1.

3.7.2. Fatty acid analysis

Fatty acid analysis of the IMF (± 30 mg) and IMF lipid fractions from *M. longissimus thoracis* were determined according to the method described in Section 3.3.3.

3.8. Sensory analysis of pork

3.8.1. Physical texture analyses

Physical texture analyses (shear force measurements) were performed with the Instron Universal Testing Machine (UTM, Model 430) so as to correlate the results regarding tenderness with the findings of the trained sensory panel. After cooking the steaks, the posterior end of the muscle was cooled down at room temperature for at least 5 hours, before shear force measurements were made. Cylindrical samples (8 cores/sample), with a 12.7 mm core diameter, were cored parallel to the grain of the meat and sheared perpendicular to the fibre direction using a Warner Bratzler shear device mounted on the Instron Universal Testing Machine (UTM, Model 430). The reported shear force value, in kilogram, represents the average of the peak force measurements of each sample.

3.8.2. Descriptive sensory analysis of the sensory properties of fresh pork

3.8.2.1. Training of the sensory panel

An externally trained, 12 member sensory panel was used for the sensory analysis of the pork. The purpose of the descriptive analysis was to determine how the samples from the experimental treatments differed in terms of specific sensory characteristics. The 12 panellists were selected based on their previous participation in descriptive sensory panels, taste and smell acuity, interest, ability to discriminate between the four basic tastes and being available for the entire study.

Evaluations were performed in individual sensory booths. Samples were evaluated under red light conditions to mask colour differences. The sensory analysis facilities conform to the American Society for Testing and Materials (ASTM) (1996) design guidelines for sensory facilities. The analyses were conducted over an 8 day period (including training). Samples from all treatments were randomly assigned to three sessions (25 minutes apart) per day. All samples were coded

with random three digit codes. Water and carrot rings, at room temperature, were served as palate cleanser in between evaluation sessions.

During the training sessions, panellists were exposed to the samples to be evaluated, in order to develop relevant terminology (Table 3.3). The 12 panellists received a representative sample of pork meat and fat from the four dietary treatments and were then trained to increase sensitivity and ability to discriminate between specific samples and sensory attributes. In order to ensure that panellists were not influenced in any way, no information, with regard to the nature of the samples, was provided. A clear definition of each attribute was developed to describe the specific attribute to be evaluated. Panellists were instructed to give a detailed description of the aroma, flavour and aftertaste attributes of the pork meat and fat samples (Table 3.3). An eight-point intensity scale was used for scoring the different characteristics of the pork meat and fat from the experimental treatments (Annexure 2).

3.8.2.2. Preparation of sensory samples

The frozen pork loin chops (stored at -18 ℃) was thawed over a period of 24 hours at 5 ℃ before cooking. The cuts were prepared and evaluated according to the American Meat Science Association and National Live Stock and Meat Board (Chicago, Illinois, 1995) research guidelines for the cookery and sensory evaluation measurements of fresh meat. Consumers usually roast meat that is low in connective tissue, such as steaks. Steak location within the *M. longissimus lumborum* was standardized and steaks from a specific end of the muscle were assigned to sensory analysis and steaks from the other end were assigned to shear force tests. The steaks were cooked according to an oven-broiling method using direct radiant heat. An equal number of steaks (± 6) from a single treatment were placed on an oven pan on a rack to allow meat juices to drain during cooking. The steaks were positioned 90 mm below the pre-heated element of an electric oven (Miele, H217 ovens) at an oven temperature of 260 ℃. As the heat radiates from only one direction, steaks were turned during cooking. The steaks were cooked to an internal temperature of 35 ℃, then turned and finished to an average internal temperature of 75-77 ℃ at the geometric centre of the steak. The hot steaks were prepared immediately for sensory evaluation. Each panellist received standardised cubes measuring 12 mm x 12 mm x 12 mm of each cooked sample.

For the analysis of the fat, cubes measuring 12 mm x 12 mm x 12 mm were used. Only the centre cubes were used and the dryer outer sides were avoided. The meat cubes were wrapped in three-digit coded foil squares (90 mm x 90 mm) and presented at 55 ℃ on pre-warmed plates to the panel. The pieces of fat were each placed into pre-heated glass beakers (60 ℃) and covered with similar pre-coded aluminium foil and placed in a pre-heated sand bath at 120 ℃ and presented simultaneously with the meat sample to the panel.

Table 3.3: Descriptions and definitions of attributes used by members of the trained sensory panel to evaluate pork fat and meat samples

DESCRIPTOR	DEFINITION
FAT AROMA:	
Fresh pork fat	Aromatic associated with fresh pork fat (cooked).
Roast pork fat (caramel)	Aromatic associated with cooked, roasted pork meat, meat extract (browned meat, caramel and sweet).
Chemical	General term for aromatics associated with many different types of compounds, such as solvents, cleaning compounds, and hydrocarbons.
Sour	Aromatics reminiscent of fruit.
Piggy (old musty)	Aromatics associated with a live pig or its habitat, or wet pig hair also associated with closed air spaces such as attics, closets (dry) and basements and turned soil (wet).
MEAT AROMA:	
Roast pork meat	Aroma associated with cooked, roasted pork meat, meat extract (browned meat, caramel and sweet).
Cooked pork meat (fresh pork)	Aroma associated with freshly cooked pork meat.
Musty	Aroma associated with closed air spaces such as attics, closets (dry) and basements and turned soil (wet).
Livery (metallic/bloody)	An aroma associated with the inside of an empty can, tinny. Regarded as a negative attribute.
JUICINESS OF MEAT:	
Initial impression of juiciness	The amount of fluid exuded on the cut surface when pressed between thumb and forefinger.
MEAT TEXTURE:	
First bite	The impression of tenderness that you form on the first bite.
Tender	The impression of tenderness of the meat when biting into the meat and evaluate whether the meat breaks easily between the teeth (tender) or has become tough / difficult to bite through.
Muscle fibre & overall tenderness	Chew sample with a light chewing action. The impression of tenderness that you form of the meat when chewing.
SUSTAINED IMPRESSION OF JUICINESS – MEAT	
Sustained impression of juiciness – meat	The impression of juiciness that is formed when chewing. It is either dry with no fluid or juicy with moisture.
MEAT FLAVOUR:	
Bland	No flavour or taste factors perceptible.
Metallic (tin/aluminium)	A flavour associated with the inside of an empty can, tinny. Regarded as a negative attribute.
Cooked pork	Flavour associated with freshly cooked pork meat.
Sour	Flavours reminiscent of fruit, (fermented).
AFTER TASTE:	
(Off flavour of meat)	
Metallic	An after taste associated with the inside of an empty can, tinny. Regarded as a negative attribute.
Sour	An aftertaste reminiscent of fermented fruit.

3.8.3. Consumer analysis of sensory properties of fresh pork

3.8.3.1. Consumer sensory panel

Sensory analysis was carried out on all four treatment groups (70 kg SFO, 70 kg CLA, 90 kg SFO and 90 kg CLA) using a 75 member untrained consumer panel consisting of 51 females and 24 males, with an average age of 37 years. A nine-point hedonic scale ranging from 1 for dislike extremely up to 9 for like extremely was used to score general preference, aroma, taste and tenderness as attributes (Table 3.4).

3.8.3.2. Preparation of sensory samples

Preparation of samples for untrained consumer sensory analysis was done as described for trained sensory panel in Section 3.8.2.2.

Table 3.4: Simplified example of the hedonic scale used for sensory analysis

Nine-point hedonic scale for general preference, aroma, taste and tenderness								
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
1	2	3	4	5	6	7	8	9

3.8.4. Myofibrillar fragment lengths

A frozen muscle (3 g) sample was placed in a 50 ml Bühler glass containing myofibrillar fragment length (MFL) extraction buffer (30 ml) [0.02 M Potassium phosphate buffer containing 100 mM KCl, 1 mM $MgCl_2$, 1 mM EDTA and 1 mM NaN_3 (pH 7.0) (4 ℃)]. Samples were allowed to thaw for 60 seconds and were then homogenised for exactly 30 seconds in a Bühler HO 4/A homogeniser, at 20000 rpm (blade turned around in order to fragment myofibrils rather than cut them). Samples were subsequently centrifuged at 3000 rpm (4 ℃) for 15 minutes. The supernatant was discarded and the pellet was suspended in MFL extraction buffer (30 ml) (4 ℃) and centrifuged at 3000 rpm (4 ℃) for 15 minutes. The supernatant was discarded and the pellet suspended in MFL extraction buffer (10 ml) (4 ℃).

The suspension was filtered under vacuum through a 1000 µm polyethylene strainer. Additional MFL extraction buffer (5 ml) (4 ℃) was used to facilitate the passing of myofibrils through the strainer. The filtrate was subsequently filtered under vacuum, through a 250 µm polyethylene strainer. This filtrate was used to measure MFL with the VIA. Myofibrils were extracted according to Culler, Parrish, Smith, & Cross (1978) with some modifications (Heinze, & Brueggermann, 1994). The myofibril fragments from the filtrate were examined with an Olympus BX40 system microscope at a 400X magnification. One hundred myofibril fragments of each sample were measured, using analySIS Life Science software package.

3.8.5. Muscle fibre typing of M. longissimus lumborum

Muscle samples (± 10 g) were cut from the *M. longissimus lumborum* and frozen in liquid N_2. The frozen samples were cut against the grain of the meat and mounted on a cryotome disc, with special mounting solution for frozen meat cuts. Cryotome discs with samples were placed in the cryotome chamber at -25 ℃ and cut to a thickness of 10-12 µm. Cuts were placed on microscope slides, stained by staining solution [0.2 N phosphate buffer (pH 7.65) (25 ml), 0.2 N succinic acid-NaOH buffer (pH 7.64) (25 ml) and 1 mg/ml nitroblue tetrasolium (NBT) (25 ml)] and incubated (37 ℃). After incubation the slides were removed, washed [0.9% NaCl, 1% formal saline (10 min), 15% alcohol and distilled H_2O] and dried. Slides were then fixed by mounting in melted glycerine jelly, dried and cleaned with distilled H_2O (Barka, & Anderson, 1963). Muscle fibre types were examined with an Olympus BX40 system microscope at a 100X magnification. Fifty measurements per muscle fibre type were done and the amount of red, intermediate and white muscle fibres were counted in 5 microscopic fields to determine the percentage of each fibre type in the samples (analySIS Life Science).

3.9. Chemical and oxidative stability studies

3.9.1. Accelerated fat oxidation test

Extraction of total lipids for oxidative stability index (OSI) measurements on backfat (± 12 g), from all 40 gilts, was performed as described in Section 3.3.1. Oxidative stability index analysis was determined by OSI instrument (Rancimat 743) on freshly extracted subcutaneous fat. Three grams of extracted fat was kept at 100 ℃, with a constant airflow of 20 L/min (AOCS, 1993; method nr. Cd 12b-92).

3.9.2. Colour and lipid stability of fresh and frozen pork

Four loin chops from each pig, from each treatment group, were individually packed into polystyrene trays, containing absorbent pads and overwrapped with oxygen-permeable polyvinyl chloride (PVC) meat stretch wrap. Two loin chops from each pig was stored at 4 ℃ for 7 days, under fluorescent light, for fresh meat stability studies. The remaining two chops were vacuum-packed and stored at -18 ℃, in the dark, for frozen storage stability studies. One of these chops was stored at -18 ℃ for 3 months and the remaining chop was stored at -18 ℃ for 6 months.

On days 0 and 7, one loin chop from each pig, stored at 4 ℃, was opened. The colour (*L**, *a** and *b** values) of both muscle and fatty tissue were assessed, in duplicate, after 30 min, using a Minolta CR-400 chromameter. Chroma, which is related to the colour intensity of the meat, was calculated according to the formula: Chroma = $\sqrt{a*^2 + b*^2}$ for both muscle and backfat (Lanari, Scheafer, & Scheller, 1995; Ripoll et al., 2011). According to Joo, Kauffman, Kim, & Kim (1995), chroma was better correlated with visual perception of pork colour than *a**-value. Hue angle was calculated according to the formula [$\tan^{-1}$(*b**/*a**)] (Ripoll et al., 2011). TBARS analyses, to determine lipid oxidation of lean meat, were done according to the following method. Two 5 g samples lean meat were removed from the middle of each loin chop and the aqueous acid extraction method of Raharjo et al. (1992) was used. An 8 g sample of backfat (inner + outer layer) was also removed for lipid extraction, using the Folch et al. (1957) method. To assess lipid oxidation in backfat, the PV was determined on 4 g of the extracted lipid sample, using the AOAC (2005) method nr. 965.33.

To assess oxidative stability during frozen storage, lean meat and backfat were sampled on day 0, at 3 months and at 6 months. TBARS values of lean meat (Raharjo et al., 1992) and PVs of backfat (AOAC, 2005; method nr. 965.33) were also determined.

3.9.3. Oxidative and colour stability of fresh and frozen pork patties

The frozen minced lean meat and backfat, earmarked for the manufacturing of processed meat products, were used to manufacture two batches of 3 kg pork patties for each treatment (dietary and slaughter weight) group, according to the formulation outlined in Table 3.5. Lean meat, backfat and salt were mixed and then minced through a 4.5 mm plate of an nr. 32 OKTO mincer. Thirty six 70 g pork patties, from each of the four treatments, were then prepared by using a hand model

Table 3.5: Pork patty formulation

Ingredients	Inclusion (%)
Lean Meat	80.00
Backfat	18.00
Salt	2.00
Total	**100.00**

patty press. Twenty four of the patties were individually packaged in polystyrene trays and wrapped an oxygen permeable PVC meat stretch-wrap. The packaged, or overwrapped, pork patties were stored at 4 ℃ until sampling on days 0, 3, 6 and 9 of fresh storage.

During the storage of the fresh patties, colour (*L**, *a** and *b** values) of each patty was measured with a Minolta CR-400 chromameter. The method for colour measurement is as described for fresh pork chops in Section 3.9.2. The remaining 12 patties were vacuum-packed and stored at -18 ℃ until sampling on day 0, 3 months and 6 months of frozen storage. Similarly to the chops, the patties were stored in the overwrapped form to create abusive storage conditions. On the chosen days, two 5 g samples from each patty were taken from each treatment for TBARS determination (Raharjo et al., 1992). A 30 g patty sample from each treatment was taken for Folch et al. (1957) lipid extraction. Peroxide value was determined on 3 g of extracted lipid, using the AOAC (2005) method nr. 965.33, to assess lipid oxidation.

3.9.4. Quality, oxidative stability and consumer preference of bacon

Brine was formulated at a 20% injection level, according to the formulation, outlined in Table 3.6. The brine was formulated to deliver the following concentrations of the ingredients in the final products: salt (2%), sucrose (0.5%), sodium nitrite (160 mg/kg) and sodium-tripolyphosphate (0.5%). The brine solution was injected to the desired level. The meat was left overnight in a curing vat at 4 ℃, to allow even distribution of the brine. Bellies were then dried at 60-65 ℃ in a smoking chamber (Crown Mills), where after it was oak smoked at 65.5-68.5 ℃, until golden brown (approximately 45 min). The smoked meat was frozen, tempered, cut and vacuum packaged in 250 g packages, as for retail purposes. The packaged bacons were stored at 4 ℃ until sampling, which took place on day 0 and weeks 3 and 6 of refrigerated storage. On the chosen sampling days, two 5 g samples were taken from each pack of bacon in the four treatment groups for TBARS analysis (Raharjo et al., 1992). Similar to the patties, a 30 g bacon sample from each pack of bacon was taken for Folch et al. (1957) lipid extraction. Lipid oxidation on the extracted lipid was determined by PV (3 g), using the AOAC (2005) method nr. 965.33 and ρ-anisidine value (0.5 g) (Hamilton, Hamilton, & Sewell, 1992). Bacon from each treatment group was also stored at -18 ℃, until used for sensory analysis. Sensory analysis were carried out on bacon from all four treatment groups (70 kg SFO, 70 kg CLA, 90 kg SFO and 90 kg CLA), using a 75 member untrained consumer panel consisting of 61 females and 14 males with an average age of 28 years. A nine-point hedonic scale ranging from 1 for dislike extremely up to 9 for like extremely was used to

Table 3.6: Bacon brine formulation for 20% pump

Ingredients	Inclusion level (%)
Salt	12.00
Sucrose	3.00
Sodium Nitrite	0.096
Sodium-Tri polyphosphate	3.00
Water	81.90
Total	**100.00**

score aroma, taste, texture and general acceptability (Table 3.4).

Packets of bacon from the four treatments were removed from the freezer and defrosted in a refrigerator at 4℃, one day before it was to be evaluated. The bacon from each dietary treatment were pan-fried separately and kept warm in stainless steel containers on hot trays. Care was taken not to cook the bacon any further or let it dry out on the hot plate during waiting periods. One rasher from each treatment, with fat intact, measuring about 40 mm x 40 mm, was served to the panellists. Each sample was placed in a pre-heated 20 ml glass bowl, covered with a square of aluminium foil. Samples in glass bowls, ready to be served to the panel, were kept warm in a *bain marie*, filled with hot water (60 ºC). The four bacon samples were coded with randomized, three-digit codes and rotated to prevent bias. Diluted apple juice [Dairy Belle's *Real Juice* apple (100% apple juice)], at room temperature, was served as palate cleanser to prevent fat build-up during tasting. This specific brand was chosen for its bland taste.

3.9.5. Quality, oxidative stability and consumer preference of salami

The minced lean meat and backfat, earmarked for the manufacturing of processed meat products, were used to manufacture 3 x 2.5 kg batches of salami from each treatment, according to the formulation outlined in Table 3.7. The lean meat and backfat were vacuum-packed and stored at -18 ℃, prior to the manufacturing of the salami. The first 40% of the frozen lean meat was chopped to a 10 mm particle size in a 20 L OKTO Bowl Cutter.

Table 3.7: Salami formulation

Ingredient	Inclusion (%)
Pork 90/10 (lean meat/backfat)	40.00
Pork 90/10	39.75
Pork backfat	15.00
Curing salt	3.05
Spice mixture	2.18
Starter culture	0.03
TOTAL	**100.00**

The starter culture (0.03%) [Bactoferm™ T-D-66, which consisted of a mixed culture of *Staphylococcus carnosus* (good flavour development and stable red colour) and *Lactobacillus plantarum* (medium to fast initiation of acidification, which results in a medium to low pH) from CHR

HANSEN, Lake Foods, Sandton, Johannesburg] was used. The starter culture and spice mixture (2.18%) (Table 3.8) was added and the meat was chopped to a fine consistency. The remaining frozen lean pork (39.75%) was added and chopped to a particle size of 20 mm. The backfat (15%) and curing salt (3.05%) (Table 3.9) were added and the mixture was chopped at low speed. After the mixture was properly mixed, it was chopped at high speed until a particle size of 4-5 mm was reached.

The meat mixture was filled into wetted Colpak Fibrous Bak 65/50 casings (Crown National, Bloemfontein) to produce 12 salamis per batch, with an average weight of ± 200 g each. The individually labelled salamis were fermented for 48 h at 22 ℃ with a relative humidity (rH) of 90%.

Table 3.8: Spice mixture used for salami manufacturing

Ingredient or spice	Inclusion (%)
Dextrose	45.95
Sucrose	45.95
White pepper	4.59
Garlic powder	2.76
Nutmeg	0.75
TOTAL	**100.00**

Table 3.9: Curing salt mixture used for salami manufacturing

Additive	Inclusion (%)
Sodium chloride	99.30
Sodium nitrate (formulated to 120 ppm in end product)	0.39
Sodium nitrite (formulated to 92 ppm in end product)	0.30
TOTAL	**100.00**

After fermentation, the salamis were oak smoked in a Crown Mills smoking chamber for 10 min at 18-22 ℃. After smoking, the salamis were ri pened at 12 ℃ at a rH of 75%. The weight loss, as loss in moisture, was monitored at time 0, 12 h, 24 h, 36 h, 48 h and then every 48 h, until a final weight loss (20%) was achieved, which indicated the end of the ripening process. After manufacturing, 3 salamis from each batch were selected for chemical analysis. After the ripening period, the remaining salamis were vacuum-packed and stored for 1 month at 4 ℃. All spices were obtained from Crown National, Bloemfontein. The dextrose, sodium chloride and sucrose were obtained from Merck (Wadeville, Gauteng) and the sodium nitrate and sodium nitrite were obtained from Sigma-Aldrich (Johannesburg). After fermentation and drying and after one month storage, chemical analyses and physical measurements were done on salamis from the experimental treatment groups.

3.9.5.1. Chemical analyses of salami

Two 5 g samples, from each of the salamis, were taken for TBARS analysis as an indicator of oxidative stability (Raharjo et al., 1992). A 10 g sample from each salami, was taken for Folch et al.

(1957) lipid extraction. Peroxide value was determined on 0.5 g extracted lipid, using the AOAC (2005) method nr. 965.33, to assess primary lipid oxidation. Free fatty acids were determined according to Pearson (1968) on 0.5 g extracted lipid. A 10 g sample, per salami, was taken to determine total acidity (TA) according to Konieko (1985).

The pH of three models from each dietary treatment group was also determined at the same intervals as for the weight loss determinations. The pH measurements were performed at room temperature (25 ℃), using a THERMO Orion STAR SERIES 3 (USA) digital pH meter equipped with probe (model MA 920). The probe was calibrated with pH 4.00 and 7.00 buffer solutions from Merck (uniVAR®, Wadeville, Gauteng, SA) each day before measurement.

3.9.5.2. Physical measurements of salami

The water activity (a_w) of each sample was measured after sample collection, using a Novasina Thermoconstanter a_w meter (model No. TH200). Water activity measurements were carried out at room temperature (25℃) after the machine was allowed to reach equilibrium with deionised distilled water. Readings given as % rH were later converted to a_w value. For colour analysis, at the end of manufacturing, the finished salamis were sliced through and left for 30 min to bloom before the measurements were taken. The colour of each sample was then measured six times, using a Minolta CR-400 chromameter. The colour measurements used were as described in Section 3.3.3.

For texture analysis at the end of manufacturing, 6 salamis from each of the four batches were used and 6 samples per individual salami were taken. Samples were left for one hour at room temperature at 23 ℃. Samples of 10 mm^3 were analysed for compression force, using an Instron Universal Testing Machine (UTM, Model 430) with a compression head at 300.00 mm/min crosshead speed. Sample compression data was generated simultaneously by the Instron Series IX AMTS 8.34.00 software. A 12.7 mm diameter core sample (also six samples for each of six salamis per batch) were analysed for shear force using the same Instron UTM with a Warner-Bratzler attachment while shear force data was simultaneously generated by the above mentioned software.

Sensory analyses were carried out on all four batches of salamis after manufacturing, using a 75 member untrained consumer panel consisting of 52 females and 23 males, with an average age of 33 years. A nine-point hedonic scale ranging from 1 for dislike extremely up to 9 for like extremely was used to score aroma, taste, firmness and overall liking as attributes (Table 3.4). The samples were encoded with a randomized three-digit code, unique to each sample, to prevent the development of bias by the consumers. Each sample consisted of a 2 mm slice of salami with a 35 mm diameter. Samples were removed from refrigerated storage, allowed to reach room temperature and then served at a room temperature of 22 ℃ under red lighting to mask any possible colour differences. Diluted apple juice was used between each sample as a palate cleanser.

3.10. Reagents

All other reagents and solvents were of analytical grade and obtained from Merck Chemicals (Pty, Ltd, Halfway House, Johannesburg, South Africa).

3.11. Statistical analysis

3.11.1. Statistical analysis of data from digestibility study

The effects of diet, period and their interactions were evaluated by means of ANOVA using the generalized linear model (GLM) procedures (NCSS, 2007) to determine the effect on digestibility coefficients of the SFO and CLA feed. The Tukey-Kramer multiple comparison test ($\alpha = 0.05$) (NCSS, 2007) was carried out to determine whether significant differences exist between treatments means.

3.11.2. Statistical analysis of the animal production study, physical and chemical data

An ANOVA procedure for balanced data (NCSS, 2007) was used to determine the effect of diet, gender, slaughter weight and their interactions on growth performance, feed efficiency, carcass characteristics, fat quality parameters, fatty acid composition and fatty acid ratios. No interactions were found to be statistically significant and were therefore not further reported on. The Tukey-Kramer multiple comparison test ($\alpha = 0.05$) (NCSS, 2007) was carried out to determine whether significant differences exist between treatment means.

3.11.3. Statistical analysis of quantitative descriptive analysis of sensory properties of fresh pork

The descriptive data obtained from the sensory panel was entered into a spreadsheet, using Microsoft Excel (2000). Data was statistically analysed using the NCSS (2007) statistical analyses computer program. The significance of all the sensory attributes, measured for each meat and fat sample, was tested by means of an ANOVA, which tested the main effects of the sample at a 95% significance level. The multivariate analysis technique, principal component analysis (PCA), was performed to reduce the large set of variants into a smaller set, in order to explain most of the variations in the entire data set (NCSS, 2007). A Pearson correlation matrix was constructed to show the correlation (positive or negative) between the sensory attributes and selected physical and histological properties of the meat (NCSS, 2007).

3.11.4. Statistical analysis of sensory data from an untrained consumer panel on fresh pork, bacon and salami

An ANOVA procedure for balanced data (NCSS, 2007) was used to determine the significance of overall acceptance for each treatment. The Tukey-Kramer multiple comparison test ($\alpha = 0.05$) was carried out to determine whether significant differences exist between treatment means (NCSS, 2007).

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Feed composition and quality

The formulation and nutrient composition of the two experimental diets are shown in Tables 3.1 and 3.2, respectively. Important fat contributing components of the diets were: soya oil cake, sunflower oil cake, yellow maize, gluten 20 and fishmeal (Table 4.1). The CLA diet contained 0.5% SFO and 0.5% CLA, while the SFO diet contained 1% SFO (Table 4.1). The SFO contributed 13.14% to the fat content of the CLA diet and 26.14% to the fat content of the SFO diet, while the CLA oil contributed 13.11% to the fat content of the of the CLA diet (Table 4.1).

The major differences in the fatty acid compositions of the two diets used were: the C16:0, C18:1*c*9, C18:2 and the CLA isomers *cis*-9, *trans*-11 and *trans*-10, *cis*-12 (Table 4.2). The difference in C16:0 can be attributed to the lower amount of this fatty acid in the CLA oil, compared to the amount in the SFO (Table 4.3). The higher amount of C18:1*c*9 in the CLA feed compared to the SFO feed (Table 4.2) can be attributed to the higher amount of C18:1*c*9 in the CLA oil compared to the SFO (Table 4.3). The SFO diet had a higher amount of C18:2 compared to the CLA diet (Table 4.2), this can be attributed to the very high amount of C18:2 in the SFO, compared to the CLA oil (Table 4.3) and the 1% inclusion of SFO in the SFO diet compared, to the 0.5% inclusion of SFO in the CLA diet (Table 4.1). The CLA diet contained approximately 4% each of the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA isomers (Table 4.2). The only difference in the fatty acid ratios of the two diets were for the total SFA, the CLA oil diet contained less SFA (C14:0, C16:0, C18:0, C20:0 and C22:0) than the SFO oil diet (Table 4.2).

The CLA diet had a considerably higher ($p<0.001$) amount of FFA throughout the experiment (Table 4.2). This can be attributed to the fact that the CLA oil used in the diet was in the FFA form. The CLA diet had significantly ($p<0.001$) lower TBARS values at the end of the experiment compared to the SFO diet (Table 4.2). This can be attributed to CLA's anti-oxidant properties (Ha et al., 1990; Hur et al., 2007). Conjugated linoleic acid may, therefore, have the potential to replace synthetic antioxidants in feed or at least allow the use of reduced levels of synthetic antioxidants in feed (Ha et al., 1990). Lipid oxidation in feed can be inhibited by synthetic antioxidants like butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), tertiary-butylhydroxyquinone (TBHQ), ethylene diamino tetra-acetic acid (EDTA) and citric acid, (Labuza, 1971; Sato, & Hegarty, 1971; Morrissey, & Tichivangana, 1985; Ladikos, & Lougovois, 1990; Qwele, Hugo, Oyedemi, Moyo, Masika, & Muchenje, 2013; Nkukwana, Muchenje, Masika, Hoffman, Dzama, & Descalzo, 2014). In recent years, however, resistance to the use of synthetic antioxidants in feed has increased (Sheehy, Morrissey, Buckley, & Wen, 1997). The synthetic antioxidant BHA has been identified as a carcinogen in laboratory animals (Haumann, 1990).

Table 4.1: Lipid content of individual lipid bearing feed components of the two experimental diets

	Soya oilcake (n = 3)	**Sunflower oilcake** (n = 3)	**Yellow maize** (n = 3)	**Gluten 20** (n = 3)	**Fishmeal** (n = 3)	**Sunflower oil** (n = 3)	**Luta CLA-60^{R}** (n = 3)
Fat content of individual feed components (%):	1.69 ± 0.54	1.37 ± 0.59	3.14 ± 0.80	1.78 ± 0.52	10.42 ± 2.13	98.82 ± 0.22	98.58 ± 0.21
% of ingredient in CLA diet:	20.00	3.00	68.06	3.00	2.00	0.50	0.50
% of ingredient in SFO diet:	20.00	3.00	68.06	3.00	2.00	1.00	0.00
Contribution of individual feed components to total fat content of diets:							
Fat contribution to CLA diet with 3.76% fat (%):	8.99	1.09	56.86	1.42	5.54	13.14	13.11
Fat contribution to SFO diet with 3.78% fat (%):	8.94	1.09	56.54	1.41	5.51	26.14	0.00

CLA = Conjugated linioleic acid; SFO = Sunflower oil

Table 4.2: Chemical properties, fatty acid composition, fatty acid ratios and other fat properties of the two diets used in the experiment

	CLA Diet (n = 12)	**SFO Diet** (n = 12)	**Significance level**
Chemical analysis			
% Fat	3.76 ± 0.19	3.78 ± 0.11	NS
Iodine value (IV)	121.51 ± 0.40	121.23 ± 0.15	NS
Fatty acid composition (%)			
C14:0	0.29 ± 0.04	0.32 ± 0.01	NS
C16:0	10.62 ± 0.09[a]	10.96 ± 0.03[b]	p<0.01
C16:1*c*9	0.32 ± 0.03	0.36 ± 0.01	NS
C17:0	0.02 ± 0.02	ND	NSA
C18:0	2.81 ± 0.19	2.87 ± 0.03	NS
C18:1*c*9	31.35 ± 0.18[b]	30.97 ± 0.10[a]	p<0.05
C18:1*c*7	0.82 ± 0.01	0.82 ± 0.01	NS
C18:2*c*9,12(*n*-6)	42.71 ± 0.46[a]	50.80 ± 0.14[b]	p<0.001
C18:2*c*9,*t*11(*n*-6)(CLA)	4.00 ± 0.10	ND	NSA
C18:2*t*10,*c*12(*n*-6)(CLA)	3.99 ± 0.04	ND	NSA
C18:3*c*9,12,15(*n*-3)	1.33 ± 0.04	1.33 ± 0.01	NS
C20:0	0.34 ± 0.01	0.34 ± 0.01	NS
C20:5*c*5,8,11,14,17(*n*-3)	0.14 ± 0.01	0.14 ± 0.01	NS
C21:0	0.10 ± 0.01	ND	NSA
C22:0	0.27 ± 0.03	0.25 ± 0.02	NS
C22:6*c*4,7,10,13,16,19(*n*-3)	0.34 ± 0.04	0.35 ± 0.01	NS
C24:0	0.43 ± 0.04	0.50 ± 0.02	NS
Fatty acid ratios:			
SFA (%)	14.89 ± 0.17[a]	15.24 ± 0.08[b]	p<0.05
MUFA (%)	32.50 ± 0.40	32.15 ± 0.50	NS
Dienoic (%)	50.79 ± 0.33	50.80 ± 0.14	NS
Trienoic (%)	1.33 ± 0.04	1.33 ± 0.01	NS
C16:0 + C18:0 (%)	13.43 ± 0.11	13.83 ± 0.06	NS
C16:1 + C18:1/C16:0 + C18:0	2.42 ± 0.01	2.32 ± 0.01	NS
C18:0/C18:2	0.06 ± 0.01	0.06 ± 0.01	NS
Pentaenoic (%)	0.14 ± 0.01	0.14 ± 0.01	NS
Hexaenoic (%)	0.34 ± 0.04	0.35 ± 0.01	NS
Penta + Hexaenoic (%)	0.48 ± 0.03	0.49 ± 0.01	NS
C16:0/C18:2	0.21 ± 0.10	0.22 ± 0.12	NS
C18:2/C18:1	1.58 ± 0.02	1.60 ± 0.01	NS
UFA (%)	85.11 ± 0.63	84.76 ± 0.54	NS
MUFA/SFA	2.18 ± 0.11	2.11 ± 0.09	NS
DBI	140.84 ± 0.45	140.51 ± 0.16	NS
PI	57.86 ± 0.35	57.88 ± 0.09	NS
PUFA (%)	52.61 ± 0.32	52.61 ± 0.13	NS
PUFA/SFA	3.53 ± 0.06	3.45 ± 0.03	NS
n-6 (%)	50.79 ± 0.33	50.80 ± 0.14	NS
n-3 (%)	1.82 ± 0.07	1.82 ± 0.01	NS
n-6/*n*-3	27.97 ± 1.21	27.96 ± 0.20	NS
Lipid Stability of Feed			
% Free Fatty Acids: Fresh Feed	20.53 ± 0.56[b]	17.92 ± 1.44[a]	p<0.001
% Free Fatty Acids: End of experiment	28.09 ± 0.67[b]	25.27 ± 0.45[a]	p<0.001
Peroxide value: Fresh Feed (milliequiv. peroxide/kg oil)	5.77 ± 1.80	6.19 ± 2.05	NS
Peroxide value: End of experiment (milliequiv. peroxide/kg oil)	21.49 ± 5.43	22.86 ± 5.06	NS
TBARS Value: Fresh Feed (mg malonaldehyde/kg feed)	1.46 ± 0.19	1.53 ± 0.40	NS
TBARS Value: End of experiment (mg malonaldehyde/kg feed)	3.20 ± 0.38[a]	3.76 ± 0.52[b]	p<0.01

Means with different superscripts in the same row differed significantly; NS = Not significant; NSA = Not statistically analysed; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.3: Fatty acid composition of individual lipid bearing feed components that differ in their contribution to the two experimental diets

	Soya oilcake (n = 3)	**Sunflower oilcake** (n = 3)	**Yellow maize** (n = 3)	**Gluten 20** (n = 3)	**Fishmeal** (n = 3)	**Sunflower oil** (n = 3)	**Luta CLA-60^{R}** (n = 3)
Fatty acid composition (%):							
C12:0	ND	ND	ND	ND	0.01 ± 0.03	ND	ND
C14:0	ND	0.02 ± 0.05	ND	ND	5.54 ± 1.46	0.02 ± 0.03	ND
C14:1*c*9	ND	ND	ND	ND	0.04 ± 0.08	ND	ND
C15:0	ND	ND	ND	ND	0.51 ± 0.08	ND	ND
C16:0	13.99 ± 0.73	6.91 ± 0.37	10.54 ± 0.49	14.95 ± 5.19	20.23 ± 2.32	6.63 ± 0.38	6.06 ± 0.40
C16:1*c*9	0.04 ± 0.06	0.02 ± 0.04	0.03 ± 0.04	0.19 ± 0.07	6.25 ± 0.77	0.05 ± 0.01	ND
C17:0	0.05 ± 0.06	0.03 ± 0.05	0.03 ± 0.04	0.03 ± 0.05	0.52 ± 0.16	0.04 ± 0.01	ND
C17:1*c*10	ND	ND	ND	ND	0.26 ± 0.16	ND	ND
C18:0	4.49 ± 0.09	5.31 ± 0.21	2.42 ± 0.11	2.33 ± 0.05	5.09 ± 1.58	4.73 ± 0.15	3.67 ± 0.05
C18:1*t*9	ND	ND	ND	ND	0.36 ± 0.37	ND	ND
C18:1*c*9	17.09 ± 1.57	23.30 ± 1.71	34.68 ± 1.06	24.49 ± 5.36	14.75 ± 5.96	23.56 ± 0.12	25.03 ± 0.17
C18:1*c*7	1.16 ± 0.56	0.11 ± 0.02	ND	0.30 ± 0.21	3.99 ± 0.75	0.55 ± 0.01	0.77 ± 0.01
C18:2*t*9,12	ND	ND	ND	ND	0.03 ± 0.05	ND	ND
C18:2*c*9,12(*n*-6)	53.95 ± 0.95	61.44 ± 1.73	49.93 ± 1.12	52.56 ± 1.23	1.69 ± 0.42	63.19 ± 0.29	1.62 ± 0.01
C18:2*c*9,*t*11(*n*-6)(CLA)	ND	ND	ND	ND	ND	ND	30.70 ± 0.54
C18:2*t*10,*c*12(*n*-6)(CLA)	ND	ND	ND	ND	ND	ND	30.59 ± 0.57
C 18:3*c*6,9,12(*n*-6)	ND	ND	ND	ND	0.09 ± 0.06	ND	ND
C18:3*c*9,12,15(*n*-3)	7.68 ± 0.28	0.38 ± 0.17	1.11 ± 0.11	3.35 ± 0.39	0.99 ± 0.14	0.15 ± 0.03	0.17 ± 0.01
C20:0	0.36 ± 0.02	0.47 ± 0.05	0.57 ± 0.02	0.64 ± 0.11	0.36 ± 0.19	0.30 ± 0.03	0.24 ± 0.02
C20:1c11	0.13 ± 0.05	0.15 ± 0.02	0.25 ± 0.02	0.20 ± 0.04	4.78 ± 2.32	0.03 ± 0.05	ND
C20:2*c*11,14(*n*-6)	0.01 ± 0.02	0.01 ± 0.03	ND	ND	0.48 ± 0.12	ND	ND
C20:3*c*8,11,14(*n*-6)	ND	ND	ND	ND	0.23 ± 0.05	ND	0.06 ± 0.02
C20:3*c*11,14,17(*n*-3)	ND	ND	ND	ND	0.07 ± 0.06	ND	ND
C20:4*c*5,8,11,14(*n*-6)	ND	ND	ND	ND	1.09 ± 0.40	ND	ND
C20:5*c*5,8,11,14,17(*n*-3)	0.01 ± 0.04	0.04 ± 0.06	ND	ND	11.95 ± 4.75	0.05 ± 0.09	ND
C21:0	ND	ND	ND	ND	ND	ND	0.30 ± 0.35
C22:0	0.58 ± 0.06	0.83 ± 0.05	0.20 ± 0.03	0.38 ± 0.04	0.19 ± 0.07	0.61 ± 0.04	0.58 ± 0.04
C22:1*c*13	ND	ND	ND	ND	0.43 ± 0.50	ND	ND
C22:2*c*13,16(*n*-6)	ND	ND	ND	ND	0.47 ± 0.26	ND	ND
C22:5(*n*-3)	ND	ND	ND	ND	1.96 ± 0.73	ND	ND
C22:6*c*4,7,10(*n*-3)	0.01 ± 0.04	ND	ND	ND	16.66 ± 4.77	ND	ND
C23:0	0.07 ± 0.07	0.02 ± 0.05	ND	0.04 ± 0.07	ND	0.01 ± 0.02	ND
C24:0	0.28 ± 0.05	0.28 ± 0.03	0.22 ± 0.02	0.36 ± 0.02	0.18 ± 0.13	0.13 ± 0.09	0.16 ± 0.01
C24:1*c*15	0.02 ± 0.05	0.20 ± 0.08	ND	ND	0.70 ± 0.49	ND	ND

ND = Not determined; CLA = Conjugated linoleic acid

4.2. Digestibility analysis of feed

As indicated in Table 3.2 diets were isonitrogenous and isocaloric. Table 4.4 indicates that no significant differences were observed for digestibility coefficients of the SFO and CLA feed. This is in agreement with the findings of Müller et al. (2000). This is a very important finding, since it implicates that any significant differences observed in parameters between SFO and CLA treatments can be attributed to the actual oil treatment effect and not to confounded effects like digestibility differences between SFO and CLA.

Table 4.4: Digestibility coefficients of nutrients in pigs fed diets with 0.5% CLA or SFO

Nutrient	SFO Diet (n = 6)	CLA Diet (n = 6)	Significance level
Protein	0.78 ± 0.06	0.80 ± 0.04	NS (p = 0.514)
Fat	0.63 ± 0.07	0.66 ± 0.08	NS (p = 0.487)
Neutral detergent fibre	0.63 ± 0.07	0.63 ± 0.06	NS (p = 0.986)
Acid detergent fibre	0.40 ± 0.09	0.39 ± 0.10	NS (p = 0.916)
Energy	0.78 ± 0.04	0.79 ± 0.03	NS (p = 0.645)
Methionine	0.45 ± 0.12	0.41 ± 0.18	NS (p = 0.639)
Lysine	0.80 ± 0.06	0.83 ± 0.05	NS (p = 0.405)

NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

4.3. Animal production experiment

4.3.1. Growth performance and feed efficiency

As indicated in Table 4.5, no significant differences were observed in the average initial weight of pigs. Slaughter weight and weight increase was significantly ($p<0.001$) influenced by slaughter weight group. Average daily gain (ADG) was significantly ($p<0.05$) influenced by gender and feed conversion ratio (FCR) was significantly influenced by diet ($p<0.1$), gender ($p<0.001$) and slaughter weight ($p<0.001$).

Table 4.5: Analysis of variance (ANOVA) on growth performance and feed efficiency for the effect of dietary treatment, gender and slaughter weight

	Diet	Gender	Slaughter weight group
Initial weight (kg)	NS	NS	NS
Slaughter weight (kg)	NS	NS	****
Weight increase (kg)	NS	NS	****
ADG (kg)	NS	**	NS
FCR	*	****	****

NS = Not significant; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001; ADG = Average daily gain; FCR = Feed conversion ratio

Although the effect of diet on FCR was only at the 90% significance level (Tables 4.5 and 4.6) it can be considered a very important finding since conflicting results was reported by Dugan et al. (1999), Ostrowska et al. (1999), Ramsay et al. (2001), Migdal et al. (2004) and Jiang et al. (2010) regarding the effect of CLA supplementation on feed efficiency. Dugan et al. (1999) and Migdal et al. (2004), who fed diets with a 2% inclusion of CLA, Ostrowska et al. (1999) who fed diets containing 0.125%, 0.25%, 0.5%, 0.75% and 1.0% CLA, Ramsay et al. (2001) who fed diets containing 0.25%, 0.5%, 1.0% and 2.0% CLA and Jiang et al. (2010) who fed diets containing 1.25% and 2.5% CLA, reported no significant effect on improvement of feed efficiency. Wiegand et al. (2001), Wiegand et al. (2002) and Wang et al. (2004), reported that feeding of 0.75% CLA to pigs improved feed efficiency.

According to Table 4.6, pigs on a CLA diet needed 0.10kg less feed to increase 1 kg in

Table 4.6: Effect of dietary treatment on growth performance and feed efficiency of pigs

	SFO-Diet (n = 72)	**CLA-Diet** (n = 72)	**Significance level**
Initial weight (kg)	30.56 ± 2.98	30.67 ± 2.87	NS
Slaughter weight (kg)	79.70 ± 13.74	80.10 ± 13.66	NS
Weight increase (kg)	49.14 ± 12.69	49.43 ± 13.08	NS
ADG (kg)	0.91 ± 0.11	0.91 ± 0.09	NS
FCR	3.07 ± 0.42[b]	2.97 ± 0.35[a]	p<0.1

Means with different superscripts in the same row differed significantly; NS = Not significant; ADG = Average daily gain; FCR = Feed conversion ratio

weight. That represents a 3.26% improvement in feed efficiency taken over a large population of a commercial piggery that represents a significant improvement in feed efficiency and may imply a significant saving on the feed bill.

Although weight increase was not significantly influenced by gender (Tables 4.5 and 4.7), gilts had lower weight increase than barrows and boars (Table 4.7). It is known that there are gender effects on growth rate of pigs (Xue et al., 1997), with boars generally having higher weight increase, followed by barrows and then gilts. The effect of gender on ADG is demonstrated in Tables 4.5 and 4.7. This study confirms the findings of Xue et al. (1997) that ADG of boars and barrows were similar when fed *ad libitium* (Table 4.7). This table also indicates that barrows had significantly higher ($p<0.05$) ADG than gilts. Leach, Ellis, Stutton, McKeith, & Wilson (1996) and Xue et al. (1997) reported similar findings. Xue et al. (1997) reported that barrows reached a maximum ADG from 70-90 kg live weight. In this study, Table 4.7 indicates that boars had significantly ($p<0.001$) lower FCR compared to gilts and barrows. These results are in agreement with those of Field (1971), Babol et al. (1995) and Conte, Boyle, O'Connell, Lynch, & Lawlor (2011), who found that intact males, as compared to gilts and castrates, had better feed efficiency on restricted feeding and grows faster than gilts and barrows. Xue et al. (1997) and Lanferdini, Lovatto, Melchior, Orlando, & Ceccantini (2013), also reported that intact males generally had better feed efficiency than castrated males.

The significant ($p<0.001$) effect of slaughter weight group on slaughter weight and weight increase can be ascribed to the use of two different slaughter weight groups (Tables 4.5 and 4.8).

Table 4.7: Effect of gender on growth performance and feed efficiency of pigs

	Boars (n = 48)	**Gilts** (n = 48)	**Barrows** (n = 48)	**Significance level**
Initial weight (kg)	30.11 ± 2.90	30.87 ± 2.50	30.86 ± 3.30	NS
Slaughter weight (kg)	80.52 ± 14.44	78.09 ± 12.79	81.09 ± 13.78	NS
Weight increase (kg)	50.41 ± 13.83	47.22 ± 12.05	50.23 ± 12.60	NS
ADG (kg)	0.91 ± 0.09[ab]	0.88 ± 0.10[a]	0.94 ± 0.10[b]	p<0.05
FCR	2.80 ± 0.32[a]	3.12 ± 0.40[b]	3.14 ± 0.35[b]	p<0.001

Means with different superscripts in the same row differed significantly; NS = Not significant; ADG = Average daily gain; FCR = Feed conversion ratio

Table 4.8: Effect of slaughter weight on growth performance and feed efficiency of pigs

	70 kg Slaughter Group (n = 72)	**90 kg Slaughter Group** (n = 72)	**Significance level**
Initial weight (kg)	30.64 ± 2.22	30.59 ± 3.50	NS
Slaughter weight (kg)	68.36 ± 5.34[a]	91.44 ± 8.76[b]	p<0.001
Weight increase (kg)	37.72 ± 4.17[a]	60.86 ± 6.57[b]	p<0.001
ADG (kg)	0.92 ± 0.10	0.89 ± 0.09	NS
FCR	2.90 ± 0.37[a]	3.15 ± 0.37[b]	p<0.001

Means with different superscripts in the same row differed significantly; NS = Not significant; ADG = Average daily gain; FCR = Feed conversion ratio

The 70 kg slaughter weight group had a significantly (p<0.001) lower FCR, compared to the 90 kg slaughter weight group (Table 4.8). This result is in agreement with the data of Latorre, Lázaro, Valencia, Medel, & Mateos (2004), who reported that increased slaughter weight resulted in a reduction of feed efficiency.

When growth performance and feed efficiency of pigs from the experimental treatment groups were compared, no significant differences were observed for initial weight and ADG (Table 4.9). Slaughter weight and weight increase were, however, significantly (p<0.001) influenced as indicated in Table 4.9. The significant effects on slaughter weight and weight increase were as a result of the two different slaughter weight groups used. The 70 kg SFO and CLA boars had a significantly (p<0.001) lower FCR, compared to the 90 kg SFO gilts, 90 kg SFO barrows and 90 kg CLA barrows (Table 4.9). These gender effects were in agreement with the findings of Babol et al. (1996), Xue et al. (1997) and Lattore et al. (2004).

Table 4.9: Growth performance and feed efficiency of pigs from the experimental treatments (n = 12 per treatment)

Slaughter weight group	**Diet**	**Gender**	**Initial weight (kg)**	**Slaughter weight (kg)**	**Weight increase (kg)**	**ADG (kg)**	**FCR**
70	**SFO**	**Boars**	30.35 ± 2.14	67.70 ± 6.13[a]	37.35 ± 4.78[a]	0.89 ± 0.11	2.74 ± 0.40[ab]
		Gilts	30.13 ± 1.87	67.60 ± 5.12[a]	37.47 ± 4.83[a]	0.91 ± 0.12	3.02 ± 0.46[abc]
		Barrows	30.82 ± 3.23	69.92 ± 6.46[a]	39.10 ± 3.81[a]	0.98 ± 0.10	3.05 ± 0.31[abc]
	CLA	**Boars**	30.50 ± 1.90	68.52 ± 4.52[a]	38.02 ± 3.44[a]	0.91 ± 0.08	2.64 ± 0.23[a]
		Gilts	31.18 ± 2.21	66.85 ± 5.05[a]	35.67 ± 3.69[a]	0.89 ± 0.09	2.98 ± 0.33[abc]
		Barrows	30.87 ± 1.97	69.57 ± 4.94[a]	38.70 ± 4.25[a]	0.94 ± 0.10	2.96 ± 0.34[abc]
90	**SFO**	**Boars**	29.98 ± 3.44	93.75 ± 8.46[b]	63.77 ± 5.95[b]	0.92 ± 0.09	2.94 ± 0.26[abc]
		Gilts	31.32 ± 2.69	87.88 ± 7.46[b]	56.57 ± 6.35[b]	0.84 ± 0.09	3.36 ± 0.39[c]
		Barrows	30.78 ± 4.29	91.37 ± 11.29[b]	60.58 ± 7.47[b]	0.89 ± 0.11	3.33 ± 0.40[c]
	CLA	**Boars**	29.62 ± 3.91	92.12 ± 9.35[b]	62.50 ± 6.25[b]	0.91 ± 0.09	2.90 ± 0.32[abc]
		Gilts	30.85 ± 3.20	90.03 ± 8.55[b]	59.18 ± 6.53[b]	0.87 ± 0.10	3.13 ± 0.36[bc]
		Barrows	30.98 ± 3.70	93.52 ± 7.27[b]	62.53 ± 5.23[b]	0.93 ± 0.08	3.24 ± 0.27[c]
Significance level			NS	p<0.001	p<0.001	NS	p<0.001

Means with different superscripts in the same column differed significantly; NS = Not significant; ADG = Average daily gain; FCR = Feed conversion ratio; CLA = Conjugated linoleic acid; SFO = Sunflower oil

4.3.2. Carcass characteristics

The effect of diet, gender and slaughter weight on carcass characteristics and Hennessey grading measurements are depicted in Table 4.10. Diet had a statistically significant effect on dressing percentage ($p<0.05$), pH_{45min} ($p<0.1$), backfat thickness ($p<0.1$) and LMC ($p<0.1$) (Table 4.10).

Table 4.10: Analysis of variance (AVOVA) on carcass characteristics and Hennessey grading data for the effect of diet, gender and slaughter weight

	Diet	**Gender**	**Slaughter weight**
Carcass characteristics:			
Warm carcass mass (kg)	NS	NS	****
Cold carcass mass (kg)	NS	NS	****
Dressing percentage	**	****	****
Carcass length (cm)	NS	NS	****
Shoulder circumference (cm)	NS	**	****
Buttock circumference (cm)	NS	NS	****
pH_{45min}	*	**	*
$pH_{24hours}$	NS	****	****
Hennessey grading measurements:			
Backfat thickness (mm)	*	****	****
Eye muscle thickness (mm)	NS	*	****
Lean meat content (%)	*	****	****
Hennessey colour score	NS	*	NS
Conformation score	NS	**	NS

NS = Not significant; * = $p<0.1$; ** = $p<0.05$; *** = $p<0.01$; **** = $p<0.001$

Gender had a statistically significant effect on all measurements (at least $p<0.1$) except warm and cold carcass mass, carcass length and buttock circumference (Table 4.10). Slaughter weight also had a statistically significant (at least $p<0.1$) effect on all measurements except for Hennessey colour score and conformation score (Table 4.10). Pigs on the CLA supplemented diet demonstrated a slight, but statistically significant ($p<0.05$) lower dressing percentage than pigs on the SFO supplemented diet (Tables 4.10 and 4.11). According to Eggert et al. (1998), Ramsay et al. (2001) and Jiang et al. (2010), CLA supplementation had no effect on dressing percentage. A possible explanation for the lower dressing percentage observed in pigs on the CLA supplemented diet may be the increase in fat hardness of internal fat surrounding the intestines and internal organs of CLA supplemented pigs. That may result in fat being removed more completely during slaughtering process, resulting in a lowered dressing percentage.

Diet also had a statistically significant ($p<0.1$) effect on pH_{45min} after slaughtering (Tables 4.10 and 4.11). Sunflower oil supplemented pigs had an average pH_{45min} of 6.47 compared to an average pH_{45min} of 6.38 for CLA supplemented pigs (Table 4.11). This effect of CLA supplementation on pH supports the findings of Szymczyk (2005) and Bee et al. (2008). They reported a reduction in the pH of the *longissimus* muscle due to dietary CLA supplementation. The lower pH_{45min} of CLA supplemented pigs may indicate a slightly higher susceptibility of these pigs

Table 4.11: The effect of dietary treatment on carcass characteristics and Hennessey grading measurements of pigs

	SFO-Diet (n = 72)	**CLA-Diet** (n = 72)	**Significance level**
Carcass characteristics:			
Warm carcass mass (kg)	62.81 ± 11.63	62.55 ± 11.44	NS
Cold carcass mass (kg)	61.20 ± 11.39	61.07 ± 11.26	NS
Dressing percentage	78.64 ± 1.99[b]	77.94 ± 1.83[a]	p<0.05
Carcass length (cm)	89.59 ± 5.93	89.79 ± 5.81	NS
Shoulder circumference (cm)	95.57 ± 6.18	95.58 ± 6.33	NS
Buttock circumference (cm)	97.89 ± 5.74	97.21 ± 7.00	NS
pH_{45min}	6.47 ± 0.31[b]	6.38 ± 0.29[a]	p<0.1
$pH_{24hours}$	5.45 ± 0.11	5.44 ± 0.13	NS
Hennessey grading measurements:			
Backfat thickness (mm)	15.12 ± 3.72[b]	14.31 ± 3.75[a]	p<0.1
Eye muscle thickness (mm)	50.43 ± 5.49	51.04 ± 7.05	NS
Lean meat content (%)	68.29 ± 1.71[a]	68.70 ± 1.72[b]	p<0.1
Hennessey colour score	63.60 ± 13.63	65.64 ± 14.02	NS
Conformation score	3.15 ± 0.36	3.18 ± 0.42	NS

Means with different superscripts in the same row differed significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

towards the PSE meat syndrome.

Meat is, however, only classified as PSE when the pH_{45min} value is below 6 (Barton-Gade, 1987; Xue et al., 1997). None of the pigs slaughtered in this experiment were classified as PSE.

Backfat thickness was also significantly (p<0.1) influenced by dietary treatment (Tables 4.10 and 4.11).The average backfat thickness of CLA supplemented pigs were 14.31 mm, compared to the SFO supplemented pigs which had an average backfat thickness of 15.12 mm (Table 4.11). Ostrowska et al. (1999), Bee et al. (2008) and Jiang et al. (2010) reported that dietary CLA reduced backfat thickness. Results from this study confirm this finding. Ramsay et al. (2001) did, however, report that a 0.5% dietary CLA inclusion level resulted in an increase in backfat thickness which contradicts this study's finding. Lean meat content is calculated from backfat thickness and thus was also significantly (p<0.1) influenced by dietary treatment (Tables 4.10 and 4.11). The CLA supplemented pigs had the highest LMC compared to the SFO supplemented pigs, which are in accordance with results of Tischendorf et al. (2002) and Larsen et al. (2009). According to Davenel, Riaublanc, Marchal, & Gandemer (1999), LMC should be less than 57% for good technological fat properties. The LMC of all the pigs in this experiment were higher than 57%.

In South Africa, backfat thickness and eye muscle thickness are used to classify pigs into one of six classification groups. Groups P (< 12 mm of backfat) and O (between 12 and 18 mm of backfat) are the leanest groups, R, C, U and S, are the fatter groups. Lean classification groups are more desirable, as producers get paid more for these pigs, because the consumer prefers these pigs. Table 4.12 indicates that, in the 70 kg slaughter weight group, 89% of the pigs on the CLA diet obtained P and O classification, compared to 81% of the pigs on the SFO diet. The same

Table 4.12: Percentage of pigs with P and O gradings in the different slaughter and diet groups

	SFO-Diet	CLA-Diet
70 kg Slaughter Group	81	89
90 kg Slaughter Group	53	61

CLA = Conjugated linoleic acid; SFO = Sunflower oil

trend was observed in the 90 kg slaughter weight group, where 61% of pigs on the CLA diet obtained P and O classification, compared to 53% of pigs on the SFO diet. This clearly illustrates that CLA supplementation improved the lean classification of pigs as was found by Eggert et al. (1998), Ostrowska et al. (1999) and Migdal et al. (2004). This finding is of practical significance for the South African pig producer, since more pigs being classified as P and O means more profitable pig production systems.

Tables 4.10 and 4.13 illustrate the effect of gender on carcass characteristics and Hennessey grading. The significantly ($p<0.001$) lower dressing percentage of boars compared to barrows, observed in Table 4.13, confirmed the findings of Babol et al. (1995) and Xue et al. (1997). They ascribed the lower dressing percentage of boars to the presence of genitalia and other accessory tissues in intact males. The significantly ($p<0.05$) higher shoulder circumference of boars and barrows, compared to gilts (Table 4.13), was also observed by Xue et al. (1997), who found that barrows had larger shoulder circumferences compared to gilts. Gender had a statistically significant ($p<0.001$) effect on backfat thickness (Tables 4.10 and 4.13), with barrows having the thickest backfat, followed by gilts with intermediate backfat thickness and boars with the thinnest backfat. Boars had a significantly ($p<0.1$) lower eye muscle thickness compared to gilts (Table 4.13). Lean meat content was also significantly ($p<0.001$) influenced by gender (Tables 4.10 and 4.13). Boars and gilts had higher LMC than barrows. Hennessey colour score was also significantly ($p<0.1$) influenced by gender (Tables 4.10 and 4.13). Boars had the lowest Hennessey colour score (Table 4.13). Boars also had the lowest pH_{45min} value (Table 4.13). The lower pH and lower Hennessey colour score of boars may indicate a slightly higher susceptibility of boars to towards the PSE meat syndrome (Barton-Gade, 1987; Xue et al., 1997). Boars also had significantly ($p<0.001$) higher $pH_{24hours}$ values compared to gilts and barrows (Table 4.13). The higher pH of boars may indicate a slightly higher susceptibility of boars to the DFD syndrome. None of the animals in this study were, however, classified as DFD. Conformation score was significantly ($p<0.05$) influenced by gender (Tables 4.10 and 4.13). Barrows had the highest conformation score, boars had the lowest score and those of gilts were intermediate. Mas et al. (2011) found no statistical difference in conformation score between boars, gilts and barrows.

The effect of slaughter weight on carcass characteristics and Hennessey grading is illustrated in Table 4.14. The porker group (70 kg) had a significantly ($p<0.001$) lower warm carcass mass of 52.82 kg, compared to the 72.54 kg of the baconer (90 kg) group. The same trend was observed for the cold carcass mass where the porkers had a cold carcass mass of 51.45 kg compared to the 70.82 kg of the baconer group (Table 4.14). The baconer group also had a

Table 4.13: Effect of gender on carcass characteristics and Hennessey grading measurements of pigs

	Boars (n = 48)	**Gilts** (n = 48)	**Barrows** (n = 48)	**Significance level**
Carcass characteristics:				
Warm carcass mass (kg)	62.48 ± 11.79	61.33 ± 11.05	64.22 ± 11.70	NS
Cold carcass mass (kg)	61.07 ± 11.58	59.85 ± 10.91	62.49 ± 11.44	NS
Dressing percentage	77.48 ± 1.36^{a}	78.35 ± 1.96^{ab}	79.05 ± 2.11^{b}	p<0.001
Carcass length (cm)	90.38 ± 5.47	89.76 ± 6.15	88.94 ± 5.93	NS
Shoulder circumference (cm)	96.48 ± 6.60^{b}	93.75 ± 6.42^{a}	96.50 ± 5.33^{b}	p<0.05
Buttock circumference (cm)	97.29 ± 5.72	97.71 ± 5.78	97.65 ± 7.61	NS
pH_{45min}	6.33 ± 0.27^{a}	6.43± 0.29^{ab}	6.51± 0.32^{b}	p<0.05
$pH_{24hours}$	5.51 ± 0.13^{b}	5.38± 0.08^{a}	5.43 ± 0.11^{a}	p<0.001
Hennessey grading measurements:				
Backfat thickness (mm)	13.24 ± 2.99^{a}	13.93 ± 3.22^{a}	16.98 ± 3.91^{b}	p<0.001
Eye muscle thickness (mm)	49.21 ± 7.75^{a}	52.02 ± 5.09^{b}	50.97 ± 5.56^{ab}	p<0.1
Lean meat content (%)	69.10 ± 1.33^{b}	68.92 ± 1.52^{b}	67.45 ± 1.80^{a}	p<0.001
Hennessey colour score	61.27 ± 14.01^{a}	67.48 ± 15.02^{b}	65.10 ± 11.78^{ab}	p<0.1
Conformation score	3.04 ± 0.20^{a}	3.19 ± 0.45^{ab}	3.27 ± 0.45^{b}	p<0.05

Means with different superscripts in the same row differed significantly; NS = Not significant

significantly (p<0.001) higher dressing percentage, compared to the porker group (Table 4.14). This confirms the findings of Babol et al. (1995) and Xue et al. (1997), who ascribed higher dressing percentage of heavier pigs to increased age. Increase in age is characterised by the growth of lean, bone and fat with the greater fat deposition being mostly responsible for the increase in dressing percentage observed in older pigs (Nieto, Lara, Barea, García-Valverde,

Table 4.14: Effect of slaughter weight on carcass characteristics and Hennessey grading measurements of pigs

	70 kg Slaughter Group (n = 72)	**90 kg Slaughter Group** (n = 72)	**Significance level**
Carcass characteristics:			
Warm carcass mass (kg)	52.82 ± 4.38^{a}	72.54 ± 7.07^{b}	p<0.001
Cold carcass mass (kg)	51.45 ± 4.28^{a}	70.82 ± 6.93^{b}	p<0.001
Dressing percentage	77.26 ± 1.70^{a}	79.32 ± 1.58^{b}	p<0.001
Carcass length (cm)	84.85 ± 2.96^{a}	94.53 ± 3.54^{b}	p<0.001
Shoulder circumference (cm)	90.63 ± 3.61^{a}	100.53 ± 3.95^{b}	p<0.001
Buttock circumference (cm)	92.83 ± 4.63^{a}	102.26 ± 3.95^{b}	p<0.001
pH_{45min}	6.47 ± 0.27^{b}	6.38 ± 0.32^{a}	p<0.1
$pH_{24hours}$	5.48 ± 0.14^{b}	5.40 ± 0.09^{a}	p<0.001
Hennessey grading measurements:			
Backfat thickness (mm)	12.68 ±2.71^{a}	16.75 ± 3.54^{b}	p<0.001
Eye muscle thickness (mm)	47.74 ± 5.60^{a}	53.72 ± 5.53^{b}	p<0.001
Lean meat content (%)	69.27 ± 1.31^{b}	67.71 ± 1.74^{a}	p<0.001
Hennessey colour score	63.24 ± 13.61	66.00 ± 13.97	NS
Conformation score	3.19 ± 0.40	3.14 ± 0.39	NS

Means with different superscripts in the same row differed significantly; NS = Not significant

Conde-Aguilera, & Aguilera, 2013).

As expected, heavier carcasses (baconers) had significantly ($p<0.001$) longer carcasses, larger shoulder circumferences and larger buttock circumferences, compared to lighter carcasses (porkers) (Table 4.14). This table also indicates that porkers had significantly thinner backfat ($p<0.001$), smaller eye muscle thickness ($p<0.001$) and higher LMC ($p<0.001$) compared to baconers. This is in agreement with the findings of Cisneros et al. (1996), who stated that increases in slaughter weight were associated with increased backfat thickness and eye muscle thickness. The porker group had significantly higher pH_{45min} ($p<0.1$) and $pH_{24hours}$ ($p<0.001$) values, compared to the baconer group (Table 4.14).

The carcass characteristics of animals from the twelve treatment groups are depicted in Table 4.15. According to Tables 4.10 and 4.15, it is clear that cold and warm carcass mass, carcass length, shoulder circumference and buttock circumference were significantly ($p<0.001$) influenced only by slaughter weight. Nieto et al. (2013) found slaughter weight to have similar effects. Dressing percentage was significantly influenced by diet ($p<0.001$), gender ($p<0.001$) and slaughter weight ($p<0.001$) (Table 4.15). The 70 kg SFO boars and gilts had a significantly lower dressing percentage, compared to 70 kg SFO barrows (Table 4.15). Babol et al. (1995) and Xue et al. (1997) also found boars and gilts to have lower dressing percentage, compared to barrows. No significant differences were observed for dressing percentage between the genders in the 70 kg CLA slaughter weight group (Table 4.15). The 90 kg SFO boars had a significantly lower dressing percentage compared to the 90 kg SFO gilts and barrows (Table 4.15). The 90 kg CLA boars had a significantly lower dressing percentage, compared to the 90 kg CLA barrows (Table 4.15). The 90 kg CLA boars had significantly ($p<0.05$) lower pH_{45min} values, compared to the 70 kg SFO gilts (Table 4.15). The 70 kg SFO boars and 70 kg CLA boars had significantly ($p<0.001$) higher $pH_{24hours}$ values, compared to all the other treatment groups, except for the 70 kg CLA barrows (Table 4.15).

The Hennessey grading data of animals from the twelve treatment groups are depicted in Table 4.16. Backfat thickness was significantly ($p<0.001$) influenced by gender (Tables 4.10 and 4.16) as previously reported by Cisneros et al. (1996). The 70 kg SFO barrows had a significantly ($p<0.001$) higher backfat thickness, compared to the 70 kg SFO gilts (Table 4.16). The same trend was observed for the 90 kg SFO group where the 90 kg SFO barrows had significantly ($p<0.001$) higher backfat thickness compared to the 90 kg SFO gilts (Table 4.16). The 90 kg CLA barrows had significantly ($p<0.001$) higher backfat thickness, compared to the 90 kg CLA boars (Table 4.16). Although not statistically significant, boars and barrows supplemented with CLA had lower backfat thickness compared to boars and barrows supplemented with SFO, as was also found by Eggert et al. (1998), Ostrowska et al. (1999), Migdal et al. (2004). Eye muscle thickness was significantly influenced by slaughter weight (Table 4.10 and 4.16). The 70 kg CLA boars had a significantly ($p<0.001$) lower eye muscle thickness compared to the 90 kg CLA boars (Table 4.16). Generally, pigs from the 70 kg slaughter weight group had lower eye muscle thickness, compared

Table 4.15: Carcass characteristics of pigs from the experimental treatments (n = 12 per treatment)

Slaughter weight	Diet	Gender	Cold carcass mass (kg)	Warm carcass mass (kg)	Dressing percentage	Carcass length (cm)	Shoulder circumference (cm)	Buttock circumference (cm)	pH_{45min}	$pH_{24hours}$
70	SFO	Boar	51.07 ± 4.97^{a}	52.23 ± 5.00^{a}	77.13 ± 1.24^{abc}	86.00 ± 3.49^{a}	90.83 ± 3.19^{a}	92.33 ± 2.90^{a}	6.47 ± 0.32^{ab}	5.60 ± 0.06^{bc}
		Gilts	50.12 ± 4.02^{a}	51.43 ± 4.05^{a}	76.08 ± 1.13^{a}	84.83 ± 2.72^{a}	88.25 ± 2.93^{a}	93.67 ± 4.31^{a}	6.56 ± 0.27^{b}	5.40 ± 0.10^{a}
		Barrows	53.78 ± 4.72^{a}	55.57 ± 4.86^{a}	79.52 ± 1.47^{efg}	83.50 ± 2.15^{a}	93.00 ± 3.38^{a}	93.67 ± 3.34^{a}	6.46 ± 0.29^{ab}	5.41 ± 0.05^{a}
	CLA	Boars	51.35 ± 4.02^{a}	52.60 ± 4.01^{a}	76.72 ± 1.16^{ab}	86.17 ± 3.04^{a}	91.58 ± 2.97^{a}	94.42 ± 2.02^{ab}	6.41 ± 0.15^{ab}	5.61 ± 0.09^{c}
		Gilts	50.63 ± 4.05^{a}	52.07 ± 4.13^{a}	77.87 ± 1.32^{bcde}	83.92 ± 2.31^{a}	88.50 ± 3.94^{a}	92.42 ± 2.61^{a}	6.40 ± 0.27^{ab}	5.37 ± 0.08^{a}
		Barrows	51.75 ± 3.71^{a}	53.02 ± 3.81^{a}	76.21 ± 1.26^{ab}	84.67 ± 3.37^{a}	91.58 ± 3.18^{a}	90.50 ± 8.87^{a}	6.52 ± 0.33^{ab}	5.47 ± 0.17^{ab}
90	SFO	Boars	71.92 ± 7.03^{b}	73.67 ± 7.07^{b}	78.55 ± 1.34^{cdef}	95.42 ± 3.78^{b}	102.8 ± 4.22^{b}	102.17 ± 2.69^{c}	6.29 ± 0.24^{ab}	5.46 ± 0.12^{a}
		Gilts	69.17 ± 6.29^{b}	70.75 ± 6.50^{b}	80.46 ± 1.30^{g}	94.36 ± 2.90^{b}	98.75 ± 3.36^{b}	102.17 ± 3.33^{c}	6.47 ± 0.28^{ab}	5.38 ± 0.09^{a}
		Barrows	71.13 ± 8.77^{b}	73.18 ± 9.00^{b}	80.10 ± 0.81^{fg}	93.42 ± 4.76^{b}	99.75 ± 3.11^{b}	103.33 ± 3.37^{c}	6.55 ± 0.41^{ab}	5.43 ± 0.07^{a}
	CLA	Boars	69.95 ± 7.50^{b}	71.43 ± 7.64^{b}	77.51 ± 1.12^{abcd}	93.92 ± 3.26^{b}	100.67 ± 5.02^{b}	100.25 ± 6.97^{bc}	6.17 ± 0.26^{a}	5.39 ± 0.10^{a}
		Gilts	69.47 ± 6.68^{b}	71.08 ± 6.67^{b}	78.97 ± 0.77^{defg}	95.92 ± 3.53^{b}	99.50 ± 3.78^{b}	102.58 ± 3.23^{c}	6.28 ± 0.31^{ab}	5.38 ± 0.06^{a}
		Barrows	73.28 ± 5.41^{b}	75.10 ± 5.52^{b}	80.35 ± 1.59^{g}	94.17 ± 2.76^{b}	101.67 ± 3.14^{b}	103.08 ± 2.39^{c}	6.52 ± 0.29^{ab}	5.39 ± 0.08^{a}
Significance level			p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.05	p<0.001

Means with different superscripts in the same column differed significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.16: Hennessey grading data of pigs from the experimental treatments (n = 12 per treatment)

Slaughter weight	Diet	Gender	Backfat thickness (mm)	Eye muscle thickness (mm)	Lean meat content (%)	Hennessey colour score	Conformation score
70	SFO	Boars	12.23 ± 2.38^{ab}	44.90 ± 5.60^{ab}	69.33 ± 1.17^{bc}	64.17 ± 15.28^{ab}	3.00 ± 0.01^{a}
		Gilts	11.43 ± 1.84^{a}	50.34 ± 6.51^{abcd}	69.98 ± 0.99^{c}	64.58 ± 13.44^{ab}	3.08 ± 0.29^{a}
		Barrows	15.43 ± 1.80^{bcd}	48.05 ± 2.15^{abc}	67.99 ± 0.83^{ab}	65.92 ± 11.62^{ab}	3.67 ± 0.49^{b}
	CLA	Boars	10.43 ± 2.15^{a}	43.87 ± 7.33^{a}	70.12 ± 1.09^{c}	58.00 ± 11.94^{a}	3.08 ± 0.29^{a}
		Gilts	12.63 ± 2.37^{abc}	50.24 ± 4.08^{abcd}	69.42 ± 1.22^{bc}	62.42 ± 17.02^{ab}	3.17 ± 0.39^{a}
		Barrows	13.93 ± 2.75^{abcd}	49.06 ± 3.54^{abcd}	68.77 ± 1.39^{bc}	64.33 ± 13.11^{ab}	3.17 ± 0.39^{a}
90	SFO	Boars	16.43 ± 2.10^{def}	52.03 ± 4.57^{bcd}	67.77 ± 1.05^{ab}	54.00 ± 10.29^{a}	3.00 ± 0.01^{a}
		Gilts	15.77 ± 3.68^{bcde}	53.93 ± 3.28^{cd}	68.18 ± 1.78^{ab}	66.67 ± 15.29^{ab}	3.17 ± 0.39^{a}
		Barrows	19.40 ± 3.59^{f}	53.30 ± 4.45^{cd}	66.47 ± 1.76^{a}	66.25 ± 13.58^{ab}	3.00 ± 0.01^{a}
	CLA	Boars	13.85 ± 1.52^{abcd}	56.03 ± 6.30^{d}	69.18 ± 0.88^{bc}	68.92 ± 14.65^{ab}	3.08 ± 0.29^{a}
		Gilts	15.87 ± 2.32^{cdef}	53.57 ± 5.26^{cd}	68.12 ± 1.21^{ab}	76.25 ± 11.75^{b}	3.33 ± 0.65^{ab}
		Barrows	19.17 ± 4.14^{ef}	53.47 ± 8.32^{cd}	66.58 ± 1.99^{a}	63.92 ± 9.89^{ab}	3.25 ± 0.45^{ab}
Significance level			p<0.001	p<0.001	p<0.001	p<0.05	p<0.01

Means with different superscripts in the same column differed significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

to pigs from the 90 kg slaughter weight group (Table 4.16). In the 70 kg slaughter weight group, gilts generally had the largest eye muscle thickness followed by barrows with intermediate eye muscle thickness and boars with the lowest eye muscle thickness (Table 4.16). This trend was also observed for the 90 kg SFO slaughter weight group (Table 4.16). Cisneros et al. (1996) also reported increased eye muscle thickness with increased slaughter weight.

Lean meat content was significantly (at least $p<0.05$) influenced by diet, gender and slaughter weight (Table 4.10 and 4.16). The 70 kg SFO gilts had a significantly ($p<0.001$) higher LMC, compared to the 70 kg SFO barrows and the 90 kg CLA boars had a significantly ($p<0.001$) higher LMC compared to the 90 kg CLA barrows (Table 4.16). Generally the 90 kg slaughter weight groups had a higher lean meat content compared to the 70 kg slaughter weight groups (Table 4.16). Hennessey colour score was significantly (at least $p<0.1$) influenced by gender (Table 4.10 and 4.16). The 70 kg CLA boars had a significantly ($p<0.05$) lower Hennessey colour score compared to the 90 kg CLA gilts (Table 4.16). In the 70 kg slaughter weight group, barrows generally had the highest Hennessey colour score, followed by the gilts, while boars had the lowest Hennessey colour score (Table 4.16). Conformation score was significantly ($p<0.05$) influenced by gender (Table 4.10 and 4.16). The 70 kg SFO barrows had a significantly ($p<0.01$) higher conformation score compared to the 70 kg SFO boars and gilts (Table 4.16). The 70 kg SFO barrows also had a significantly ($p<0.01$) higher conformation score compared to the 90 kg SFO boars, gilts and barrows (Table 4.16).

4.4. Backfat quality

4.4.1. Chemical properties and fatty acid composition of backfat of pigs from all treatment groups

Table 4.17 indicates that all physical fat quality parameters (EFC, FFDM, moisture, IV and RI) were significantly influenced by gender and slaughter weight, whereas only IV and RI were significantly influenced by dietary treatment. According to Tables 4.17 and 4.18, dietary treatment had no significant effect on EFC, FFDM and moisture content. Only IV and RI were significantly influenced by dietary treatment. From Tables 4.17 and 4.18 it is clear that the IV ($p<0.001$) and RI ($p<0.001$) of CLA supplemented pigs were significantly lower compared to the IV and RI of SFO supplemented pigs. The CLA supplemented pigs had an IV of 66.46 and RI of 1.46022 compared to IV of 71.47 and RI of 1.46061 for the SFO supplemented pigs. That is an indication that backfat from CLA supplemented pigs is more suitable for the use in processed meat products.

Boars had the lowest EFC ($p<0.001$), the highest FFDM ($p<0.05$) and the highest amount of moisture ($p<0.001$) in the backfat (Table 4.19). Similar results were reported by Barton-Gade (1987), Babol et al. (1995), Xue et al. (1997) and Pauly, Springs, O'Doherty, Kragten, & Bee (2009). Tables 4.17 and 4.19 indicated that IV and RI were also significantly ($p<0.001$) influenced by gender. Barrows had a significantly lower IV ($p<0.001$) and RI ($p<0.001$) compared to gilts and boars. This can be attributed to the fact that boar backfat has a more unsaturated fatty acid profile,

Table 4.17: Analysis of variance (ANOVA) on chemical properties of backfat for the effect of dietary treatments, gender and slaughter weight

	Diet	Gender	Slaughter weight
% Extractable fat	NS	****	****
% Fat free dry matter	NS	**	***
% Moisture	NS	****	****
Iodine value	****	****	****
Refraction index	****	****	****

NS = Not significant; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

Table 4.18: Effect of dietary treatment on chemical properties of backfat of pigs

	SFO-Diet (n = 72)	CLA-Diet (n = 72)	Significance level
% Extractable fat	72.26 ± 6.12	71.53 ± 5.77	NS
% Fat free dry matter	11.99 ± 2.07	11.83 ± 1.67	NS
% Moisture	15.76 ± 5.42	16.64 ± 4.92	NS
Iodine value	71.47 ± 4.38^{b}	66.46 ± 4.56^{a}	p<0.001
Refraction index	1.46061 ± 0.00052^{b}	1.46022 ± 0.00060^{a}	p<0.001

Means with different superscripts in the same row differed significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.19: Effect of gender on the chemical properties of backfat of pigs

	Boars (n = 48)	Gilts (n = 48)	Barrows (n = 48)	Significance level
% Extractable fat	68.22 ± 5.42^{a}	73.08 ± 5.98^{b}	74.38 ± 4.55^{b}	p<0.001
% Fat free dry matter	12.51 ± 1.97^{b}	11.66 ± 1.53^{a}	11.56 ± 1.98^{a}	p<0.05
% Moisture	19.27 ± 4.27^{b}	15.26 ± 5.90^{a}	14.07 ± 3.64^{a}	p<0.001
Iodine value	71.94 ± 4.78^{c}	68.83 ± 5.00^{b}	66.13 ± 3.81^{a}	p<0.001
Refraction index	1.46081 ± 0.00057^{c}	1.46035 ± 0.00055^{b}	1.46007 ± 0.00040^{a}	p<0.001

Means with different superscripts in the same row differed significantly.

compared to gilts and barrows (Barton-Gade, 1987; Babol et al., 1995; Xue et al., 1997).

According to Tables 4.17 and 4.20 backfat from heavier baconer pigs had significantly higher % EFC (p<0.001), lower FFDM (p<0.01) and lower moisture content (p<0.001) than the lighter porker pigs. This is in agreement with the findings of Bruwer, Heinze, Zondagh, & Naudé, (1991), who found backfat from heavier pigs to contain more adipose tissue and less moisture. The 90 kg baconer pigs had a significantly lower IV (p<0.001) and RI (p<0.001) than the 70 kg porker pigs (Table 4.20). This is an indication that the lighter “porker” pigs had more unsaturated backfat, with poorer technological properties, than the heavier “baconer” pigs. It was reported that heavier pigs had a more physiological mature fat with a higher SFA profile (Wood et al., 1989).

The comparison of all treatment groups in Table 4.21 indicates that the 70 kg CLA boars had the lowest % EFC and the 90 kg CLA gilts had the highest % EFC. It was previously reported that backfat from heavier pigs have higher % EFC (Barton-Gade, 1987; Babol et al., 1995; Xue et al., 1997; Pauly et al., 2009). Although not statistically significant, boars generally had the lowest EFC

Table 4.20: Effect of slaughter weight on quality characteristics of backfat of pigs

	70 kg Slaughter Group (n = 72)	**90 kg Slaughter Group** (n = 72)	**Significance level**
% Extractable fat	69.33 ± 6.05[a]	74.45 ± 4.60[b]	p<0.001
% Fat free dry matter	12.41 ± 1.74[b]	11.41 ± 1.88[a]	p<0.01
% Moisture	18.25 ± 5.63[b]	14.14 ± 3.70[a]	p<0.001
Iodine value	70.73 ± 5.03[b]	67.20 ± 4.59[a]	p<0.001
Refraction index	1.46066 ± 0.00059[b]	1.46016 ± 0.00048[a]	p<0.001

Means with different superscripts in the same row differed significantly.

Table 4.21: Quality characteristics of backfat of pigs from the experimental treatments (n = 12 per treatment)

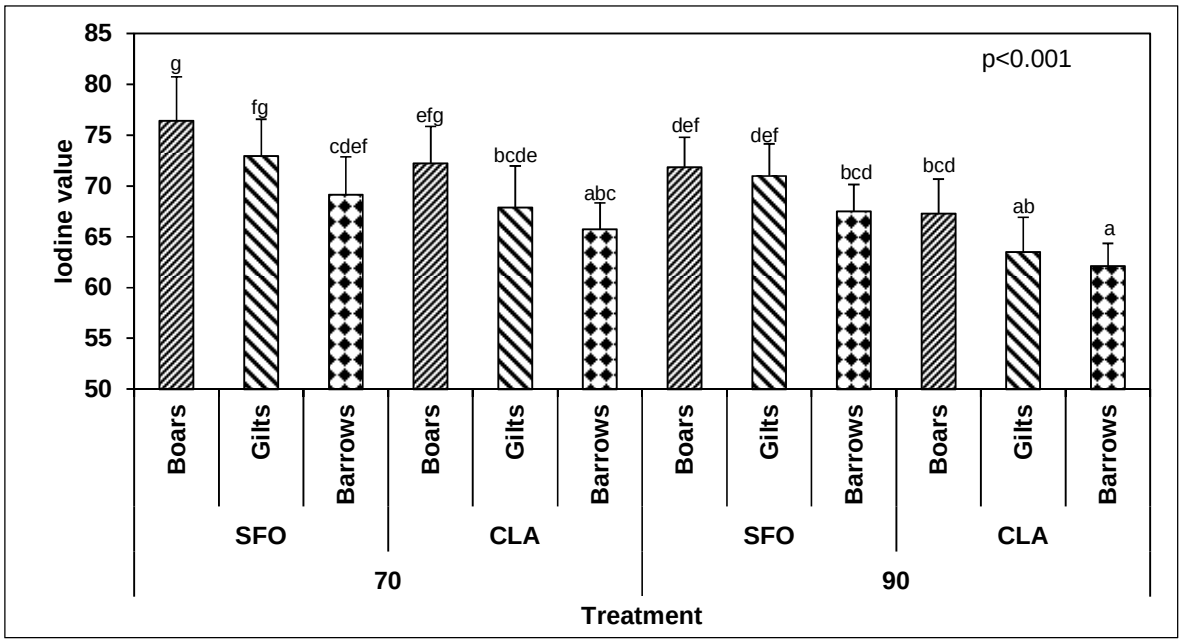
Slaughter weight	**Diet**	**Gender**	**% Extractable fat**	**% Fat free dry matter**	**% Moisture**
70	**SFO**	**Boars**	66.62 ± 3.79[ab]	13.01 ± 1.07[ab]	20.38 ± 3.75[de]
		Gilts	69.06 ± 7.67[ab]	12.58 ± 1.65[ab]	18.35 ± 8.33[cde]
		Barrows	72.55 ± 6.79[bcd]	12.45 ± 2.20[ab]	15.00 ± 5.7[abcd]
	CLA	**Boars**	64.62 ± 4.89[a]	13.62 ± 1.86[b]	21.76 ± 3.82[e]
		Gilts	70.26 ± 5.39[abc]	11.69 ± 1.31[ab]	18.05 ± 5.61[bcde]
		Barrows	72.91 ± 2.39[bcd]	11.13 ± 1.10[a]	15.96 ± 2.59[abcd]
90	**SFO**	**Boars**	72.76 ± 3.89[bcd]	11.23 ± 2.54[ab]	16.01 ± 2.49[abcde]
		Gilts	76.27 ± 2.52[cd]	11.29 ± 1.39[ab]	12.45 ± 2.43[ab]
		Barrows	76.29 ± 4.42[cd]	11.37 ± 2.69[ab]	12.34 ± 2.26[ab]
	CLA	**Boars**	68.89 ± 5.67[ab]	12.19 ± 1.41[ab]	18.92 ± 4.82[de]
		Gilts	76.74 ± 2.57[d]	11.08 ± 1.50[a]	12.18 ± 1.99[a]
		Barrows	75.77 ± 2.23[cd]	11.27 ± 1.48[ab]	12.96 ± 1.63[abc]
Significance level			p<0.001	p<0.01	p<0.001

Means with different superscripts in the same column differed significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

followed by gilts and barrows with the highest % EFC (Table 4.21). This was not the case for the 90 kg CLA group, where the gilts had the highest % EFC. The FFDM of the 70 kg CLA boars was significantly (p<0.01) higher compared to the FFDM of the 70 kg CLA barrows and the 90 kg CLA gilts (Table 4.21). This is in agreement with previous findings that indicated that backfat from boars had higher FFDM content compared to backfat from barrows and gilts and that backfat from lighter pigs had higher FFDM content in their backfat than that from heavier pigs (Barton-Gade, 1987; Babol et al., 1995; Xue et al., 1997; Pauly et al., 2009).

The moisture content of backfat of the 90 kg CLA gilts was significantly (p<0.001) lower compared to the moisture content of the 70 kg CLA boars (Table 4.21). Backfat from heavier pigs had a lower moisture content than backfat from lighter pigs (Table 4.21) This is in agreement with previous findings (Babol et al., 1995; Xue et al., 1997; Pauly et al., 2009). Although not statistically significant, backfat from boars generally had a higher moisture content compared to gilts and barrows (Table 4.21). This is in agreement with previous findings that the backfat from boars had more moisture compared to gilts and barrows (Barton-Gade, 1987).

From Figure 4.1 and 4.2 it is clear that backfat from the lighter 70 kg pigs had higher IV and RI values compared to the heavier 90 kg pigs. Heavier pigs had a more physiological mature fat with a higher SFA profile (Wood et al., 1989). From Figure 4.1 and 4.2 it can also be observed that backfat from boars always had the highest IV and RI, followed by gilts and then barrows. It was previously reported that boar backfat had a more unsaturated fatty acid profile, compared to gilts and barrows (Barton-Gade, 1987; Babol et al., 1995; Xue et al., 1997). From Figure 4.1 and 4.2 it is clear that backfat from pigs on the CLA diets generally had lower IV and RI values and therefore better fat quality, compared to backfat from pigs on the SFO diets. These IV and RI trends indicate that backfat from boars had the poorest fat quality, with those of gilts intermediate and those of barrows the best. It also indicated that lighter pigs had more unsaturated backfat with poorer technological properties compared to heavier pigs (Figure 4.1 and Figure 4.2).

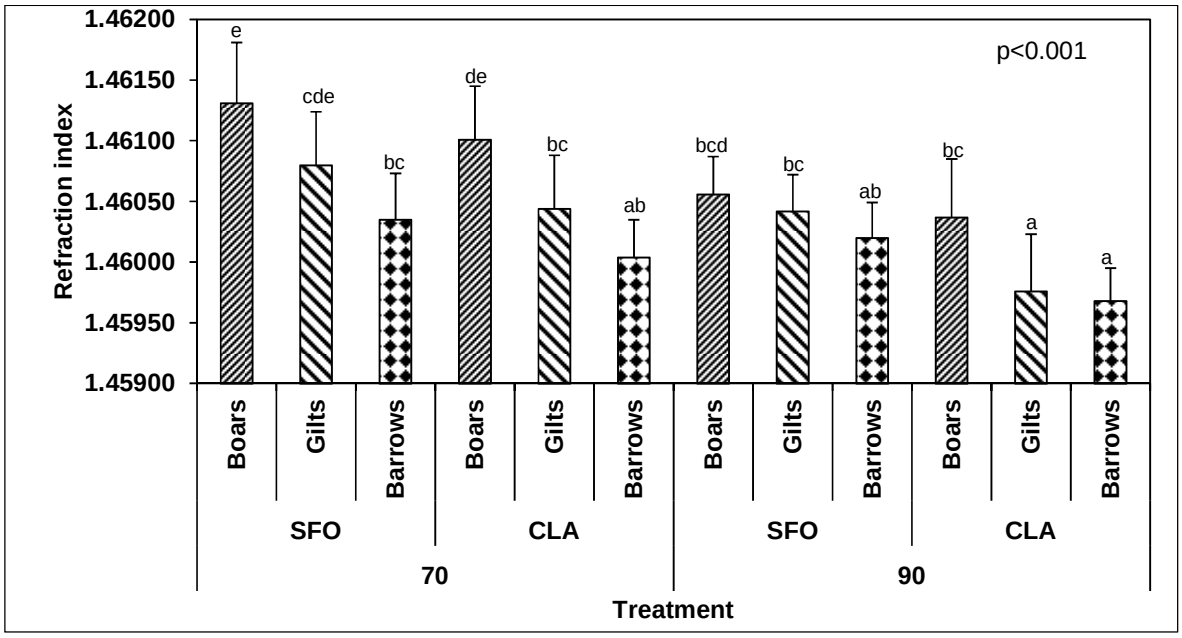


Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.1: Iodine value of backfat of pigs from the experimental treatment groups (n = 12 per treatment)

Table 4.22 indicates that, as in the case of physiochemical properties, most fatty acids and fatty acid ratios were significantly influenced by diet. A large number of fatty acids and fatty acid ratios were also influenced by gender and slaughter weight.

Dietary CLA supplementation resulted in a significant ($p<0.001$) increase in C14:0, C15:0, C16:0, C16:1*c*9, C17:0, C18:0, C18:1*t*9 and both the CLA isomers (*cis*-9, *trans*-11 and *trans*-10, *cis*-12) (Table 4.23). Dietary CLA supplementation resulted in a significant ($p<0.001$) decrease in C18:1*c*9, C18:1*c*7, C18:2, C20:1, C20:2, C20:3 and C20:4 (Table 4.23). As far as fatty acid ratios were concerned dietary supplementation with CLA resulted in a significantly ($p<0.001$) higher SFA



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.2: Refraction index of backfat of pigs from the experiemental treatment groups (n = 12 per treatment)

and a significantly ($p<0.001$) lower MUFA content (Table 4.23). This finding is in agreement with Szymczyk (2005) and Averette Gatlin et al. (2006), who found that dietary CLA supplementation, resulted in increased SFA.

It was found that subcutaneous fat of barrows contained significantly higher levels of C14:0 ($p<0.1$), C16:0 ($p<0.001$), C18:0 ($p<0.05$) and C20:0 ($p<0.001$) and significantly lower levels of C18:2 ($p<0.001$), C18:3*n*-3 ($p<0.1$), C20:2 ($p<0.001$), C20:3 ($p<0.001$), C20:4 ($p<0.001$) and C22:6 ($p<0.001$), compared to boars (Table 4.24). Barrows had a significantly ($p<0.001$) higher SFA and significantly ($p<0.001$) lower PUFA content compared to boars (Table 4.24). The content of individual fatty acids and fatty acid ratios of gilts were generally intermediate between those of boars and barrows (Table 4.24). This is in agreement with the findings of Barton-Gade (1987), Babol et al. (1995) and Xue et al. (1997) who concluded that boars tend to have a more unsaturated fatty acid profile compared to barrows which have a more saturated fatty acid profile and gilts having an intermediate fatty acid profile.

The backfat of the heavier 90 kg baconer pigs had a significantly higher C16:0 ($p<0.1$), C18:0 ($p<0.1$), C20:0 ($p<0.01$) and SFA ($p<0.1$) content compared to the lighter 70 kg porker pigs (Table 4.25). The lighter 70 kg porker pigs had a significantly higher C18:2 ($p<0.001$), C18:3*n*-3 ($p<0.001$), C20:4 ($p<0.01$), C22:6 ($p<0.001$) and PUFA ($p<0.001$) content. This can be attributed to the fact the heavier pigs have a physiological more mature fat that is more saturated (Wood et al., 1989).

Table 4.22: Analysis of variance (ANOVA) on fatty acid composition and fatty acid ratios for the effect of dietary treatment, gender and slaughter weight

	Diet	Gender	Slaughter weight
Fatty acid composition (%)			
C14:0	****	*	NS
C15:0	****	NS	NS
C16:0	****	****	*
C16:1*c*9	****	NS	NS
C17:0	****	NS	NS
C18:0	****	**	*
C18:1*t*9	****	NS	NS
C18:1*c*9	****	NS	NS
C18:1*c*7	****	NS	NS
C18:2*c*9,12(*n*-6)	NS	****	****
C18:2*c*9,*t*11(*n*-6)(CLA)	****	NS	NS
C18:2*t*10,*c*12(*n*-6)(CLA)	****	NS	NS
C18:3*c*9,12,15(*n*-3)	NS	*	****
C20:0	NS	***	***
C20:1*c*11	****	NS	NS
C20:2*c*11,14(*n*-6)	****	****	NS
C20:3*c*11,14,17(*n*-3)	****	****	NS
C20:4*c*5,8,11,14(*n*-6)	****	****	***
C22:6*c*4,7,10(*n*-3)	NS	****	****
Fatty acid ratios:			
SFA (%)	****	****	*
MUFA (%)	****	NS	NS
PUFA (%)	NS	****	****

NS = Not significant; CLA = Conjugated linoleic acid; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

The fatty acid content and fatty acid ratios of all twelve treatment groups are indicated in Tables 4.26 – 4.29. According to Table 4.26, the subcutaneous fat from SFO supplemented pigs had a significantly (p<0.001) lower C14:0 content compared to the subcutaneous fat from CLA pigs. The C15:0, C16:0, C17:0, C18:0 and C20:0 contents of backfat from CLA supplemented pigs, as seen in Table 4.26, were generally higher, compared to the backfat from the SFO supplemented pigs. That is in agreement with the findings of Szymczyk (2005) and Averette Gatlin et al. (2006). It was found that backfat from barrows generally had higher levels of C16:0 and C18:0, compared to gilts and boars (Table 4.26). Other researchers found similar higher C16:0 and C18:0 in backfat from gilts compared to boars (Barton-Gade, 1987; Babol et al., 1995; Xue et al., 1997). The heavier 90 kg baconer pigs also had higher amounts of SFA (C14:0, C16:0, C18:0 and C20:0) compared to lighter 70 kg porker pigs (Table 4.26) (Wood et al., 1989).

The 70 kg CLA barrows had a significantly (p<0.001) higher C16:1*c*9 content compared to the 70 kg CLA boars (Table 4.27). The C16:1*c*9, C18:1*t*9, C18:1*c*9 and C18:1*c*7 content of backfat from CLA supplemented pigs were generally lower, compared to SFO supplemented pigs (Table 4.27). The 70 kg CLA boars had significantly (p<0.001) lower C20:1 content compared to the 70 kg

Table 4.23: Effect of diet on the fatty acid composition of backfat of pigs

Diet	**SFO-Diet** (n = 72)	**CLA-Diet** (n = 72)	**Significance level**
FAME (% of total fatty acids)			
C14:0	1.45 ± 0.12[a]	2.21 ± 0.29[b]	p<0.001
C15:0	0.01 ± 0.02[a]	0.05 ± 0.04[b]	p<0.001
C16:0	26.09 ± 1.16[a]	29.10 ± 1.63[b]	p<0.001
C16:1*c*9	2.16 ± 0.30[a]	2.40 ± 0.34[b]	p<0.001
C17:0	0.39 ± 0.11[a]	0.52 ± 0.14[b]	p<0.001
C18:0	10.83 ± 1.21[a]	13.74 ± 1.21[b]	p<0.001
C18:1*t*9	0.02 ± 0.02[a]	0.06 ± 0.02[b]	p<0.001
C18:1*c*9	38.65 ± 1.61[b]	31.86 ± 1.28[a]	p<0.001
C18:1*c*7	2.51 ± 0.17[b]	2.10 ± 0.14[a]	p<0.001
C18:2*c*9,12(*n*-6)	16.01 ± 2.15	15.57 ± 2.20	NS
C18:2*c*9,*t*11(*n*-6)(CLA)	0.02 ± 0.03[a]	0.50 ± 0.08[b]	p<0.001
C18:2*t*10,*c*12(*n*-6)(CLA)	0.01 ± 0.01[a]	0.19 ± 0.03[b]	p<0.001
C18:3*c*9,12,15(*n*-3)	0.44 ± 0.26	0.49 ± 0.25	NS
C20:0	0.17 ± 0.03	0.16 ± 0.02	NS
C20:1*c*11	0.52 ± 0.10[b]	0.44 ± 0.10[a]	p<0.001
C20:2*c*11,14(*n*-6)	0.49 ± 0.06[b]	0.40 ± 0.05[a]	p<0.001
C20:3*c*11,14,17(*n*-3)	0.05 ± 0.02[b]	0.03 ± 0.03[a]	p<0.001
C20:4*c*5,8,11,14(*n*-6)	0.16 ± 0.03[b]	0.13 ± 0.04[a]	p<0.001
C22:6*c*4,7,10(*n*-3)	0.06 ± 0.05	0.05 ± 0.05	NS
Fatty acid ratios:			
SFA (%)	38.94 ± 2.16[a]	45.78 ± 2.53[b]	p<0.001
MUFA (%)	43.85 ± 1.72[b]	36.86 ± 1.36[a]	p<0.001
PUFA (%)	17.21 ± 2.42	17.36 ± 2.44	NS

Means with different superscripts in the same row differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

SFO barrows (Table 4.27). Backfat from the heavier 90 kg baconer pigs tend to contain higher amounts of MUFA (C16:1*c*9, C18:1*t*9, C18:1*c*9, C18:1*c*7 and C20:1) compared to lighter 70 kg porker pigs (Table 4.27).

As far as PUFA content was concerned, boars had higher C18:2, C18:3*n*-3, C20:2, C20:3, C20:4 and C22:6 values, compared to gilts and barrows (Table 4.28). The CLA supplemented groups had lower contents of C18:2, C18:3*n*-3, C20:2, C20:3, C20:4 and C22:6 compared to the SFO supplemented groups (Table 4.28). The lighter 70 kg porker pigs had higher amounts of PUFA (C18:2, C18:3*n*-3, C20:2, C20:3, C20:4 and C22:6) compared to heavier baconer pigs (Table 4.28).

Backfat from the CLA supplemented groups had significantly higher SFA (p<0.001) and lower MUFA (p<0.001) content compared to backfat form the SFO supplemented groups (Table 4.29). This increase in SFA content as a result of dietary CLA supplementation is in agreement with pervious findings from Averette Gatlin et al. (2002), Smith et al. (2002), Szymczyk, (2005), Averette Gatlin et al. (2006), Larsen et al. (2009) and Jiang et al. (2010). Generally, barrows had a higher SFA content and lower MUFA and PUFA content, compared to gilts and boars (Table 4.29).

Table 4.24: Effect of gender on the fatty acid composition of backfat of pigs

Diet	Boars (n = 48)	Gilts (n = 48)	Barrows (n = 48)	Significance level
FAME (% of total fatty acids)				
C14:0	1.73 ± 0.35[a]	1.81 ± 0.43[ab]	1.94 ± 0.51[b]	p<0.1
C15:0	0.04 ± 0.03	0.03 ± 0.03	0.03 ± 0.04	NS
C16:0	26.56 ± 1.74[a]	27.47 ± 1.84[b]	28.75 ± 2.02[c]	p<0.001
C16:1*c*9	2.27 ± 0.34	2.24 ± 0.30	2.33 ± 0.38	NS
C17:0	0.47 ± 0.13	0.43 ± 0.13	0.47 ± 0.16	NS
C18:0	11.68 ± 1.97[a]	12.38 ± 1.89[ab]	12.79 ± 1.69[b]	p<0.05
C18:1*t*9	0.04 ± 0.03	0.04 ± 0.03	0.03 ± 0.03	NS
C18:1*c*9	35.17 ± 3.60	35.55 ± 3.68	35.03 ± 3.89	NS
C18:1*c*7	2.31 ± 0.29	2.32 ± 0.25	2.29 ± 0.23	NS
C18:2*c*9,12(*n*-6)	17.42 ± 1.82[c]	15.60 ± 2.06[b]	14.33 ± 1.39[a]	p<0.001
C18:2*c*9,*t*11(*n*-6)(CLA)	0.29 ± 0.28	0.25 ± 0.24	0.24 ± 0.23	NS
C18:2*t*10,*c*12(*n*-6)(CLA)	0.10 ± 0.11	0.09 ± 0.09	0.09 ± 0.09	NS
C18:3*c*9,12,15(*n*-3)	0.52 ± 0.31[b]	0.47 ± 0.24[ab]	0.40 ± 0.21[a]	p<0.1
C20:0	0.15 ± 0.03[a]	0.17 ± 0.02[b]	0.17 ± 0.03[b]	p<0.01
C20:1*c*11	0.46 ± 0.12	0.48 ± 0.09	0.50 ± 0.10	NS
C20:2*c*11,14(*n*-6)	0.47 ± 0.07[b]	0.44 ± 0.06[ab]	0.42 ± 0.06[a]	p<0.001
C20:3*c*11,14,17(*n*-3)	0.06 ± 0.02[c]	0.04 ± 0.02[b]	0.02 ± 0.02[a]	p<0.001
C20:4*c*5,8,11,14(*n*-6)	0.17 ± 0.04[c]	0.14 ± 0.03[b]	0.12 ± 0.03[a]	p<0.001
C22:6*c*4,7,10(*n*-3)	0.07 ± 0.05[b]	0.06 ± 0.05[b]	0.03 ± 0.04[a]	p<0.001
Fatty acid ratios:				
SFA (%)	40.64 ± 3.80[a]	42.28 ± 3.95[ab]	44.16 ± 4.02[b]	p<0.001
MUFA (%)	40.25 ± 3.92	40.63 ± 3.78	40.18 ± 3.88	NS
PUFA (%)	19.11 ± 2.16[c]	17.09 ± 2.23[b]	15.66 ± 1.45[a]	p<0.001

Means with different superscripts in the same row differ significantly; NS = Not significant; CLA = Conjugated linoleic acid

This finding was previously reported by Nürnberg et al. (1998). Generally, backfat from the heavier 90 kg pigs had a lower PUFA content, compared to backfat from the lighter 70 kg pigs. Wood et al. (1989) reported pigs with a heavier slaughter weight had a physiologically more mature fat that is more saturated.

Dugan et al. (2001) and Lo Fiego et al. (2005a) reported that meat from pigs can contain relatively low levels of CLA (0.1-0.2% of total fatty acids) naturally. These low levels can be seen in Figure 4.3 for the SFO supplemented pigs that received no dietary CLA supplementation. This is in agreement with the findings of Eggert et al. (1998), who also found CLA in the subcutaneous fat of SFO supplemented pigs. Dietary supplementation with CLA resulted in a significant increase in the content of both CLA isomers (C18:2*c*9,*t*11 and C18:2*t*10,*c*12) in the backfat of CLA supplemented compared to SFO supplemented pigs (Figure 4.3). An interesting observation was the increase in C18:2*c*9,*t*11 and C18:2*t*10,*c*12 CLA content with increased slaughter weight of CLA supplemented pigs (Figure 4.3). The 90 kg slaughter weight group was exposed to the CLA supplemented diet for a longer period and had significantly (p<0.001) higher CLA levels in the backfat than the 70 kg slaughter weight group. Since the CLA content of the diet was kept constant throughout the study,

Table 4.25: Effect of slaughter weight on the fatty acid composition of backfat of pigs

Diet	**70 kg Slaughter Group** (n = 72)	**90 kg Slaughter Group** (n = 72)	**Significance level**
FAME (% of total fatty acids)			
C14:0	1.77 ± 0.41	1.88 ± 0.47	NS
C15:0	0.04 ± 0.03	0.03 ± 0.04	NS
C16:0	27.28 ± 2.11[a]	27.91 ± 1.98[b]	p<0.1
C16:1*c*9	2.29 ± 0.34	2.27 ± 0.34	NS
C17:0	0.47 ± 0.14	0.44 ± 0.14	NS
C18:0	11.99 ± 1.64[a]	12.57 ± 2.09[b]	p<0.1
C18:1*t*9	0.04 ± 0.03	0.04 ± 0.03	NS
C18:1*c*9	34.90 ± 3.20	35.60 ± 4.14	NS
C18:1*c*7	2.28 ± 0.24	2.33 ± 0.28	NS
C18:2*c*9,12(*n*-6)	16.68 ± 2.11[b]	14.89 ± 1.86[a]	p<0.001
C18:2*c*9,*t*11(*n*-6)(CLA)	0.24 ± 0.22	0.28 ± 0.28	NS
C18:2*t*10,*c*12(*n*-6)(CLA)	0.09 ± 0.09	0.10 ± 0.10	NS
C18:3*c*9,12,15(*n*-3)	0.58 ± 0.23[b]	0.34 ± 0.23[a]	p<0.001
C20:0	0.16 ± 0.03[a]	0.17 ± 0.02[b]	p<0.01
C20:1*c*11	0.47 ± 0.12	0.49 ± 0.09	NS
C20:2*c*11,14(*n*-6)	0.45 ± 0.07	0.44 ± 0.06	NS
C20:3*c*11,14,17(*n*-3)	0.04 ± 0.03	0.04 ± 0.02	NS
C20:4*c*5,8,11,14(*n*-6)	0.15 ± 0.04[b]	0.14 ± 0.04[a]	p<0.01
C22:6*c*4,7,10(*n*-3)	0.08 ± 0.05[b]	0.03 ± 0.04[a]	p<0.001
Fatty acid ratios:			
SFA (%)	41.71 ± 3.93[a]	43.01 ± 4.30[b]	p<0.1
MUFA (%)	39.98 ± 3.35	40.73 ± 4.26	NS
PUFA (%)	18.31 ± 2.35[b]	16.26 ± 2.05[a]	p<0.001

Means with different superscripts in the same row differ significantly; NS = Not significant; CLA = Conjugated linoleic acid

this observation can only be explained in terms of exposure time to CLA - meaning that exposure to CLA over a longer period resulted in an elevated level of CLA in subcutaneous fat.

From the physical and chemical properties (Table 4.21) and the fatty acid composition of backfat (Table 4.24) it could be concluded that the physical and chemical properties and fatty acid composition of backfat from gilts were intermediate to that of boars and barrows. Other authors also found the fat properties of gilts to be intermediate to those of boars and barrows (Barton-Gade, 1987; Babol et al., 1995; Xue et al., 1997). It was therefore decided to conduct the further advanced meat and fat quality work only on the gilts from the experimental treatment groups. Ten gilts per treatment group were randomly selected for this purpose.

4.4.2. Physical and chemical properties of backfat of gilts from the experimental treatment groups

According to Table 4.30, the physical properties (fat hardness, *L** and Hue angle) were significantly influenced by dietary treatment.

Table 4.26: Saturated fatty acid content of subcutaneous fat of pigs from the experimental treatments (n = 12 per treatment)

Slaughter weight	Diet	Gender	C14:0	C15:0	C16:0	C17:0	C18:0	C20:0
70	SFO	Boars	1.38 ± 0.09^{a}	0.04 ± 0.03^{abcd}	24.82 ± 1.02^{a}	0.49 ± 0.13^{abc}	9.88 ± 1.05^{a}	0.15 ± 0.03^{a}
		Gilts	1.44 ± 0.12^{a}	0.01 ± 0.01^{a}	25.93 ± 1.23^{ab}	0.34 ± 0.08^{a}	10.66 ± 1.15^{ab}	0.16 ± 0.02^{ab}
		Barrows	1.49 ± 0.14^{a}	0.01 ± 0.02^{ab}	27.03 ± 0.76^{b}	0.41 ± 0.12^{ab}	11.91 ± 1.25^{bc}	0.18 ± 0.02^{b}
	CLA	Boars	1.83 ± 0.16^{b}	0.06 ± 0.03^{cd}	26.85 ± 0.97^{b}	0.56 ± 0.12^{bc}	12.59 ± 0.62^{cd}	0.15 ± 0.02^{a}
		Gilts	2.15 ± 0.24^{c}	0.05 ± 0.03^{bcd}	28.65 ± 1.31^{c}	0.49 ± 0.10^{abc}	13.35 ± 0.67^{de}	0.16 ± 0.02^{ab}
		Barrow	2.33 ± 0.26^{cd}	0.06 ± 0.04^{cd}	30.40 ± 1.16^{de}	0.54 ± 0.16^{bc}	13.60 ± 0.80^{de}	0.16 ± 0.02^{ab}
90	SFO	Boars	1.52 ± 0.15^{a}	0.02 ± 0.02^{abc}	25.81 ± 0.91^{ab}	0.40 ± 0.11^{ab}	10.30 ± 0.93^{a}	0.16 ± 0.02^{ab}
		Gilts	1.40 ± 0.08^{a}	0.01 ± 0.02^{ab}	26.14 ± 0.98^{ab}	0.38 ± 0.10^{a}	11.02 ± 0.73^{ab}	0.18 ± 0.02^{ab}
		Barrow	1.45 ± 0.06^{a}	0.01 ± 0.01^{a}	26.81 ± 0.57^{b}	0.34 ± 0.06^{a}	11.23 ± 1.15^{abc}	0.18 ± 0.03^{ab}
	CLA	Boars	2.19 ± 0.21^{c}	0.04 ± 0.03^{abcd}	28.77 ± 0.88^{c}	0.43 ± 0.12^{ab}	13.98 ± 1.40^{de}	0.16 ± 0.02^{ab}
		Gilts	2.26 ± 0.22^{cd}	0.04 ± 0.04^{abcd}	29.16 ± 1.05^{cd}	0.49 ± 0.14^{abc}	14.50 ± 1.32^{e}	0.18 ± 0.03^{ab}
		Barrow	2.49 ± 0.16^{d}	0.07 ± 0.04^{d}	30.77 ± 0.61^{e}	0.61 ± 0.15^{c}	14.44 ± 1.20^{e}	0.17 ± 0.02^{ab}
Significance level			p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.01

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.27: Monounsaturated fatty acid content of subcutaneous fat of pigs from the experimental treatments (n = 12 per treatment)

Slaughter weight	Diet	Gender	C16:1*c*9	C18:1*t*9	C18:1*c*9	C18:1*c*7	C20:1*c*11
70	SFO	Boars	2.39 ± 0.34^{abc}	0.01 ± 0.02^{a}	37.60 ± 1.41^{b}	2.54 ± 0.20^{bc}	0.50 ± 0.13^{abc}
		Gilts	2.16 ± 0.23^{a}	0.02 ± 0.01^{a}	37.92 ± 1.70^{bc}	2.47 ± 0.18^{bc}	0.48 ± 0.09^{abc}
		Barrows	2.02 ± 0.29^{a}	0.01 ± 0.01^{a}	37.89 ± 1.16^{bc}	2.37 ± 0.12^{b}	0.58 ± 0.09^{c}
	CLA	Boars	2.16 ± 0.31^{ab}	0.06 ± 0.02^{b}	32.67 ± 0.98^{a}	2.07 ± 0.11^{a}	0.40 ± 0.13^{a}
		Gilts	2.42 ± 0.29^{abc}	0.06 ± 0.02^{b}	31.86 ± 1.35^{a}	2.08 ± 0.09^{a}	0.44 ± 0.10^{ab}
		Barrow	2.62 ± 0.23^{c}	0.05 ± 0.03^{b}	31.48 ± 1.16^{a}	2.13 ± 0.14^{a}	0.43 ± 0.09^{ab}
90	SFO	Boars	2.22 ± 0.32^{abc}	0.02 ± 0.02^{a}	39.30 ± 1.39^{bcd}	2.59 ± 0.12^{c}	0.50 ± 0.08^{abc}
		Gilts	2.08 ± 0.24^{a}	0.02 ± 0.02^{a}	39.75 ± 1.45^{d}	2.56 ± 0.14^{bc}	0.53 ± 0.09^{bc}
		Barrow	2.12 ± 0.30^{a}	0.01 ± 0.01^{a}	39.43 ± 1.30^{cd}	2.51 ± 0.20^{bc}	0.53 ± 0.11^{bc}
	CLA	Boars	2.32 ± 0.38^{abc}	0.06 ± 0.01^{b}	31.12 ± 0.91^{a}	2.05 ± 0.16^{a}	0.46 ± 0.13^{abc}
		Gilts	2.32 ± 0.32^{abc}	0.07 ± 0.02^{b}	32.66 ± 1.32^{a}	2.16 ± 0.17^{a}	0.47 ± 0.07^{abc}
		Barrow	2.56 ± 0.30^{bc}	0.05 ± 0.02^{b}	31.34 ± 1.21^{a}	2.13 ± 0.17^{a}	0.46 ± 0.06^{abc}
Significance level			p<0.001	p<0.001	p<0.001	p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.28: Polyunsaturated fatty acid content of subcutaneous fat of pigs from the experimental treatments (n = 12 per treatment)

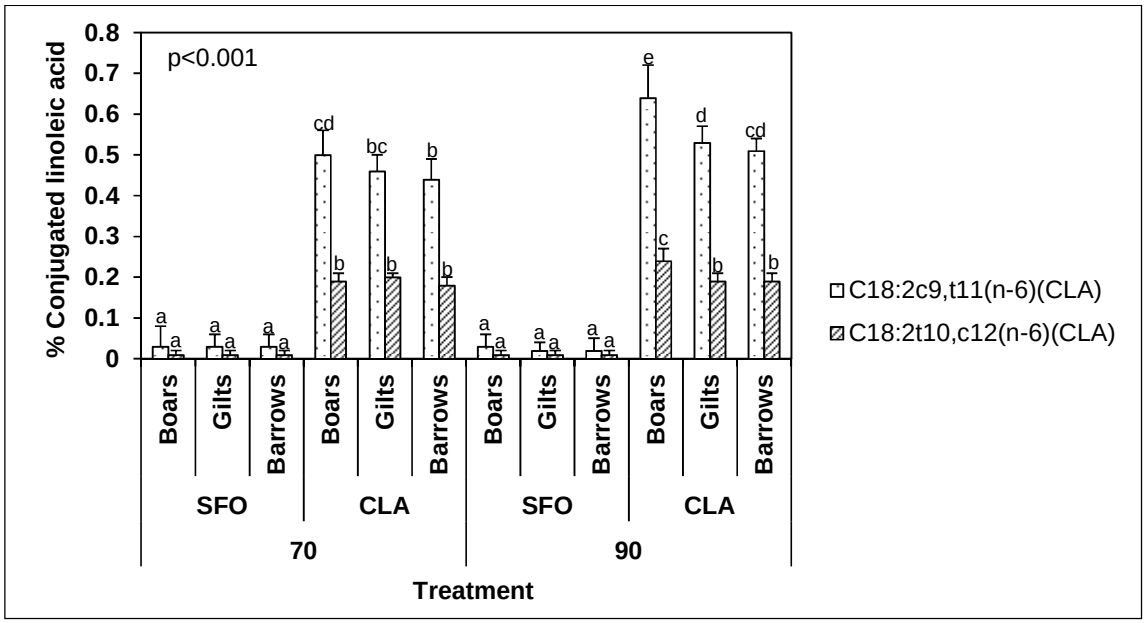
Slaughter weight	Diet	Gender	C18:2*c*9,12 (*n*-6)	C18:3*c*9,12,15 (*n*-3)	C20:2*c*11,14 (*n*-6)	C20:3*c*11,14,17 (*n*-3)	C20:4*c*5,8,11,14 (*n*-6)	C22:6*c*4,7,10 (*n*-3)
70	SFO	Boars	18.59 ± 1.49^{f}	0.73 ± 0.13^{d}	0.54 ± 0.05^{e}	0.07 ± 0.01^{d}	0.18 ± 0.03^{f}	0.09 ± 0.04^{bc}
		Gilts	17.04 ± 1.64^{def}	0.58 ± 0.20^{bcd}	0.49 ± 0.07^{cde}	0.05 ± 0.02^{cd}	0.16 ± 0.03^{def}	0.09 ± 0.05^{bc}
		Barrows	14.96 ± 1.26^{abc}	0.46 ± 0.16^{abcd}	0.46 ± 0.05^{bcd}	0.03 ± 0.02^{abc}	0.13 ± 0.03^{abcd}	0.04 ± 0.05^{ab}
	CLA	Boars	18.49 ± 0.76^{ef}	0.68 ± 0.31^{cd}	0.43 ± 0.05^{abc}	0.06 ± 0.01^{d}	0.18 ± 0.04^{f}	0.10 ± 0.03^{c}
		Gilts	16.46 ± 2.16^{bcde}	0.55 ± 0.27^{abcd}	0.40 ± 0.05^{ab}	0.03 ± 0.03^{abc}	0.14 ± 0.03^{bcde}	0.08 ± 0.05^{bc}
		Barrow	14.57 ± 1.10^{abc}	0.50 ± 0.18^{abcd}	0.37 ± 0.05^{a}	0.01 ± 0.02^{a}	0.11 ± 0.02^{abc}	0.06 ± 0.05^{abc}
90	SFO	Boars	16.07 ± 1.97^{bcd}	0.30 ± 0.27^{ab}	0.50 ± 0.05^{de}	0.06 ± 0.02^{cd}	0.17 ± 0.03^{ef}	0.05 ± 0.04^{abc}
		Gilts	14.91 ± 1.75^{abc}	0.30 ± 0.23^{ab}	0.48 ± 0.04^{cde}	0.04 ± 0.02^{cd}	0.15 ± 0.03^{cdef}	0.05 ± 0.05^{abc}
		Barrow	14.47 ± 1.68^{ab}	0.25 ± 0.22^{a}	0.47 ± 0.04^{bcd}	0.03 ± 0.02^{abc}	0.14 ± 0.02^{abcde}	0.02 ± 0.03^{a}
	CLA	Boars	16.55 ± 1.38^{cdef}	0.39 ± 0.29^{abc}	0.42 ± 0.05^{abc}	0.04 ± 0.02^{bcd}	0.15 ± 0.04^{bcdef}	0.03 ± 0.04^{ab}
		Gilts	14.00 ± 1.17^{a}	0.44 ± 0.15^{abcd}	0.40 ± 0.03^{ab}	0.03 ± 0.02^{abc}	0.11 ± 0.02^{ab}	0.01 ± 0.03^{a}
		Barrow	13.34 ± 1.05^{a}	0.38 ± 0.18^{abc}	0.38 ± 0.05^{a}	0.02 ± 0.02^{ab}	0.10 ± 0.01^{a}	0.01 ± 0.02^{a}
Significance level			p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.29: SFA, MUFA and PUFA content of subcutaneous fat of pigs from the experimental treatments (n = 12 per treatment)

Slaughter weight	Diet	Gender	SFA (%)	MUFA (%)	PUFA (%)
70	SFO	Boars	36.75 ± 1.86^{a}	43.04 ± 1.63^{bc}	20.21 ± 1.68^{de}
		Gilts	38.53 ± 2.32^{ab}	43.05 ± 1.96^{bc}	18.42 ± 1.82^{cde}
		Barrows	41.02 ± 1.78^{cd}	42.87 ± 1.16^{b}	16.11 ± 1.29^{ab}
	CLA	Boars	42.03 ± 1.28^{d}	37.36 ± 1.20^{a}	20.61 ± 1.03^{e}
		Gilts	44.85 ± 1.72^{e}	36.85 ± 1.41^{a}	18.30 ± 2.33^{bcd}
		Barrows	47.08 ± 1.59^{fg}	36.70 ± 1.28^{a}	16.22 ± 1.25^{abc}
90	SFO	Boars	38.20 ± 1.36^{ab}	44.62 ± 1.36^{bc}	17.17 ± 2.23^{abc}
		Gilts	39.13 ± 1.41^{bc}	44.93 ± 1.46^{c}	15.94 ± 1.94^{a}
		Barrows	40.01 ± 1.50^{bcd}	44.61 ± 1.49^{bc}	15.39 ± 1.78^{a}
	CLA	Boars	45.56 ± 1.82^{ef}	36.00 ± 1.18^{a}	18.45 ± 1.63^{cde}
		Gilts	46.63 ± 1.55^{efg}	37.68 ± 1.23^{a}	15.69 ± 1.30^{a}
		Barrows	48.55 ± 1.17^{g}	36.54 ± 1.42^{a}	14.91 ± 1.15^{a}
Significance level			p<0.001	p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.3: Conjugated linoleic acid content of backfat of pigs from the experimental treatments (n = 12 per treatment)

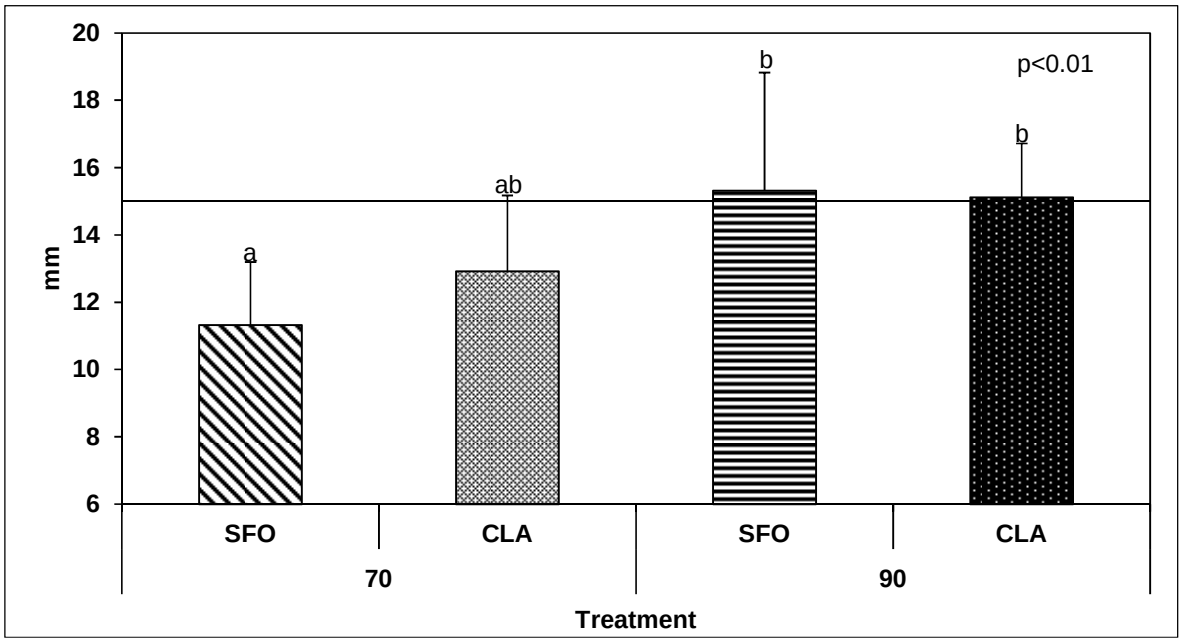
Table 4.30: Analysis of variance (ANOVA) for the physical and chemical characteristics of backfat of importance in the manufacturing of processed meat products

	Diet	Slaughter weight
Physical properties:		
Backfat thickness (mm)	NS	****
Fat Hardness	****	****
Colour *L** - Value	**	**
Colour *a** - Value	NS	***
Colour *b** - Value	NS	****
Chroma	NS	****
Hue angle	**	NS
Chemical properties:		
Extractable Fat content (%)	NS	****
Fat free dry matter (%)	NS	*
Moisture (%)	NS	****
Iodine value (IV)	****	NS
Refraction Index (RI)	***	***

NS = Not significant; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

All the physical properties, except Hue angle, were significantly influenced by slaughter weight (Table 4.30). Only IV and RI were significantly influenced by dietary treatment, whereas all the chemical properties, except IV, were significantly influenced by slaughter weight (Table 4.30).

Figure 4.4 clearly indicates that the 70 kg slaughter weight groups had lower backfat thickness compared to the 90 kg slaughter weight groups (Cisneros et al., 1996). The 70 kg SFO gilts had a significantly ($p<0.01$) lower backfat thickness, compared to the 90 kg SFO gilts and 90 kg CLA gilts. For good fat quality, Davenel et al. (1999) proposed a minimum backfat thickness of 15 mm. Only the 90 kg slaughter weight pigs conformed to this fat quality parameter. Although diet did not have a statistically significant effect on backfat thickness within the slaughter weight groups, the backfat thickness of the 70 kg CLA gilts were slightly higher, compared to the 70 kg SFO gilts. This confirmed the findings of Ramsay et al. (2001), who reported that a 0.5% inclusion of CLA resulted in an increase in backfat thickness. The opposite effect was observed in the 90 kg slaughter weight group, where the CLA supplemented gilts had a slightly lower backfat thickness than the SFO supplemented gilts. This finding is more in line with the observation of Ostrowska et al. (1999) and Bee et al. (2008), who reported that dietary CLA supplementation results in reduced backfat thickness.

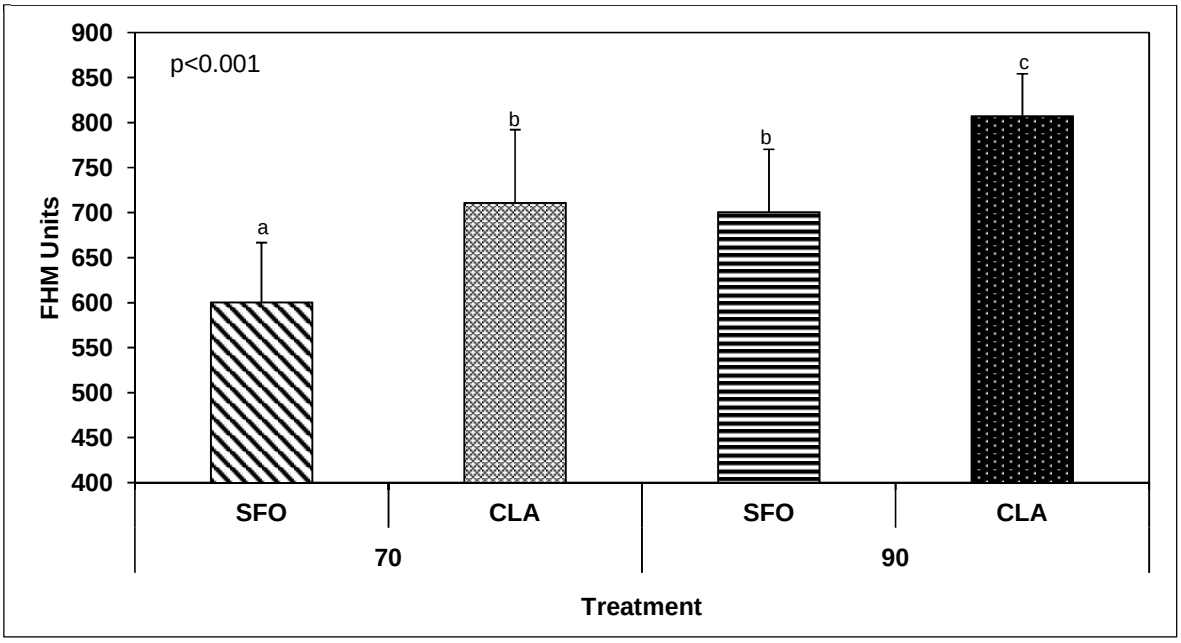


Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.4: Backfat thickness of gilts from the experimental treatment groups (n = 10 per treatment)

When backfat thickness of all SFO supplemented pigs were compared to backfat thickness of all CLA supplemented pigs, the backfat thickness of the CLA supplemented group were significantly ($p<0.01$) lower (14.31 mm for CLA vs. 15.12 mm for SFO) than the SFO supplemented groups (Table 4.11). A possible reason why the backfat thickness from the 70 kg CLA gilts increased and the 90 kg CLA gilts decreased could be that the 90 kg CLA gilts were exposed to the CLA diet for a longer period of time. The difference in CLA levels is shown in Figure 4.3.

Gilts on the CLA supplemented diet had significantly ($p<0.001$) firmer backfat, compared to the gilts on the SFO supplemented diet (Figure 4.5). This firmer backfat found in the CLA supplemented pigs could be attributed to an increase in SFA and a decrease in UFA in the backfat of the CLA supplemented pigs, as previously observed (Szymczyk, 2005; Averette Gatlin et al., 2006; Bee et al., 2008). Wood et al. (1999) stated that fat hardness is directly controlled by the fatty acid composition of the fat, thus a higher SFA content would lead to a firmer fat.



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.5: Backfat firmness of gilts from the experimental treatment groups (n = 10 per treatment)

The colour of backfat may range from nearly pure white to yellow (Wood, 1984; Hugo et al., 2007). Researchers are therefore mostly interested in the *L** and *b** measurements of backfat. Backfat from the 90 kg SFO group had significantly ($p<0.05$) higher *L** values compared to backfat from the 70 kg CLA group (Table 4.31). The *L** values of the backfat of the 90 kg slaughter weight group were generally slightly higher compared to the 70 kg slaughter weight group (Table 4.31). That means that pigs from the heavier slaughter weight group have whiter fat compared to fat from the lower slaugher weight group. As far *a** values are concerned, no dietary differences were observed between dietary treatments (Table 4.31). Redness of backfat was mostly slaughter weight related, with backfat from the 70 kg porker pigs having a significantly ($p<0.05$) higher *a** value compared to backfat from the 90 kg baconer pigs (Table 4.31). Although not statistically significant, the CLA supplemented groups had higher *a** values, compared to the SFO supplemented groups. This is in agreement with Thiel-Cooper, Sparks, Wiegand, Parrish, & Ewan (1998) and Szymczyk (2005), who reported that dietary CLA, at levels from 0-1%, may protect meat and fat colour.

Table 4.31: Physical characteristics of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Colour *L** - Value	Colour *a** - Value	Colour *b** - Value	Chroma	Hue angle
70	**SFO**	74.05 ± 2.32^{ab}	5.49 ± 1.29^{b}	7.75 ± 0.78^{b}	9.52 ± 1.33^{b}	55.13 ± 4.37^{ab}
	CLA	72.61 ± 2.02^{a}	5.54 ± 0.79^{b}	7.57 ± 0.75^{b}	9.39 ± 1.00^{b}	53.87 ± 2.49^{ab}
90	**SFO**	75.92 ± 1.58^{b}	4.22 ± 0.76^{a}	6.21 ± 0.74^{a}	7.52 ± 1.00^{a}	55.94 ± 2.71^{b}
	CLA	74.39 ± 2.44^{ab}	5.15 ± 0.78^{ab}	6.60 ± 0.75^{a}	8.38 ± 0.98^{ab}	52.10 ± 3.03^{a}
Significance Level		p<0.05	p<0.05	p<0.001	p<0.01	p<0.1

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

As far as *b** values were concerned, no dietary effects were observed (Table 4.31). Yellowness of backfat was only a function of slaughter weight. Backfat from the 90 kg baconer pigs showed significantly (p<0.001) lower *b** values than the 70 kg porker pigs. It is known that backfat from heavier pigs are more mature with a higher SFA profile compared to backfat from the lighter porker pigs which is more immature with a more unsaturated fatty acid profile and more yellow backfat (Wood et al., 1989). No dietary differences were observed for Chroma value of backfat (Table 4.31). The heavy slaughter weight groups generally had lower backfat Chroma values than the lighter slaughter weight groups. Chroma (colour intensity or saturation index) is related to the quantity of pigments and high values represent a more vivid colour and denote lack of greyness (Ripoll et al., 2011). This indicates that backfat from the heavy slaughter weight groups had a less pronounced red colour (Table 4.31). No significant slaughter weight effects were observed for backfat Hue angle value (Table 4.31). The Hue angle value of backfat of the 90 kg CLA group was significantly (p<0.1) lower, compared to the 90 kg SFO group (Table 4.31). Hue angle is the attribute of colour perception denoted by blue, green yellow, purple, etc. and is related to the state of pigments. Hue angle is a good indicator of discolouration of meat (Ripoll et al., 2011). A larger hue angle indicates a less red colour (Lee, Kim, Liang, & Song, 2003).

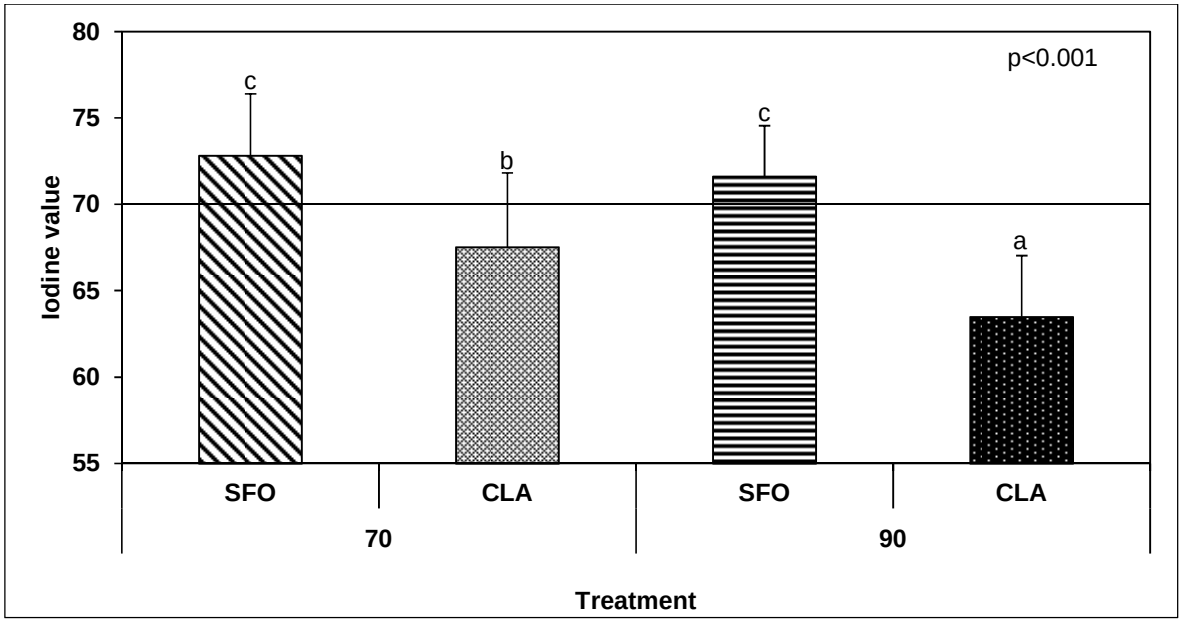
Extractable fat content of backfat of gilts were influenced by slaughter weight with backfat of the 90 kg slaughter weight group having significantly (p<0.01) higher % EFC compared to backfat from the 70 kg slaughter weight group (Table 4.32). Prabucki (1991) proposed an EFC % of at least 84% for good quality fat. None of the treatment groups conformed to the minimum % EFC requirement of more than 84% EFC. Backfat from the 90 kg baconer pigs also had significantly (p<0.05) lower moisture content, compared to backfat from the 70 kg porker pigs. Bruwer et al. (1991) also found heavier pigs to have higher extractable fat and lower moisture content.

Figure 4.6 indicates that backfat from both the 70 kg and 90 kg CLA gilts had significantly (p<0.001) lower IV, compared to backfat from the SFO supplemented gilts. Backfat of good technological quality has an IV of less than 70 (Barton-Gade, 1983). Only backfat from the CLA supplemented gilts from both weight groups conformed to this quality requirement (Figure 4.6).

Table 4.32: Chemical characteristics of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	% Extractable Fat	% FFDM	% Moisture
70	SFO	68.26 ± 8.11[a]	12.45 ± 1.74	19.30 ± 8.83[c]
	CLA	69.82 ± 5.79[a]	11.63 ± 1.35	18.55 ± 6.06[bc]
90	SFO	75.70 ± 2.38[b]	11.13 ± 1.44	13.17 ± 1.92[ab]
	CLA	76.55 ± 2.65[b]	11.17 ± 1.63	12.27 ± 2.07[a]
Significance level		p<0.01	NS	p<0.05

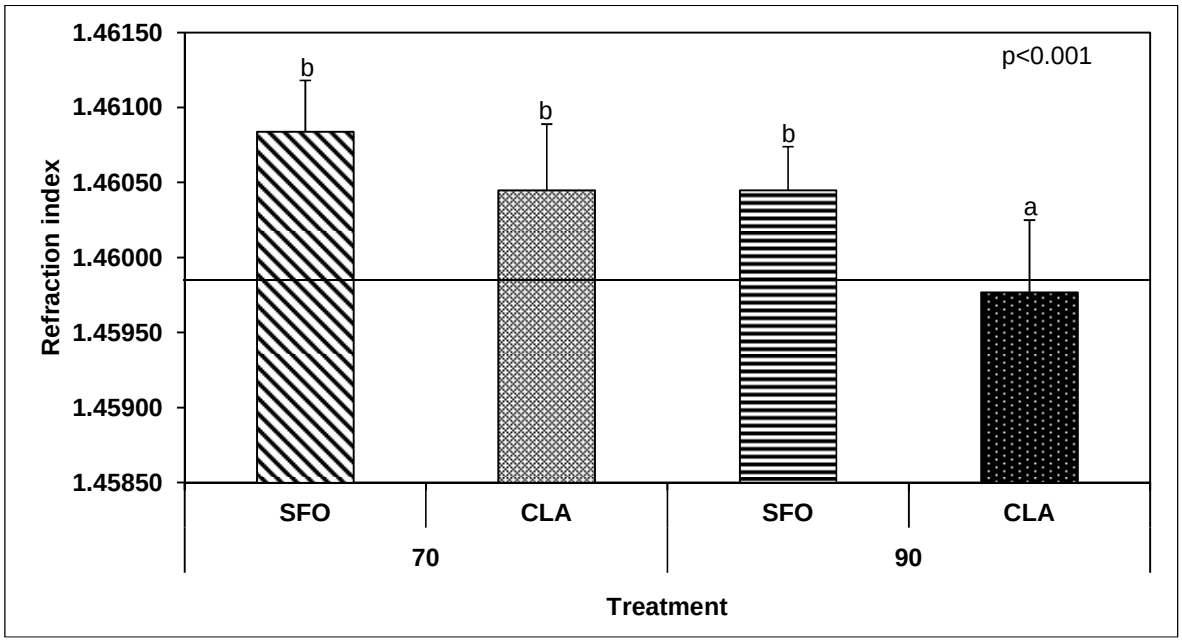
Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.6: Iodine value of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

The RI followed the same trend as IV, with backfat from the CLA supplemented gilts having lower RI compared to backfat from the SFO supplemented gilts (Figure 4.7). Backfat from the 90 kg CLA slaughter weight group had significantly (p<0.001) lower RI value, compared to backfat from the other three treatment groups. For backfat to be of good technological quality, the RI should be less than 1.4598 (Houben et al., 1983). Figure 4.7 clearly indicates that only the 90 kg CLA gilts could conform to this very strict fat quality parameter. Table 4.33 indicates that most fatty acids and fatty acid ratios were significantly influenced by dietary treatment and to a lesser extent by slaughter weight. Table 4.34 indicates that dietary CLA supplementation resulted in a significant (at least p<0.01) increase in SFA (C14:0, C15:0, C16:0, C17:0 and C18:0) content in backfat of gilts. This is in agreement with Szymczyk (2005), Averette Gatlin et al. (2006) and Bee et al. (2008), who also reported that dietary CLA increased the percentage of C14:0, C16:0 and C18:0.



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.7: Refraction index of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

For backfat of good technological properties, backfat should have a C18:0 content of more than 12% (Lizardo et al., 2002). Both the 70 kg and 90 kg CLA gilts had a C18:0 content of more than 12%, whereas none of the SFO gilts could conform to this fat quality criterion (Table 4.34).

Dietary CLA supplementation had an interesting effect on the MUFA content of backfat. According to Szymczyk (2005), dietary CLA supplementation resulted in a decrease in MUFA content. Table 4.35 indicates that backfat of the 90 kg CLA gilts had significantly ($p<0.01$) higher C16:1*c*9 content, compared to the 90 kg SFO gilts. The C18:1*t*9 was also significantly ($p<0.001$) higher for both the 70 kg and 90 kg CLA supplemented gilts, compared to the 70 kg and 90 kg SFO gilts. On the contrary, C18:1*c*9 and C18:1*c*7 contents were significantly ($p<0.001$) decreased by dietary CLA supplementation (Table 4.35). This decreased amount of C18:1*c*9 and C18:1*c*7 is in line with the findings of Szymczyk (2005).

Most PUFA (C18:2*c*9,12; C20:2*c*11,14; C20:3*c*11,14,17; C20:4*c*5,8,11,14) were significantly (at least $p<0.05$) lower in backfat of CLA supplemented gilts compared to backfat of SFO supplemented gilts (Tables 4.33 and 4.36). This decrease in PUFA content is in agreement with the findings of Szymczyk (2005), Averette Gatlin et al. (2006) and Bee et al. (2008), who reported that a significant increase in SFA content, as a result of CLA supplementation, will result in a significant decrease in PUFA content. For good fat quality the C18:2 content of backfat should be between 12-15% (Lizardo et al., 2002). Only backfat from the 90 kg CLA gilts with a C18:2 content of 14.12% conformed to this fat quality parameter (Table 4.36). Dietary CLA supplementation resulted in elevated CLA levels in backfat (Table 4.36).

Fatty acid changes in backfat due to dietary CLA supplementation also had an influence on

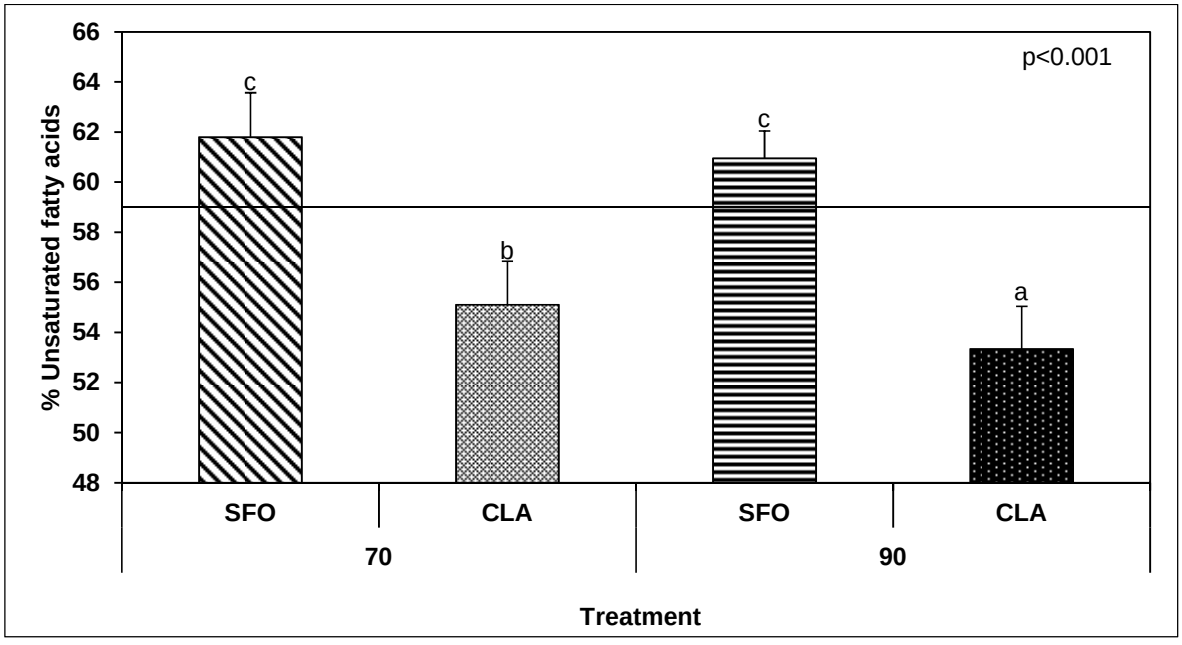
Table 4.33: Analysis of variance (ANOVA) on the fatty acid composition and fatty acid ratios for the effect of dietary treatment and slaughter weight

	Diet	**Slaughter weight**
FAME (% of total fatty acids)		
C14:0	****	NS
C15:0	****	NS
C16:0	****	NS
C16:1*c*9	****	NS
C17:0	****	NS
C18:0	****	NS
C18:1*t*9	****	NS
C18:1*c*9	****	NS
C18:1*c*7	****	NS
C18:2*c*9,12(*n*-6)	NS	****
C18:2c9,t11(*n*-6)(CLA)	****	NS
C18:2*t*10,*c*12(*n*-6)(CLA)	****	NS
C18:3*c*9,12,15(*n*-3)	NS	**
C20:0	NS	**
C20:1*c*11	NS	NS
C20:2*c*11,14(*n*-6)	****	NS
C20:3*c*11,14,17(*n*-3)	***	NS
C20:4*c*5,8,11,14(*n*-6)	***	*
C22:6*c*4,7,10(*n*-3)	*	**
Fatty acid ratios:		
MUFA (%)	****	NS
Dienoic (%)	NS	****
Trienoic (%)	NS	**
Tetraenoic (%)	***	*
Hexaenoic (%)	*	**
C16:0 + C18:0 (%)	****	NS
C16:1 + C18:1/C16:0 + C18:0	****	NS
C18:0/C18:2	****	***
C18:2/C18:1	****	***
C16:0/C18:2	***	***
SFA (%)	****	**
UFA (%)	****	NS
MUFA/SFA	****	NS
DBI	****	**
PI	NS	****
PUFA (%)	NS	****
PUFA/SFA	****	***
$^{\Delta}$9 desaturase index	****	NS
Atherogenicity index	****	NS
n-6 (%)	NS	****
n-3 (%)	NS	***
n-6/*n*-3	NS	***

NS = Not significant; CLA = Conjugated linoleic acid; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

the fatty acid ratios with health and nutritional importance (Table 4.37). Monounsaturated fatty acids decreased, SFA increased, MUFA/SFA ratio decreased, PUFA/SFA ratio decreased and AI increased in the backfat of CLA supplemented gilts (Table 4.37). These changes can all be considered negative from a health point of view (Rhee, Davidson, Knabe, Cross, Zirpin, & Rhee, 1988; Warnants et al., 1998; Enser, 2000). Peroxidisability index (PI), PUFA, *n*-6 and *n*-3 fatty acid content as well as the *n*-6/*n*-3 ratio, were not significantly influenced by dietary CLA supplementation but were significantly (at least $p<0.05$) influenced slaughter weight (Tables 4.33 and 4.37). Heavier pigs have a more saturated fatty acid profile (Table 4.37), lower PUFA content and lower PI (Table 4.37). This results in lower *n*-6 and *n*-3 fatty acids and *n*-6/*n*-3 ratio (Table 4.37). Wood et al. (1989) found similar results for heavier pigs compared to lighter pigs.

The increase in the SFA (Table 4.37) and decrease in UFA (Figure 4.8) content of backfat of CLA supplemented pigs is in agreement with the findings of Han et al. (2011), who attributed the increase in SFA and decrease in UFA to the inhibition of $^{\Delta}9$ desaturase activity and mRNA expression of CLA. Tables 4.33 and 4.37 indicate that dietary CLA supplementation resulted in a significantly ($p<0.001$) lower $^{\Delta}9$ desaturase activity in backfat of both the 70 kg and 90 kg CLA supplementation groups compared to the corresponding SFO supplementation groups. This is in agreement with the findings of Larsen et al. (2009). Tables 4.33 and 4.37 indicate that backfat from CLA supplemented gilts had significantly ($p<0.001$) higher SFA content compared to backfat from the SFO supplemented gilts.



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.8: Unsaturated fatty acid content of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Table 4.34: Saturated fatty acid content of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C14:0	C15:0	C16:0	C17:0	C18:0	C20:0
70	SFO	1.43 ± 0.13^{a}	0.01 ± 0.02^{a}	25.71 ± 1.06^{a}	0.36 ± 0.07^{a}	10.54 ± 0.77^{a}	0.16 ± 0.02^{a}
	CLA	2.12 ± 0.25^{b}	0.05 ± 0.03^{c}	28.59 ± 1.37^{b}	0.51 ± 0.10^{b}	13.45 ± 0.66^{b}	0.16 ± 0.03^{ab}
90	SFO	1.40 ± 0.07^{a}	0.01 ± 0.02^{ab}	26.01 ± 0.54^{a}	0.37 ± 0.08^{a}	11.07 ± 0.76^{a}	0.18 ± 0.01^{b}
	CLA	2.26 ± 0.22^{b}	0.04 ± 0.04^{bc}	29.11 ± 1.11^{b}	0.51 ± 0.15^{b}	14.58 ± 1.38^{c}	0.17 ± 0.02^{ab}
Significance level		p<0.001	p<0.01	p<0.001	p<0.01	p<0.001	p<0.1

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.35: Monounsaturated fatty acid content of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C16:1*c*9	C18:1*t*9	C18:1*c*9	C18:1*c*7	C20:1*c*11
70	SFO	2.15 ± 0.20^{ab}	0.02 ± 0.01^{a}	38.27 ± 1.48^{b}	2.49 ± 0.15^{b}	0.49 ± 0.09
	CLA	2.35 ± 0.25^{b}	0.06 ± 0.02^{b}	31.85 ± 1.48^{a}	2.06 ± 0.09^{a}	0.45 ± 0.10
90	SFO	2.02 ± 0.21^{a}	0.02 ± 0.02^{a}	39.61 ± 1.51^{b}	2.52 ± 0.13^{b}	0.52 ± 0.09
	CLA	2.34 ± 0.25^{b}	0.07 ± 0.02^{b}	32.49 ± 0.89^{a}	2.16 ± 0.18^{a}	0.47 ± 0.06
Significance level		p<0.01	p<0.001	p<0.001	p<0.001	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.36: Polyunsaturated fatty acid content of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

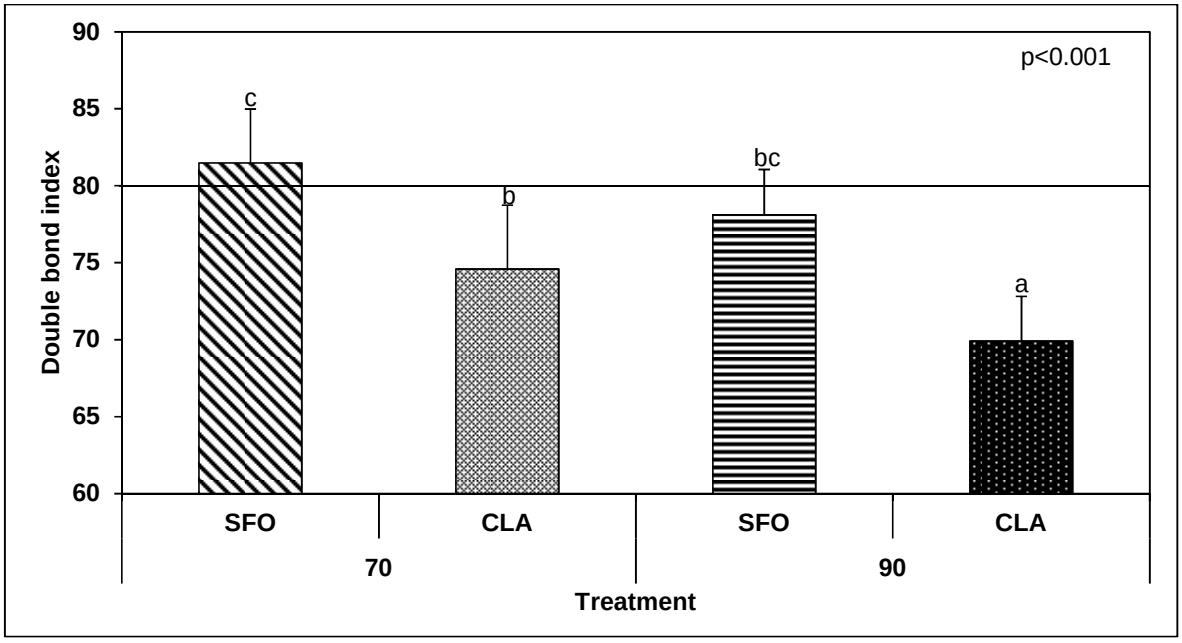
Slaughter weight	Diet	C18:2*c*9,12 (*n*-6)	C18:2*c*9,*t*11 (*n*-6)(CLA)	C18:2*t*10,*c*12 (*n*-6)(CLA)	C18:3*c*9,12,15 (*n*-3)	C20:2*c*11,14 (*n*-6)	C20:3*c*11,14,17 (*n*-3)	C20:4*c*5,8,11,14 (*n*-6)	C22:6*c*4,7,10 (*n*-3)
70	SFO	17.00 ± 1.73^{b}	0.02 ± 0.03^{a}	ND	0.57 ± 0.21^{b}	0.49 ± 0.07^{b}	0.05 ± 0.02^{b}	0.16 ± 0.03^{b}	0.09 ± 0.05^{b}
	CLA	16.52 ± 2.19^{b}	0.45 ± 0.04^{b}	0.19 ± 0.02	0.53 ± 0.29^{ab}	0.41 ± 0.05^{a}	0.03 ± 0.03^{a}	0.14 ± 0.04^{b}	0.07 ± 0.05^{b}
90	SFO	15.23 ± 1.62^{ab}	0.01 ± 0.02^{a}	ND	0.28 ± 0.25^{a}	0.49 ± 0.02^{b}	0.05 ± 0.02^{b}	0.16 ± 0.02^{b}	0.06 ± 0.05^{ab}
	CLA	14.12 ± 1.06^{a}	0.52 ± 0.03^{c}	0.20 ± 0.02	0.43 ± 0.16^{ab}	0.40 ± 0.04^{a}	0.03 ± 0.02^{a}	0.11 ± 0.02^{a}	0.02 ± 0.04^{a}
Significance level		p<0.01	p<0.001	NS	p<0.05	p<0.001	p<0.05	p<0.01	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Backfat with a more saturated fatty acid profile will usually have better technological properties compared to backfat with a more unsaturated fatty acid profile (Gandemer, 2002).

For fat of good quality, backfat should have a SFA content of more than 41% (Häuser et al., 1991). Backfat from both the 70 kg and 90 kg CLA supplementation groups conformed to this fat quality parameter (Table 4.37). According to Prabucki (1991), good quality backfat should have a total UFA content of less than 59%. Backfat from both the CLA supplementation groups conformed to this requirement, while backfat from both SFO supplementation groups had a total UFA content of more than 59% (Figure 4.8).

Monounsaturated fatty acid content should be less than 57% for good fat quality (Lizardo et al., 2002). All the treatment groups conformed to this quality parameter. The CLA supplementation groups had even lower MUFA content compared to the SFO supplementation groups (Table 4.37). Polyunsaturated fatty acid content should be less than 15% for good fat quality fat (Houben et al., 1983). None of the treatment groups could conform to this fat quality parameter (Table 4.37). Good quality backfat should have a DBI of less than 80 (Prabucki, 1991). All the treatment groups, except the 70 kg SFO gilts, could conform to this fat quality requirement (Figure 4.9). The DBI value of backfat of both the CLA supplementation group were lower (better fat quality than those of the SFO supplementation groups) (Figure 4.9).



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.9: Double bond index of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

The C16:0 + C18:0 and C16:0/C18:2 fatty acid ratios were positively correlated with fat firmness (Lea et al., 1970; Cameron et al., 1990; Enser, 1984). According to Table 4.38 backfat

from both the CLA supplementation groups had significantly ($p<0.001$) higher ratios for C16:0 + C18:0 compared to the SFO supplementation groups. The C16:0/C18:2 ratio was only significantly ($p<0.01$) higher for backfat from the 90 kg CLA supplementation compared to backfat from the 90 kg SFO group The ratio of C16:1 + C18:1/C16:0 + C18:0 is not correlated to carcass mass but is also used as an indicator of fat firmness (Cameron et al., 1990). Backfat from both the CLA supplementation groups had a significantly ($p<0.001$) lower C16:1 + C18:1/C16:0 + C18:0 ratio compared to backfat from the SFO supplemented group (Table 4.38). Good quality, backfat should have a dienoic fatty acid content of less than 10%, a trienoic fatty acid content of less than 1%, a tetraenoic fatty acid content of less than 0.5% and pentaenoic + hexaenoic fatty acid content of less than 1% (Häuser et al., 1991). All of the treatment groups had a dienoic fatty acid content of more than 10%, an trienoic content of less than 1%, an tetraenoic content of less than 0.5% and a pentaenoic + hexaenoic content of less than 1% (Table 4.38).

These fat quality parameters supported the findings of Figure 4.5 that backfat from the CLA supplementation groups were firmer and therefore of better quality compared to backfat from the SFO supplemented groups. Normally the improvement of the health properties of backfat is accompanied with deterioration in the technological quality of backfat (Hugo et al., 2007). In this case a contradiction is observed in the backfat of pigs with elevated CLA levels. Although CLA is a PUFA, which results in an improvement of the health properties of fat, the backfat of CLA supplemented pigs also demonstrated improved technological properties (Table 4.38).

According to Table 4.39 the actual CLA content of backfat was significantly ($p<0.001$) influenced by dietary treatment. The CLA supplemented pigs were expected to have a higher CLA content compared to the SFO supplemented pigs. Slaughter weight had a significant ($p<0.05$) effect on total CLA content and recommended daily allowance (RDA) (Table 4.39). The actual CLA levels of backfat in gilts are shown in Figure 4.10. The C18:2*c*9,*t*11 content ranged between ± 550 mg/100 g backfat for the 70 kg CLA group and ± 650 mg/100 g backfat for the 90 kg CLA group. The C18:2*t*10*c*12 isomer was deposited at the much lower levels of ± 200 mg/100 g CLA in backfat than the C18:2*c*9,*t*11 isomer (Figure 4.10). The total amount of CLA in backfat (Table 4.40) followed the same trend as the individual CLA isomers (Figure 4.10).

Table 4.40 clearly indicates that the total CLA content was significantly ($p<0.001$) higher for the CLA supplemented groups. The 90 kg CLA supplemented group had the highest total amount of CLA per 100 g backfat, followed by the 70 kg CLA supplemented group. This was also observed for the individual isomers (Figure 4.10). According to Crumb (2011), the RDA for CLA is 3.5 g per day. A 100 g backfat portion of the 90 kg CLA supplemented group could supply a significantly higher percentage of the RDA for CLA than a similar portion from the 70 kg CLA group (Table 4.40).

Table 4.37: Fatty acid ratios with health and nutritional importance of backfat of gilts from the experiental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	MUFA (%)	SFA (%)	MUFA/SFA	PI	PUFA (%)	$^{\Delta}$9 desaturase index	Atherogenicity Index	PUFA/SFA	*n*-6 (%)	*n*-3 (%)	*n*-6/*n*-3
70	SFO	43.42 ± 1.65^{b}	38.20 ± 1.77^{a}	1.14 ± 0.08^{b}	21.19 ± 2.35^{c}	18.38 ± 1.91^{b}	3.89 ± 0.36^{b}	0.51 ± 0.04^{a}	0.48 ± 0.07^{c}	17.67 ± 1.76^{b}	0.71 ± 0.26^{b}	45.40 ± 70.73^{a}
	CLA	36.77 ± 1.52^{a}	44.89 ± 1.74^{b}	0.82 ± 0.05^{a}	20.74 ± 2.83^{bc}	18.34 ± 2.36^{b}	2.53 ± 0.11^{a}	0.67 ± 0.06^{b}	0.41 ± 0.07^{b}	17.71 ± 2.26^{b}	0.63 ± 0.33^{ab}	69.36 ± 98.07^{a}
90	SFO	44.69 ± 1.45^{b}	39.04 ± 1.09^{a}	1.15 ± 0.05^{b}	18.59 ± 2.26^{ab}	16.27 ± 1.83^{a}	3.82 ± 0.28^{b}	0.52 ± 0.02^{a}	0.42 ± 0.06^{b}	15.88 ± 1.66^{ab}	0.39 ± 0.27^{a}	103.17 ± 116.98^{b}
	CLA	37.52 ± 1.03^{a}	46.66 ± 1.71^{c}	0.81 ± 0.05^{a}	17.66 ± 1.44^{a}	15.82 ± 1.18^{a}	2.41 ± 0.31^{a}	0.72 ± 0.05^{b}	0.34 ± 0.04^{a}	15.34 ± 1.12^{a}	0.48 ± 0.17^{ab}	60.27 ± 97.83^{ab}
Significance level		p<0.001	p<0.001	p<0.001	p<0.01	p<0.01	p<0.001	p<0.001	p<0.001	p<0.01	p<0.05	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.38: Fatty acid ratios of technological importance of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

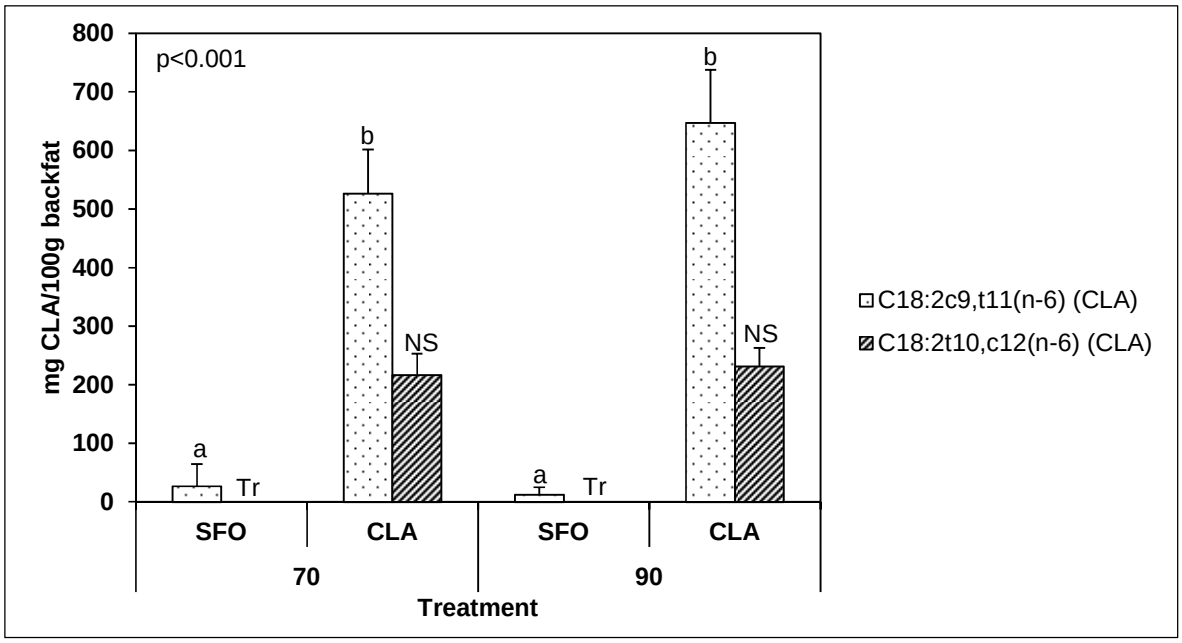
Slaughter weight	Diet	Dienoic (%)	Trienoic (%)	Tetraenoic (%)	Hexaenoic (%)	Penta + Hexaenoic (%)	C16:0 + C18:0 (%)	C16:1 + C18:1/ C16:0 + C18:0	C18:0/C18:2	C16:0/C18:2	C18:2/C18:1
70	SFO	17.51 ± 1.74^{bc}	0.62 ± 0.21^{b}	0.16 ± 0.03^{b}	0.09 ± 0.05^{b}	0.09 ± 0.05^{b}	36.24 ± 1.66^{a}	1.19 ± 0.08^{b}	0.63 ± 0.09^{a}	1.53 ± 0.18^{a}	0.42 ± 0.05^{ab}
	CLA	17.57 ± 2.23^{c}	0.56 ± 0.31^{ab}	0.14 ± 0.04^{b}	0.07 ± 0.05^{ab}	0.07 ± 0.05^{ab}	42.05 ± 1.64^{b}	0.86 ± 0.05^{a}	0.80 ± 0.13^{b}	1.70 ± 0.27^{a}	0.51 ± 0.08^{c}
90	SFO	15.73 ± 1.64^{ab}	0.33 ± 0.25^{a}	0.16 ± 0.02^{b}	0.06 ± 0.05^{ab}	0.06 ± 0.05^{ab}	37.08 ± 1.03^{a}	1.19 ± 0.05^{b}	0.74 ± 0.12^{ab}	1.73 ± 0.20^{a}	0.36 ± 0.05^{a}
	CLA	15.23 ± 1.11^{a}	0.46 ± 0.16^{ab}	0.11 ± 0.02^{a}	0.02 ± 0.04^{a}	0.02 ± 0.04^{a}	43.69 ± 1.67^{c}	0.85 ± 0.05^{a}	0.99 ± 0.13^{c}	1.98 ± 0.20^{b}	0.43 ± 0.03^{b}
Significance level		p<0.01	p<0.1	p<0.01	p<0.05	p<0.05	p<0.001	p<0.001	p<0.01	p<0.01	p<0.001

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.39: Analysis of variance (ANOVA) on the actual CLA content of backfat for the effect of dietary treatment and slaughter weight

	Diet	Slaughter weight
Actual CLA content:		
C18:2*c*9,*t*11(*n*-6)CLA (mg/100 g)	****	NS
C18:2*t*10,*c*12(*n*-6)CLA (mg/100 g)	****	NS
mg total conjugated linoleic acid (CLA) (mg/100 g)	****	**
% of RDA of 100 g portion	****	**

NS = Not significant; CLA = Conjugated linoleic acid; RDA = Recommended daily allowance;* = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001



Bars with different superscripts differ significantly; NS = Not significant; Tr = Trace amounts; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.10: Actual CLA content of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Table 4.40: Actual CLA content of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	mg Total CLA (mg/100 g backfat)	% of RDA of 100 g portion
70	**SFO**	26.70 ± 37.88^{a}	0.76 ± 1.08^{a}
	CLA	743.38 ± 108.01^{b}	21.24 ± 3.09^{b}
90	**SFO**	12.33 ± 26.00^{a}	0.35 ± 0.74^{a}
	CLA	878.64 ± 119.61^{c}	25.10 ± 3.42^{c}
Significance level		p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.41 gives the fatty acid profile of the different lipid fractions of backfat. Table 4.41

indicates that C18:2*c*9,12 was deposited at a significantly (p<0.001) higher proportion in the phospholipid fraction compared to the neutral lipid fraction of backfat. Wood et al. (2008) also found that C18:2*c*9,12 is deposited at a much higher concentration in the phospholipid fraction, compared to the neutral- and glycolipid fraction. According to Table 4.41, both CLA isomers (*cis*-9, *trans*-11 and *trans*-10, *cis*-12) were preferentially deposited in the neutral- and glycolipid fractions. As expected, backfat from the 90 kg group contained the highest amount of both CLA isomers (*cis*-9, *trans*-11 and *trans*-10, *cis*-12) in the neutral- and glycolipid fractions (Table 4.41). The neutral lipid fraction contained significantly (p<0.001) higher amounts of both CLA isomers (*cis*-9, *trans*-11 and *trans*-10, *cis*-12) (Table 4.41). From Table 4.41 and Figure 4.10 it can be concluded that the *cis*-9, *trans*-11 CLA isomer is the main CLA isomer found in food, as Lo Fiego et al. (2005a) proposed.

Table 4.41: Content of different isomers of C18:2 (%) in the neutral-, glycol- and phospholipid fractions of backfat of CLA supplemented gilts of 70 kg and 90 kg slaughter weight (n = 10 per treatment)

Lipid Fraction	Slaughter Weight	C18:2c9,12 (n-6)	C18:2c9,t11(n-6) (CLA)	C18:2t10,c12(n-6) (CLA)	Total CLA
Neutral Lipid	**70**	16.37 ± 2.25^{a}	0.45 ± 0.05^{c}	0.18 ± 0.03^{bc}	0.63 ± 0.07^{c}
	90	14.06 ± 1.01^{a}	0.51 ± 0.03^{d}	0.21 ± 0.02^{c}	0.72 ± 0.05^{d}
Glycolipid	**70**	15.63 ± 2.21^{a}	0.39 ± 0.05^{b}	0.14 ± 0.06^{b}	0.52 ± 0.10^{b}
	90	13.71 ± 1.22^{a}	0.40 ± 0.06^{b}	0.16 ± 0.04^{b}	0.56 ± 0.09^{bc}
Phospholipid	**70**	21.15 ± 2.94^{b}	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}
	90	15.58 ± 4.07^{a}	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}
Significance level		p<0.001	p<0.001	p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid

4.5. Belly fat quality

4.5.1. Physical and chemical properties of belly fat of gilts from all treatment groups

Table 4.42 indicates that the physical properties [(fat hardness and colour (*a**, Hue angle)] and chemical properties (IV and RI) of belly fat were significantly (at least p<0.1) influenced by dietary treatment. Slaughter weight had a statistically significant (at least p<0.1) effect on physical [fat hardness, colour (*L**, *b**, Chroma)] and chemical (% EFC, % moisture, IV and RI) properties of belly fat. Belly fat hardness (Figure 4.11) followed the same trend as backfat hardness (Figure 4.5). Bellies from the CLA supplemented groups were significantly (p<0.001) firmer compared to bellies from the SFO supplemented groups while bellies from the 90 kg CLA slaughter weight group were significantly (p<0.001) firmer compared to bellies from the 70 kg CLA slaughter weight group (Figure 4.11). This is a very important finding, since bellies are used in bacon manufacturing. The use of soft fat may lead to separation between muscle and fat layers of bacon. The use of soft fat in bacon manufacturing will therefore lead to losses during slicing (Dugan et al., 1999; Eggert et al., 1999; Eggert et al., 2001; Wiegand et al., 2001 and Joo et al., 2002). Conjugated linoleic acid

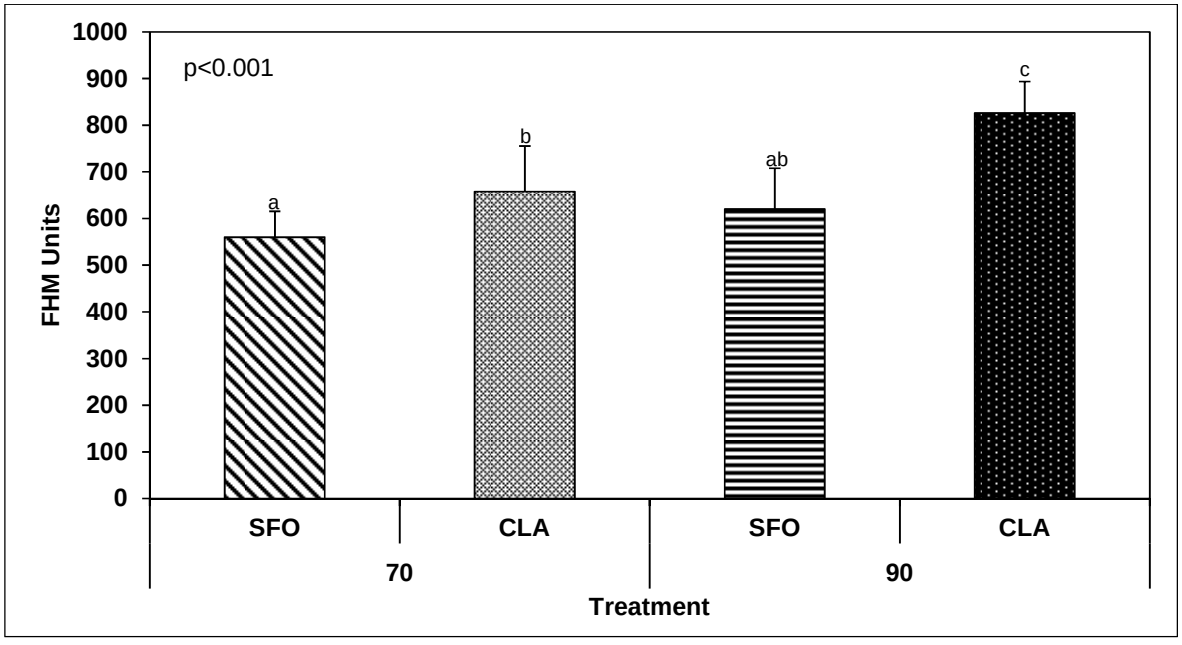
Table 4.42: Analysis of variance (ANOVA) on the physical and chemical characteristics of belly fat of importance in the manufacturing of processed meat products

	Diet	Slaughter weight
Physical properties:		
Fat Hardness	****	****
Colour *L** - Value	NS	**
Colour *a** - Value	*	NS
Colour *b** - Value	NS	****
Chroma	NS	***
Hue angle	*	NS
Chemical properties:		
Extractable Fat (%)	NS	****
Fat free dry matter (%)	NS	NS
Moisture (%)	NS	****
Iodine value (IV)	****	*
Refraction Index (RI)	****	***

NS = Not significant; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

supplementation may, therefore, result in more profitable bacon production.

Table 4.43 indicates that treatment had no effect on belly fat colour *L**, colour *a** and Hue angle values, but colour *b**-value and Chroma were significantly (p<0.01) influenced by slaughter weight. Similar to backfat (Table 4.31), the belly fat of the 70 kg slaughter weight groups had significantly (p<0.01) higher *b** values compared to the belly fat of the 90 kg slaughter weight group (Table 4.43).



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.11: Belly fat firmness of gilts from the experimental treatment groups (n = 10 per treatment)

Table 4.43: Physical properties of belly fat from gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Colour *L** - Value	Colour *a** - Value	Colour *b** - Value	Chroma	Hue angle
70	SFO	72.64 ± 2.02	4.89 ± 1.15	6.94 ± 0.56^{b}	8.52 ± 1.08^{b}	55.27 ± 4.58
	CLA	72.01 ± 2.10	5.11 ± 0.75	7.03 ± 0.70^{b}	8.69 ± 0.95^{b}	54.09 ± 2.30
90	SFO	74.13 ± 2.18	4.20 ± 0.79	5.87 ± 0.76^{a}	7.23 ± 1.01^{a}	54.54 ± 3.09
	CLA	73.92 ± 2.50	4.93 ± 0.65	6.24 ± 0.61^{ab}	7.96 ± 0.77^{ab}	51.77 ± 3.24
Significance level		NS	NS	p<0.01	p<0.01	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

A lower *b** value (whiter fat) could be as a result of a more saturated fatty acid profile of heavier pigs (Wood et al., 1989). Chroma values were also significantly (p<0.01) higher for belly fat from the 70 kg slaughter weight group compared to the 90 kg slaughter weight group. Chroma is related to the quantity of pigments and high values represent a more vivid colour, and denote lack of greyness (Ripoll et al., 2011). This indicates that belly fat from the 70 kg slaughter weight group had a more pronounced red colour (Table 4.43).

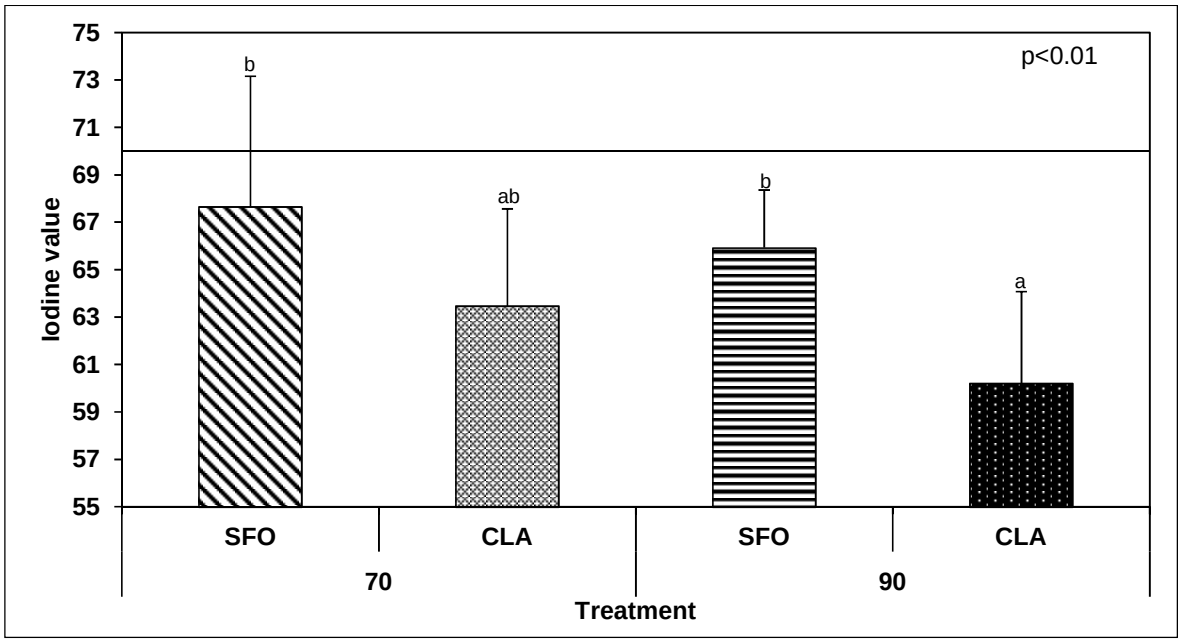
Table 4.44 indicates that the % EFC and moisture content of belly fat were significantly influenced by slaughter weight (p<0.001). This is in agreement with the findings of Bruwer et al. (1991), who found that fat tissue from heavier pigs contained more lipid and less moisture than fat tissue from lighter pigs. Belly fat has to comply with the same quality parameters as backfat (Häuser et al., 1990). Good technological quality fat should have an EFC % higher than 84% Prabucki (1991). None of the treatment groups could conform to this quality parameter (Table 4.44).

Table 4.44: Chemical properties of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	% Extractable Fat	% FFDM	% Moisture
70	SFO	63.38 ± 4.82^{a}	8.84 ± 1.71	27.78 ± 4.41^{b}
	CLA	63.62 ± 7.75^{a}	9.28 ± 1.65	27.10 ± 7.27^{b}
90	SFO	73.29 ± 4.73^{b}	7.91 ± 2.04	18.79 ± 4.18^{a}
	CLA	72.62 ± 3.20^{b}	8.52 ± 1.90	18.86 ± 2.59^{a}
Significance level		p<0.001	NS	p<0.001

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

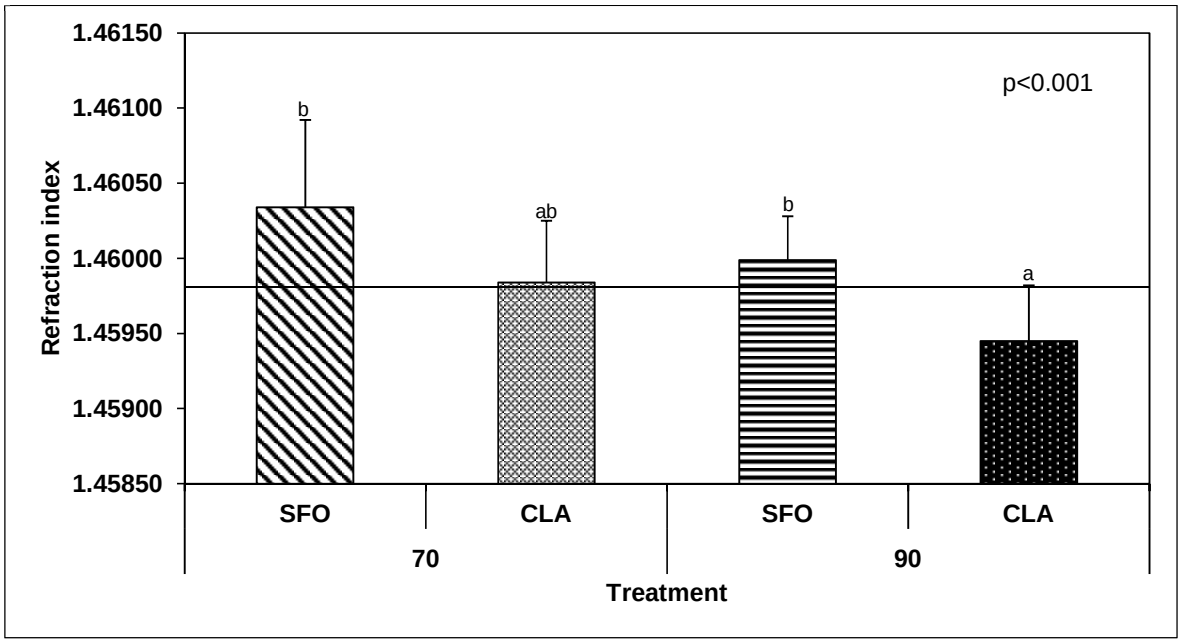
For good quality belly fat, Barton-Gade (1983) proposed an IV of less than 70 and Houben et al. (1983) proposed an RI of less than 1.4598. From Figure 4.12 it is clear that belly fat from all the treatment groups had an IV of less than 70. The belly fat from the CLA supplemented groups had lower IV compared to the belly fat from the SFO supplemented groups and in the case of the 90 kg slaughter weight groups this difference was significant (p<0.01). From Figure 4.13 it is evident that



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.12: Iodine value of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

the CLA supplemented gilts had a lower RI compared to the SFO gilts for both the 70 kg and 90 kg slaughter weight groups and in the case of the 90 kg slaughter weight group the difference was significant (p<0.01).



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.13: Refraction index of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Only the 90 kg CLA gilts had a RI value of less than 1.4598 proposed by Houben et al. (1983) as the maximum value for good fat quality.

4.5.2. Belly fatty acid composition

Most of the fatty acids and fatty acid ratios of belly fat were significantly (at least $p<0.1$) influenced by dietary treatment and many were significantly (at least $p<0.1$) influenced by slaughter weight (Table 4.45). Table 4.46 indicates the actual CLA content was significantly influenced by dietary treatment ($p<0.001$) and slaughter weight ($p<0.001$). The main SFA (C14:0, C16:0 and C18:0), MUFA (C16:1*c*9, C18:1*t*9, C18:1*c*9, C18:1*c*7 and C20:1) and PUFA (C18:2*c*9,*t*11; C18:2*t*10,*c*12; C20:2 and C20:4) of belly fat were significantly (at least $p<0.05$) influenced by dietary treatment (Table 4.47 – 4.49). Other authors, namely Szymczyk, (2005), Averette Gatlin et al. (2006) and Bee et al. (2008), found similar results.

The CLA supplemented groups had significantly ($p<0.001$) higher amounts of SFA and lower amounts of MUFA (Table 4.50). As in backfat (Table 4.37), the increased SFA content and decreased PUFA content in belly fat (Table 4.50) can be attributed to the inhibition of $^{\Delta}9$ desaturase activity and mRNA expression by CLA (Han et al., 2011). Dietary CLA supplementation can be considered important from a health and nutritional point of view. Table 4.50 and Figure 4.14 indicate that dietary CLA supplementation resulted in a significant decreases in MUFA ($p<0.001$), MUFA/SFA ($p<0.001$), UFA ($p<0.001$), $^{\Delta}9$ desaturase ($p<0.001$) and PUFA/SFA ($p<0.05$). A significant increase in SFA ($p<0.001$), and AI ($p<0.001$) was observed in the belly fat of the CLA supplemented groups. These changes can all be considered negative from a health point of view (Rhee et al., 1988; Warnants et al., 1998; Enser, 2000). The *n*-3 fatty acid content ($p<0.01$) and *n*-6/*n*-3 ratio of belly fat was significantly ($p<0.001$) influenced only by slaughter weight. Belly fat from the 70 kg CLA gilts had a significantly ($p<0.01$) higher *n*-3 fatty acid content compared to the 90 kg SFO and CLA gilts. Belly fat from the 70 kg slaughter weight groups had a significantly ($p<0.001$) lower *n*-6/*n*-3 ratio compared to the 90 kg slaughter weight gilts (Table 4.50). Wood et al. (1989) observed a similar effect on the *n*-6/*n*-3 ratio between different slaughter weight groups. Peroxidisability index, PUFA content, *n*-6 fatty acid content was not significantly influenced by either dietary treatment or slaughter weight (Table 4.50). According to Gandermer (2002), fat with a more saturated fatty acid profile will have better technological properties. That is the reason why backfat (Table 4.37) and belly fat (Table 4.50) of pigs from the CLA supplemented groups should have better technological properties.

Improvement of the technological properties of fat resulted in deterioration in the health properties. As in the case of backfat (Table 4.37), a contradiction is observed in the belly fat of pigs with elevated CLA levels (Table 4.49). Although CLA is a PUFA, that results in an improvement of the health properties of fat, the belly fat of CLA supplemented pigs also demonstrated improved technological properties (Table 4.51). For good fat quality, belly fat should have a C18:0 content of more than 12% (Lizardo et al., 2002).

Table 4.45: Analysis of variance (ANOVA) on fatty acid composition and fatty acid ratios for the effect of dietary treatment and slaughter weight

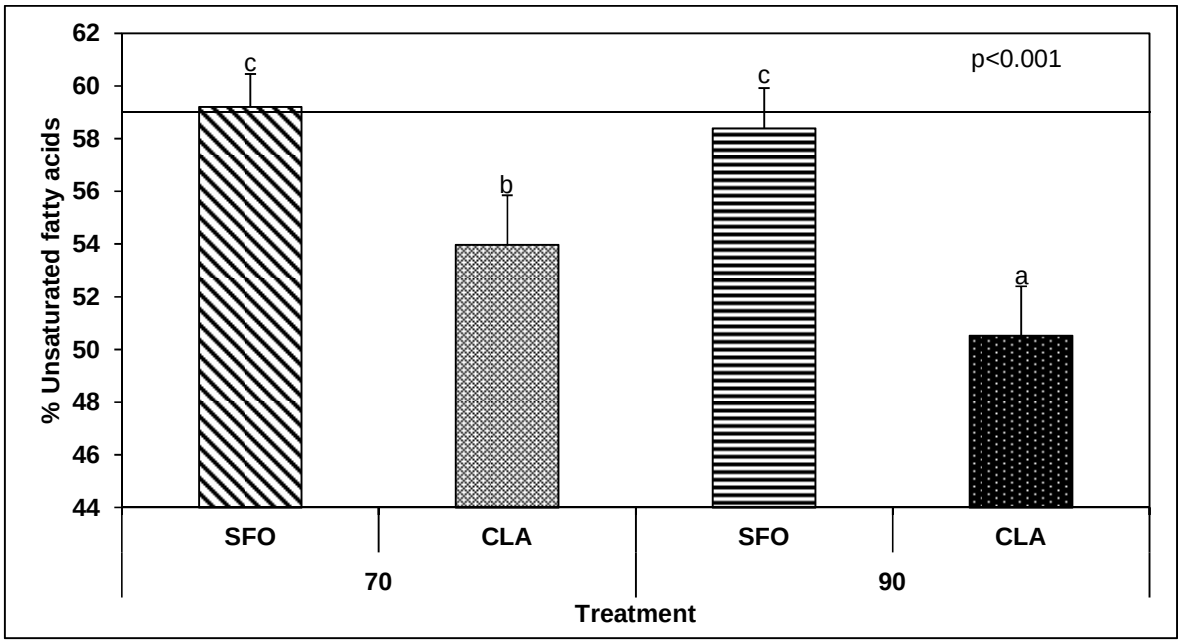
	Diet	**Slaughter weight**
FAME (% of total fatty acids)		
C14:0	****	NS
C15:0	*	NS
C16:0	****	NS
C16:1*c*9	****	****
C17:0	***	NS
C18:0	****	****
C18:1*t*9	****	NS
C18:1*c*9	****	NS
C18:1*c*7	****	****
C18:2*c*9,12(*n*-6)	NS	NS
C18:2*c*9,*t*11(*n*-6)(CLA)	****	****
C18:2*t*10,*c*12(*n*-6)(CLA)	****	***
C18:3*c*9,12,15(*n*-3)	*	****
C20:0	*	NS
C20:1*c*11	***	NS
C20:2*c*11,14(*n*-6)	****	NS
C20:3c11,14,17(*n*-3)	NS	NS
C20:4*c*5,8,11,14(*n*-6)	***	***
C22:6*c*4,7,10(*n*-3)	NS	NS
Fatty acid ratios:		
MUFA (%)	****	***
Dienoic (%)	NS	NS
Trienoic (%)	NS	****
Tetraenoic (%)	***	***
Hexaenoic (%)	NS	NS
C16:0 + C18:0 (%)	****	****
C16:1 + C18:1/C16:0 + C18:0	****	****
C18:0/C18:2	***	***
C16:0/C18:2	**	NS
C18:2/C18:1	****	NS
SFA (%)	****	****
UFA (%)	****	****
MUFA/SFA	****	****
DBI	****	***
PI	NS	NS
PUFA (%)	NS	NS
$^{\Delta}$9 desaturase index	****	****
Atherogenicity Index	****	***
PUFA/SFA	***	*
n-6 (%)	NS	NS
n-3 (%)	NS	****
n-6/*n*-3	NS	****

NS = Not significant; CLA = Conjugated linoleic acid; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

Table 4.46: Analysis of variance (ANOVA) on the actual CLA content of belly fat for the effect of dietary treatment and slaughter weight

	Diet	Slaughter weight
Actual CLA) content:		
C18:2c9,t11(n-6)CLA (mg/100 g)	****	****
C18:2t10,c12(n-6) CLA (mg/100 g)	****	****
mg total conjugated linoleic acid (CLA) (mg/100 g)	****	****
% of RDA of 100 g portion	****	****

NS = Not significant; CLA = Conjugated linoleic acid; RDA = Recommended daily allowance; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.14: Unsaturated fatty acid of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Both the 70 kg and 90 kg CLA supplemented groups conformed to this criterion, whereas none of the SFO slaughter weight groups could conform to this quality parameter (Table 4.47). Enser (1983) reported that the C18:2 content of fat should be less than 15% when bellies are used for the manufacturing of good quality bacon. All treatment groups conformed to this quality parameter (Table 4.49). According to Enser (1983) the C18:0/C18:2 ratio should be less than 1.47 for the manufacturing of good quality bacon. All treatment groups conformed to this quality criterion (Table 4.51).

For good fat quality, belly fat should have a SFA content of more than 41% (Häuser et al., 1990). All the treatment groups except the 70 kg SFO supplemented group had more than 41% SFA (Table 4.50).

Table 4.47: Saturated fatty acid content of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C14:0	C15:0	C16:0	C17:0	C18:0	C20:0
70	SFO	1.61 ± 0.10^{a}	0.01 ± 0.01	28.21 ± 0.77^{a}	0.26 ± 0.05^{a}	10.52 ± 0.92^{a}	0.12 ± 0.02
	CLA	2.42 ± =0.20^{b}	0.01 ± 0.02	31.12 ± 1.21^{b}	0.35 ± 0.10^{ab}	12.11 ± 0.83^{b}	0.12 ± 0.02
90	SFO	1.60 ± 0.13^{a}	0.01 ± 0.01	28.11 ± 0.95^{a}	0.31 ± 0.10^{ab}	11.36 ± 1.13^{ab}	0.14 ± 0.02
	CLA	2.61 ± 0.23^{b}	0.01 ± 0.02	32.21 ± 1.50^{b}	0.38 ± 0.08^{b}	14.07 ± 1.14^{c}	0.12 ± 0.01
Significance Level		p<0.001	NS	p<0.001	p<0.05	p<0.001	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.48: Monounsaturated fatty acid of belly fat from gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C16:1*c*9	C18:1*t*9	C18:1*c*9	C18:1*c*7	C20:1*c*11
70	SFO	2.87 ± 0.28^{b}	0.03 ± 0.02^{a}	38.48 ± 1.46^{c}	2.86 ± 0.13^{c}	0.44 ± 0.08^{ab}
	CLA	3.57 ± 0.38^{c}	0.05 ± 0.01^{b}	32.58 ± 1.02^{b}	2.66 ± 0.16^{b}	0.40 ± 0.11^{a}
90	SFO	2.38 ± 0.35^{a}	0.02 ± 0.02^{a}	38.97 ± 1.47^{c}	2.64 ± 0.10^{b}	0.51 ± 0.07^{b}
	CLA	3.02 ± 0.40^{b}	0.04 ± 0.01^{b}	30.86 ± 1.50^{a}	2.33 ± 0.30^{a}	0.39 ± 0.07^{a}
Significance Level		p<0.001	p<0.001	p<0.001	p<0.001	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.49: Polyunsaturated fatty acid content of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C18:2*c*9,12 (*n*-6)	C18:2*c*9,*t*11 (*n*-6)(CLA)	C18:2*t*10,*c*12 (*n*-6)(CLA)	C18:3*c*9,12,15 (*n*-3)	C20:2*c*11,14 (*n*-6)	C20:3*c*11,14,17 (*n*-3)	C20:4*c*5,8,11,14 (*n*-6)	C22:6*c*4,7,10 (*n*-3)
70	SFO	13.34 ± 1.64	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}	0.54 ± 0.07^{b}	0.35 ± 0.05^{b}	0.03 ± 0.03	0.18 ± 0.02^{b}	0.07 ± 0.04
	CLA	13.17 ± 1.68	0.31 ± 0.04^{b}	0.13 ± 0.02^{b}	0.58 ± 0.08^{b}	0.30 ± 0.04^{a}	0.03 ± 0.03	0.16 ± 0.04^{b}	0.05 ± 0.06
90	SFO	12.85 ± 1.65	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}	0.41 ± 0.06^{a}	0.37 ± 0.02^{b}	0.03 ± 0.02	0.16 ± 0.03^{b}	0.06 ± 0.05
	CLA	12.35 ± 1.77	0.44 ± 0.06^{c}	0.16 ± 0.03^{c}	0.45 ± 0.07^{a}	0.30 ± 0.04^{a}	0.02 ± 0.02	0.12 ± 0.03^{a}	0.04 ± 0.05
Significance level		NS	p<0.001	p<0.001	p<0.001	p<0.01	NS	p<0.001	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.50: Fatty acid ratios with health and nutritional importance of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	MUFA (%)	SFA (%)	MUFA/SFA	Peroxidizability index	PUFA (%)	$^{\Delta}$9 desaturase index	Atherogenicity Index	PUFA/SFA	*n*-6 (%)	*n*-3 (%)	*n*-6/*n*-3
70	SFO	44.69 ± 1.67^{c}	40.72 ± 1.26^{a}	1.10 ± 0.06^{c}	17.25 ± 2.05	14.52 ± 1.79	3.96 ± 0.39^{c}	0.59 ± 0.02^{a}	0.36 ± 0.05^{b}	13.87 ± 1.68	0.65 ± 0.12^{bc}	21.85 ± 2.31^{a}
	CLA	39.25 ± 1.03^{b}	46.14 ± 1.86^{b}	0.85 ± 0.05^{b}	17.15 ± 2.32	14.73 ± 1.89	2.92 ± 0.21^{b}	0.76 ± 0.06^{b}	0.32 ± 0.05^{b}	14.07 ± 1.76	0.66 ± 0.14^{c}	21.84 ± 2.89^{a}
90	SFO	44.53 ± 1.55^{c}	41.51 ± 1.61^{a}	1.07 ± 0.07^{c}	16.29 ± 2.08	13.87 ± 1.78	3.70 ± 0.44^{c}	0.59 ± 0.04^{a}	0.34 ± 0.05^{b}	13.38 ± 1.68	0.49 ± 0.12^{a}	28.05 ± 4.65^{b}
	CLA	36.65 ± 1.92^{a}	49.41 ± 1.87^{c}	0.74 ± 0.06^{a}	15.90 ± 2.35	13.88 ± 2.00	2.38 ± 0.24^{a}	0.85 ± 0.07^{c}	0.28 ± 0.05^{a}	13.37 ± 1.89	0.51 ± 0.12^{ab}	26.91 ± 3.32^{b}
Significance Level		p<0.001	p<0.001	p<0.001	NS	NS	p<0.001	p<0.001	p<0.05	NS	p<0.01	p<0.001

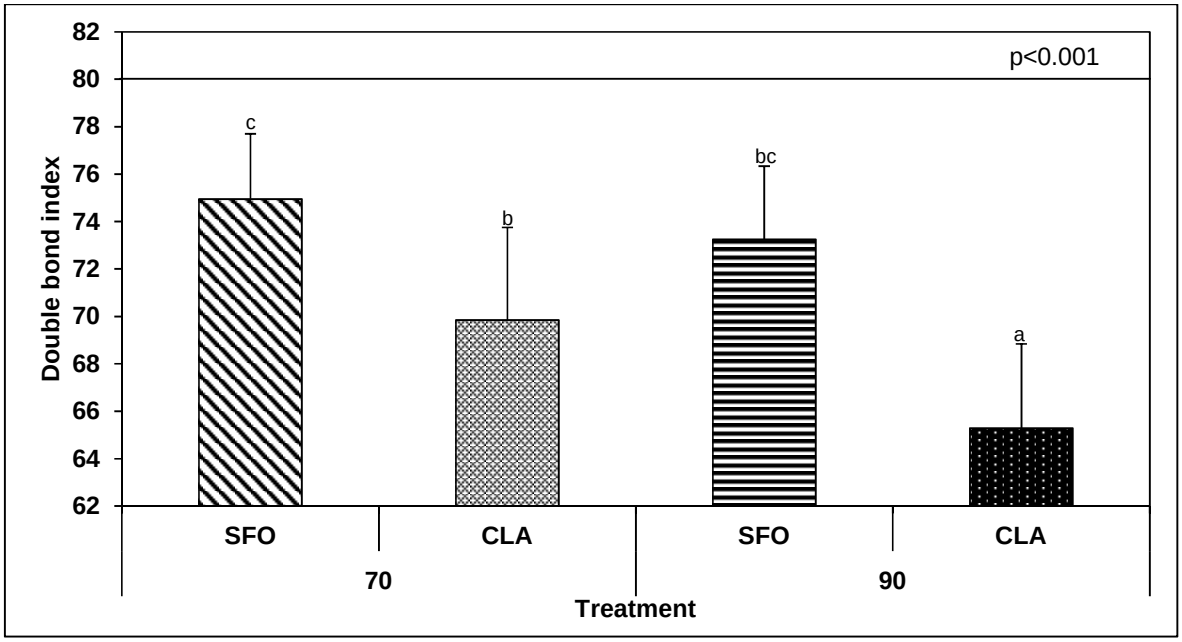
Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.51: Fatty acid ratios of technological and nutritional importance of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Dienoic (%)	Trienoic (%)	Tetraenoic (%)	Hexaenoic (%)	Penta + Hexaenoic (%)	C16:0 + C18:0 (%)	C16:1 + C18:1 / C16:0+C18:0	C18:0/C18:2	C16:0/C18:2	C18:2/C18:1
70	SFO	13.70 ± 1.67	0.57 ± 0.09^{b}	0.18 ± 0.02^{b}	0.07 ± 0.04	0.07 ± 0.04	38.73 ± 1.24^{a}	1.14 ± 0.07^{c}	0.80 ± 0.15^{a}	2.15 ± 0.31	0.32 ± 0.05^{a}
	CLA	13.92 ± 1.74	0.61 ± 0.10^{b}	0.16 ± 0.04^{b}	0.05 ± 0.06	0.05 ± 0.06	43.23 ± 1.77^{b}	0.90 ± 0.05^{b}	0.91 ± 0.17^{a}	2.33 ± 0.38	0.39 ± 0.05^{b}
90	SFO	13.22 ± 1.66	0.44 ± 0.08^{a}	0.16 ± 0.03^{b}	0.06 ± 0.05	0.06 ± 0.05	39.47 ± 1.58^{a}	1.12 ± 0.07^{c}	0.90 ± 0.17^{a}	2.22 ± 0.34	0.31 ± 0.05^{a}
	CLA	13.26 ± 1.87	0.47 ± 0.09^{a}	0.12 ± 0.03^{a}	0.04 ± 0.05	0.04 ± 0.05	46.28 ± 1.84^{c}	0.79 ± 0.06^{a}	1.11 ± 0.19^{b}	2.54 ± 0.41	0.39 ± 0.07^{b}
Significance Level		NS	p<0.001	p<0.001	NS	NS	p<0.001	p<0.001	p<0.01	NS	p<0.01

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

According to Prabucki (1991) good quality belly fat should have a total UFA content of less than 59%. As was the case with the SFA content, all the treatment groups, except the 70 kg SFO supplemented group, had less than 59% UFA belly fat (Figure 4.14). Belly fat from the CLA supplemented groups had significantly lower ($p<0.001$) UFA content compared to belly fat from the SFO treatment groups (Figure 4.14). For good quality fat, belly fat should have a double bond index (DBI) of less than 80 (Prabucki, 1991). All the treatment groups could conform to this fat quality parameter. The CLA treatment groups had significantly ($p<0.001$) lower DBI compared to the SFO treatment groups (Figure 4.15).



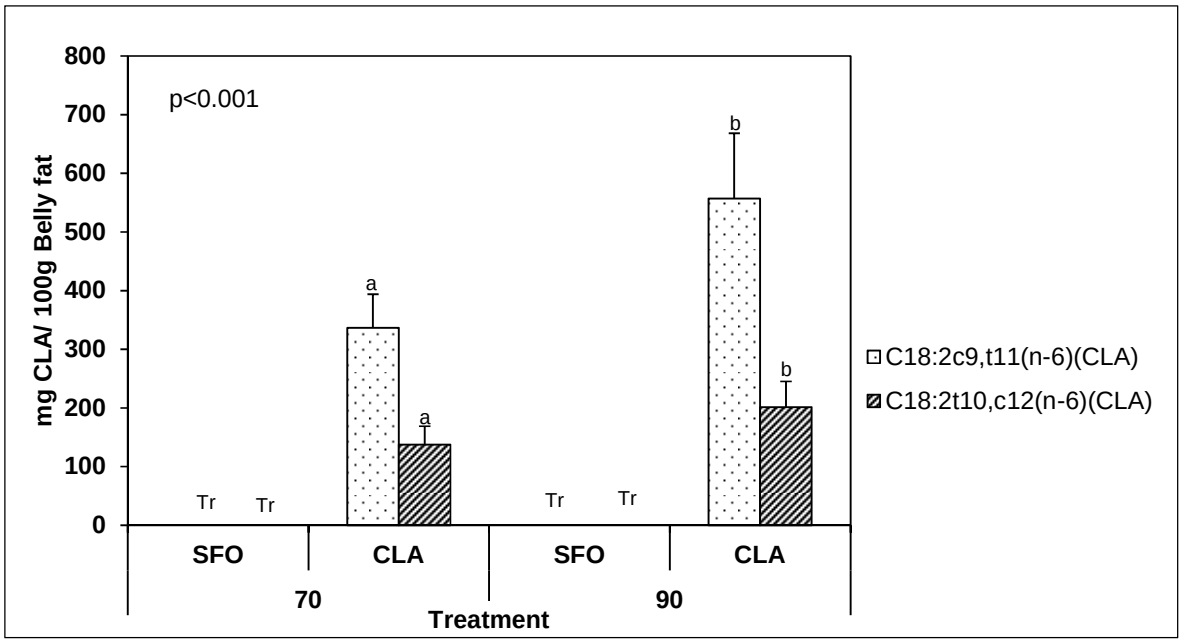
Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.15: Double bond index of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

As in the case of backfat (Table 4.38), belly fat from the CLA supplemented groups had significantly ($p<0.001$) higher C16:0 + C18:0 ratios compared to belly fat from SFO supplemented groups (Table 4.51). Belly fat from the CLA supplemented groups had a significantly ($p<0.001$) lower C16:1 + C18:1/C16:0 + C18:0 ratio compared to belly fat from the SFO supplemented group (Table 4.51). For good quality fat, belly fat should have a dienoic fatty acid content of less than 10%, a trienoic fatty acid content of less than 1%, a tetraenoic fatty acid content of less than 0.5% and pentaenoic + hexaenoic fatty acid content of less than 1% (Häuser et al., 1991). All the treatment groups had a dienoic content of more than 10%, an trienoic content of less than 1%, a tetraenoic content of less than 0.5% and a pentaenoic + hexaenoic content of less than 1% (Table 4.51).

An interesting observation was the statistically significant ($p<0.001$) increase in C18:2*c*9,*t*11

and C18:2*t*10,*c*12 CLA contents with increased slaughter weight (Figure 4.16). The 90 kg slaughter weight group that was exposed for a longer period of time to the CLA supplemented diet had significantly ($p<0.001$) higher CLA levels in the belly fat compared to the 70 kg slaughter weight group. Since the CLA content of the diet was kept constant throughout the study this observation can only be explained in terms of exposure time to CLA, meaning that exposure to CLA over a longer period resulted in an elevated level of CLA in the subcutaneous fat. The actual CLA content of belly fat followed the same trend as that of backfat (Figure 4.10). The CLA supplemented groups had significantly higher amounts of CLA deposited into the adipose tissue compared to the SFO supplemented pigs (Figure 4.16).



Bars with different superscripts differ significantly; Tr = Trace amounts; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.16: Actual CLA content of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

The CLA content in belly fat was in the range of 300 mg CLA/100g of belly fat for the 70 kg CLA group and 600 mg CLA/100g of belly fat for the 90 kg CLA group (Figure 4.16) compared to the backfat where the CLA content was in the range of 500 mg CLA/100g of backfat for the 70 kg CLA group and 600 mg CLA/100g of backfat of the 90 kg CLA group (Figure 4.10). An interesting observation is that no CLA was detected in the belly fat of the SFO supplemented pigs (Figure 4.16), opposed to the backfat where low levels of CLA were detected in the SFO supplemented pigs (Figure 4.10). Backfat had a higher % EFC (Table 4.32) compared to the belly fat (Table 4.44). This might possibly explain why backfat had a higher CLA content compared to the belly fat. Total CLA content for belly fat ranged from 474 mg CLA/100 g belly fat for the 70 kg slaughter weight group to 758 mg CLA/100 g belly fat for the 90 kg slaughter weight group (Table 4.52).

Table 4.52: Actual CLA content of belly fat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	mg Total CLA (mg/100 g belly fat)	% of RDA of 100 g portion
70	SFO	Tr	Tr
	CLA	474.08 ± 86.57[a]	13.55 ± 2.47[a]
90	SFO	Tr	Tr
	CLA	758.81 ± 152.48[b]	21.68 ± 4.36[b]
Significance Level		p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; Tr = Trace amounts; CLA = Conjugated linoleic acid; SFO = Sunflower oil; RDA = Recommended daily allowance

A 100 g portion of belly fat from the 70 kg CLA supplemented group would supply 13.55% of the total RDA of CLA opposed to 100 g of belly fat from the 90 kg slaughter that would supply 21.68% of the RDA for CLA (Table 4.52).

The content of the different lipid fractions of belly fat followed the same trend as that of backfat (Table 4.41), with C18:2*c*9,12 being mostly deposited in the phospholipid fraction and the two CLA isomers (C18:2*c*9,*t*11 and C18:2*t*10*c*12) being mostly deposited in the neutral- and glycolipid fraction (Table 4.53). Belly fat lipid fractions (Table 4.53) contained lower amounts of C18:2 and CLA isomers (*cis*-9, *trans*-11 and *trans*-10, *cis*-12) compared to backfat lipid fractions (Table 4.41). A possible explanation for this could be that backfat had a higher % EFC (Table 4.32) compared to belly fat (Table 4.44). Linoleic acid content was significantly higher in the phospholipid fraction (p<0.001) compared to the neutral- and glycolipid fractions as previously observed by Wood et al. (2008). The neutral lipid fraction of belly fat from the 90 kg gilts had a significantly higher proportion of the *cis*-9, *trans*-11 CLA isomer compared to the 70 kg gilts (Table 4.53).

4.6. Quality of *M. longissimus thoracis*

4.6.1. Physical and chemical properties of M. longissimus thoracis of gilts from all treatment groups

As in the case of backfat (Table 4.30) and belly fat (Table 4.42), the physical (*L**-, *a**-, *b**-value, Chroma and WHC) and chemical properties (FFDM and moisture content) of *M*. *longissimus thoracis* were significantly (at least p<0.05) influenced by dietary treatment (Table 4.54). The physical properties (Hue angle, drip loss and WHC) and chemical properties (FFDM, moisture and calculated IV) of *M*. *longissimus thoracis* were significantly (at least p<0.05) influenced by slaughter weight (Table 4.54).

The 90 kg CLA supplemented gilts had a slight, but not significantly, lower fat percentage and higher meat percentage compared to the fat percentage and meat percentage of the 90 kg SFO supplemented gilts (Table 4.55). O'Quinn et al. (2000) and Ritzenhaler et al. (2001), reported an overall reduction in percentage body fat as a result of dietary CLA supplementation.

Table 4.53: Content of different isomers of C18:2 (%) in the neutral-, glycol- and phospholipid fractions of belly fat of CLA supplemented gilts of 70 and 90 kg slaughter weight (n = 10 per treatment)

Lipid Fraction	Slaughter Weight	C18:2c9,12 (n-6)	C18:2c9,t11(n-6) (CLA)	C18:2t10,c12(n-6) (CLA)	Total CLA
Neutral Lipid	**70**	13.12 ± 1.68[a]	0.32 ± 0.04[c]	0.11 ± 0.02[c]	0.43 ± 0.06[c]
	90	12.31 ± 1.75[a]	0.44 ± 0.05[d]	0.18 ± 0.03[d]	0.62 ± 0.08[d]
Glycolipid	**70**	12.33 ± 1.63[a]	0.25 ± 0.06[b]	0.07 ± 0.06[b]	0.32 ± 0.11[b]
	90	12.05 ± 1.67[a]	0.33 ± 0.08[c]	0.13 ± 0.06[c]	0.46 ± 0.13[c]
Phospholipid	**70**	18.73 ± 2.95[b]	0.01 ± 0.01[a]	0.01 ± 0.01[a]	0.01 ± 0.01[a]
	90	18.97 ± 7.38[b]	0.01 ± 0.01[a]	0.01 ± 0.01[a]	0.01 ± 0.01[a]
Significance level		p<0.001	p<0.001	p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid

Table 4.54: Analysis of variance (ANOVA) on the physical and chemical properties of *M. longissimus thoracis* of importance in the manufacturing of processed meat products

	Diet	Slaughter weight
Loin chop composition:		
% Fat	NS	NS
% Meat	NS	NS
Physical properties:		
$pH_{24hours}$	NS	NS
Colour *L** - Value	**	NS
Colour *a** - Value	****	NS
Colour *b** - Value	****	NS
Chroma	****	NS
Hue angle	NS	**
Drip Loss (%)	NS	****
Water Holding Capacity (Meat Area / Total Area)	**	**
Chemical properties:		
Extractable Fat (%)	NS	NS
Fat free dry matter (%)	***	***
Moisture (%)	***	****
Iodine value (Calculated)	NS	***

NS = Not significant; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

According to Tables 4.54 and 4.56, no significant differences were observed for $pH_{24hours}$ and Hue angle. This is in agreement with the findings of Jiang et al. (2010) that dietary CLA had no effect on pH. For meat to be classified as DFD, the $pH_{24hours}$ should be between 6.2 and 6.6, the $pH_{24hours}$ of normal meat is in the order of 5.5. Table 4.56 clearly indicates that none of the treatment groups could be classified as DFD.

Table 4.55: Composition of *M. longissimus thoracis* steaks of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	% Fat	% Meat
70	**SFO**	36.83 ± 4.81	63.17 ± 4.81
	CLA	37.76 ± 6.89	62.24 ± 6.89
90	**SFO**	40.21 ± 6.68	59.79 ± 6.68
	CLA	37.85 ± 5.25	62.15 ± 5.25
Significance level		NS	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.56 clearly indicates that the 70 kg CLA supplemented gilts had a significantly ($p<0.01$) higher colour *L**-value compared to the 70 kg SFO supplemented gilts. These higher *L**-values may be attributed to an increased content of white muscle fibres previously observed in muscle after dietary CLA supplementation (Joo et al., 2013).

Table 4.56: Physical properties of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	$pH_{24hours}$	Colour *L** - Value	Colour *a** - Value	Colour *b** - Value	Chroma	Hue angle
70	**SFO**	5.38 ± 0.05	52.59 ± 1.31^{a}	7.33 ± 0.88^{a}	6.39 ± 0.73^{a}	9.73 ± 1.08^{a}	41.07 ± 2.33
	CLA	5.38 ± 0.09	56.48 ± 1.65^{b}	9.51 ± 1.17^{c}	8.17 ± 1.06^{b}	12.55 ± 1.45^{b}	40.63 ± 2.96
90	**SFO**	5.38 ± 0.08	54.98 ± 2.96^{b}	$8.02 \pm =1.26^{ab}$	7.37 ± 1.30^{ab}	10.91 ± 1.72^{ab}	42.50 ± 3.27
	CLA	5.40 ± 0.06	55.14 ± 2.64^{b}	8.82 ± 1.35^{bc}	8.43 ± 1.53^{b}	12.22 ± 1.92^{b}	43.52 ± 3.15
Significance level		NS	p<0.01	p<0.01	p<0.01	p<0.01	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Cojugated linoleic acid; SFO = Sunflower oil

The *M. longissimus thoracis* from the 70 kg CLA supplemented gilts had significantly ($p<0.01$) higher *a**-values compared to the *M. longissimus thoracis* from the SFO supplemented gilts (Table 4.56). The same trend, although not statistically significant, was observed for the 90 kg CLA and SFO groups (Table 4.56). Exactly the same trend as for the *L** and *a** values was observed for the b* values. Szymczyk (2005) reported that meat from CLA supplemented animals had significantly higher *L**, *a** and *b** values. These findings also confirm the antioxidant properties of CLA, found in literature (Szymczyk, 2005). A relationship exists between lipid and pigment oxidation in muscle (Gray, Gomaa, & Buckley, 1996; Ripoll, González-Calvo, Molino, Calvo, & Joy, 2013). Meat from both the 70 kg and 90 kg CLA supplemented gilts had a higher Chroma value, implying a more vivid colour (Table 4.56). Although not statistically significant, meat from the 90 kg CLA supplemented gilts had a larger hue angle compared to the 70 kg CLA supplemented gilts, indicating a less red product (Table 4.56). This is in agreement with Lee et al. (2003) who reported a larger hue angle indicates a less red product.

Table 4.57 indicates that the 90 kg slaughter weight groups had a significantly ($p<0.01$) higher drip loss compared to the 70 kg slaughter weight groups. This is the opposite of what would be expected, since lighter pigs are more susceptible to the PSE meat syndrome and would normally have higher drip loss. Water-holding capacity was significantly ($p<0.01$) influenced by dietary treatment within the 90 kg slaughter weight groups (Table 4.57). The *M. longissimus thoracis* from the 90 kg CLA supplemented gilts had a significantly ($p<0.01$) higher WHC compared to the *M. longissimus thoracis* from the 90 kg SFO supplemented gilts. Joo et al. (2002) and Szymczyk (2005) reported that WHC of pork can be increased with dietary CLA supplementation. According to Andersen (2000) and Olsson et al. (2005), pork with a higher WHC will have improved technological properties.

Table 4.57: Quality parameter of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Drip Loss (%)	WHC (Meat Area / Total Area)
70	**SFO**	4.91 ± 1.17^{a}	0.36 ± 0.02^{b}
	CLA	5.00 ± 1.06^{a}	0.37 ± 0.03^{b}
90	**SFO**	6.31 ± 1.36^{b}	0.32 ± 0.03^{a}
	CLA	6.74 ± 1.11^{b}	0.36 ± 0.04^{b}
Significance level		$p<0.01$	$p<0.01$

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.58 indicates that in the 90 kg slaughter weight group, dietary CLA supplementation resulted in a slight but not significant decrease in EFC %, a significant ($p<0.001$) increase in FFDM and a significant ($p<0.001$) decrease in moisture content. The 70 kg CLA supplemented gilts followed the same trend, although not significant, as the 90 kg CLA supplemented gilts (Table 4.58). Dietary treatment had a slight, but not significant, effect on IV since both the 70 kg and 90 kg CLA supplemented gilts had a slightly lower IV compared to the SFO supplemented gilts. Slaughter weight had a more pronounced effect on the IV of IMF in the 70 kg slaughter weight groups. These groups generally had higher IV compared to the heavier slaughter weight groups. In the case of the 70 kg and 90 kg SFO groups, this difference was significant ($p<0.05$) (Table 4.58). This is an indication that lighter porker pigs had a more unsaturated IMF profile compared to the heavier baconer pigs. According to Wood et al. (1989), heavier pigs had a more physiological mature fat with a more saturated fatty acid profile.

4.6.2. Fatty acid composition of IMF from M. longissimus thoracis

Table 4.59 indicates that, as in the case of backfat (Table 4.33) and belly fat (Table 4.45), dietary treatment and slaughter weight had a significant (at least $p<0.1$) influence on many fatty acid and fatty acid ratios of IMF.

For the IMF content, SFA (C14:0, C15:0, C16:0 and C20:0), MUFA (C16:1*c*9, C18:1*t*9 and

Table 4.58: Chemical properties of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Extractable fat content (%)	Fat free dry matter (%)	Moisture (%)	Iodine value (Calculated)
70	SFO	1.45 ± 0.27	23.60 ± 0.51^{a}	74.91 ± 0.43^{c}	73.31 ± 4.73^{b}
	CLA	1.51 ± 0.19	24.08 ± 0.64^{a}	74.41 ± 0.63^{bc}	69.64 ± 4.23^{ab}
90	SFO	1.56 ± 0.35	24.14 ± 0.51^{a}	74.22 ± 0.41^{b}	67.79 ± 6.51^{a}
	CLA	1.52 ± 0.15	24.88 ± 0.41^{b}	73.60 ± 0.42^{a}	66.36 ± 3.41^{a}
Significance level		NS	p<0.001	p<0.001	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

C18:1*c*9) and PUFA (C18:2; C18:3*n*-3; C20:2 and C22:6) were significantly (at least p<0.01) influenced by dietary treatment or slaughter weight (Table 4.60 – 4.62). The CLA supplemented groups had significantly higher amounts of SFA (Table 4.63). This observation is in agreement with the findings of Szymczyk (2005) and Bee et al. (2008). The effect of dietary CLA supplementation on the fatty acid profile of IMF was less pronounced compared to backfat (Table 4.34 – 4.37) and belly fat (Table 4.47 – 4.49) (Ramsay et al., 2001). This increase in SFA content can possibly be ascribed to the decrease, although not statistically significant, of the $^{\Delta}$9 desaturase index in the IMF of CLA supplemented animals (Table 4.63). Although the $^{\Delta}$9 desaturase index did not differ significantly between SFO and CLA supplemented animals the $^{\Delta}$9 desaturase index was generally lower for IMF from CLA supplemented animals compared to IMF from SFO supplemented animals. Migdal et al. (2004) and Larson et al. (2009) reported that a decrease in the $^{\Delta}$9 desaturase index resulted in an increase in SFA content in IMF.

Although dietary CLA supplementation resulted in elevated CLA levels in IMF (Table 4.62), which can be considered as a positive attribute from a health point of view (Migdal et al., 2004; Larsen et al., 2009), some other health properties of the IMF were negatively influenced by elevated CLA levels (Table 4.63). The elevated CLA levels caused a decrease in: PUFA and *n*-6 fatty acids as well as in the following ratios: MUFA/SFA, PUFA/SFA and *n*-6/*n*-3 and an increase in AI (Table 4.63). These changes can all be considered negative from a health point of view (Rhee et al., 1988; Warnants et al., 1998; Enser, 2000). The MUFA/SFA and *n*-3 fatty acid were statistically (at least p<0.1) influenced by slaughter weight. The 90 kg slaughter weight group had significantly lower *n*-6 (p<0.05) and *n*-3 (p<0.1) content compared to the 70 kg SFO supplemented group. This can be attributed to the more SFA profile of the 90 kg slaughter weight group (Wood et al., 1989).

Normally the improvement of the health properties of IMF is accompanied by deterioration in the technological quality of IMF (Hugo et al., 2007). A contradiction is observed in the IMF of pigs with elevated CLA levels. Although CLA is a PUFA, that results in an improvement of the health properties of fat, the IMF of CLA supplemented pigs also demonstrated improved technological properties (Table 4.64).

Table 4.59: Analysis of variance (ANOVA) on fatty acid composition and fatty acid ratios for the effect of dietary treatment and slaughter weight

	Diet	**Slaughter weight**
FAME (% of total fatty acids)		
C14:0	***	NS
C15:0	**	NS
C16:0	****	*
C16:1*c*9	****	NS
C17:0	NS	NS
C18:0	NS	**
C18:1*t*9	****	NS
C18:1*c*9	*	**
C18:1*c*7	NS	NS
C18:2*c*9,12(*n*-6)	NS	***
C18:2*c*9,*t*11(*n*-6)(CLA)	****	NS
C18:2*t*10,*c*12(*n*-6)(CLA)	****	NS
C18:3*c*9,12,15(*n*-3)	NS	**
C20:0	NS	**
C20:1*c*11	NS	NS
C20:2*c*11,14(*n*-6)	****	**
C20:3*c*11,14,17(*n*-3)	NS	**
C20:4*c*5,8,11,14(*n*-6)	NS	*
C22:6*c*4,7,10(*n*-3)	NS	**
Fatty acid ratios:		
MUFA (%)	NS	**
Dienoic (%)	NS	***
Trienoic (%)	NS	**
Tetraenoic (%)	NS	*
Hexaenoic (%)	NS	**
C16:0 + C18:0 (%)	****	**
C16:1 + C18:1/C16:0 + C18:0	**	NS
C18:0/C18:2	NS	****
C16:0/C18:2	*	****
C18:2/C18:1	NS	***
SFA (%)	****	**
UFA (%)	**	NS
MUFA/SFA	***	NS
DBI	NS	***
PI	NS	**
PUFA (%)	NS	***
$^{\Delta}$9 desaturase index	NS	NS
Atherogenicity Index	****	*
PUFA/SFA	NS	***
n-6 (%)	NS	***
n-3 (%)	NS	**
n-6/*n*-3	**	NS

NS = Not significant; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

Table 4.60: Saturated fatty acid content of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C14:0	C15:0	C16:0	C17:0	C18:0	C20:0
70	SFO	1.16 ± 0.19^{a}	0.14 ± 0.10^{b}	25.44 ± 1.19^{a}	0.32 ± 0.08	12.04 ± 0.55	0.12 ± 0.02^{a}
	CLA	1.44 ± 0.20^{b}	0.13 ± 0.09^{b}	27.47 ± 1.14^{b}	0.32 ± 0.06	12.18 ± 0.45	0.12 ± =0.02^{ab}
90	SFO	1.33 ± 0.18^{ab}	0.04 ± 0.02^{a}	26.27 ± 0.85^{a}	0.28 ± 0.08	12.60 ± 0.78	0.14 ± 0.02^{b}
	CLA	1.47 ± 0.17^{b}	0.18 ± 0.07^{b}	28.19 ± 0.64^{b}	0.29 ± 0.10	12.48 ± 0.49	0.13 ± 0.02^{ab}
Significance level		p<0.01	p<0.01	p<0.001	NS	NS	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.61: Monounsaturated fatty acid content of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C16:1*c*9	C18:1*t*9	C18:1*c*9	C18:1*c*7	C20:1*c*11
70	SFO	2.68 ± 0.45^{a}	0.05 ± 0.02^{a}	34.42 ± 3.48^{ab}	3.77 ± 0.28	0.37 ± 0.15
	CLA	3.35 ± 0.42^{b}	0.08 ± 0.03^{b}	33.65 ± 1.05^{a}	3.80 ± 0.24	0.40 ± 0.11
90	SFO	2.69 ± 0.55^{a}	0.04 ± 0.02^{a}	36.84 ± 2.94^{b}	3.70 ± 0.33	0.52 ± 0.18
	CLA	3.66 ± 0.43^{b}	0.07 ± 0.03^{b}	34.55 ± 1.52^{ab}	3.92 ± 0.28	0.39 ± 0.15
Significance level		p<0.001	p<0.01	p<0.05	NS	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.62: Polyunsaturated fatty acid content of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	C18:2*c*9,12 (*n*-6)	C18:2*c*9,*t*11 (*n*-6)(CLA)	C18:2*t*10,*c*12 (*n*-6)(CLA)	C18:3*c*9,12,15 (*n*-3)	C20:2*c*11,14 (*n*-6)	C20:3*c*11,14,17 (*n*-3)	C20:4*c*5,8,11,14 (*n*-6)	C22:6*c*4,7,10 (*n*-3)
70	SFO	14.46 ± 2.27^{b}	0.06 ± 0.01^{a}	ND	0.09 ± 0.02^{b}	0.33 ± 0.05^{c}	0.44 ± 0.13	2.73 ± 0.95	0.44 ± 0.11^{b}
	CLA	13.23 ± 1.62^{ab}	0.20 ± 0.03^{b}	0.07 ± 0.01	0.07 ± 0.02^{ab}	0.27 ± 0.03^{b}	0.38 ± 0.15	2.21 ± 0.55	0.43 ± 0.09^{b}
90	SFO	11.90 ± 2.74^{a}	0.05 ± 0.01^{a}	ND	0.06 ± 0.02^{a}	0.30 ± 0.05^{bc}	0.33 ± 0.17	2.03 ± 1.01	0.30 ± 0.12^{a}
	CLA	11.28 ± 1.63^{a}	0.19 ± 0.02^{b}	0.06 ± 0.01	0.06 ± 0.02^{a}	0.22 ± 0.02^{a}	0.31 ± 0.06	1.99 ± 0.43	0.41 ± 0.10^{ab}
Significance level		p<0.01	p<0.001	NS	p<0.05	p<0.001	NS	NS	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.63: Fatty acid ratios of health and nutritional importance of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	MUFA (%)	SFA (%)	MUFA/SFA	PI	PUFA (%)	$^{\Delta}$9 desaturase index	Atherogenicity Index	PUFA/SFA	*n*-6 (%)	*n*-3 (%)	*n*-6/*n*-3
70	SFO	41.28 ± 4.15	39.22 ± 1.45^{a}	1.05 ± 0.11^{ab}	31.33 ± 6.42^{b}	18.53 ± 3.18^{b}	3.19 ± 0.41	0.50 ± 0.04^{a}	0.47 ± 0.09^{b}	17.57 ± 2.98^{b}	0.96 ± 0.23^{b}	18.98 ± 4.02^{ab}
	CLA	41.27 ± 1.39	41.65 ± 1.48^{bc}	0.99 ± 0.04^{a}	27.96 ± 4.52^{ab}	16.86 ± 2.33^{ab}	3.09 ± 0.15	0.57 ± 0.05^{bc}	0.41 ± 0.07^{ab}	15.99 ± 2.11^{ab}	0.87 ± 0.23^{ab}	18.79 ± 2.29^{ab}
90	SFO	43.78 ± 3.52	40.68 ± 1.24^{b}	1.08 ± 0.09^{b}	24.63 ± 7.92^{a}	14.97 ± 4.03^{a}	3.24 ± 0.41	0.54 ± 0.04^{ab}	0.37 ± 0.11^{a}	14.28 ± 3.74^{a}	0.69 ± 0.30^{a}	22.83 ± 5.82^{b}
	CLA	42.60 ± 1.93	42.74 ± 0.88^{c}	1.00 ± 0.04^{ab}	24.81 ± 4.12^{a}	14.53 ± 2.20^{a}	3.09 ± 0.17	0.60 ± 0.03^{c}	0.34 ± 0.06^{a}	13.75 ± 2.05^{a}	0.78 ± 0.17^{ab}	17.88 ± 1.73^{a}
Significance level		NS	p<0.001	p<0.05	p<0.1	p<0.05	NS	p<0.001	p<0.01	p<0.05	p<0.1	p<0.05

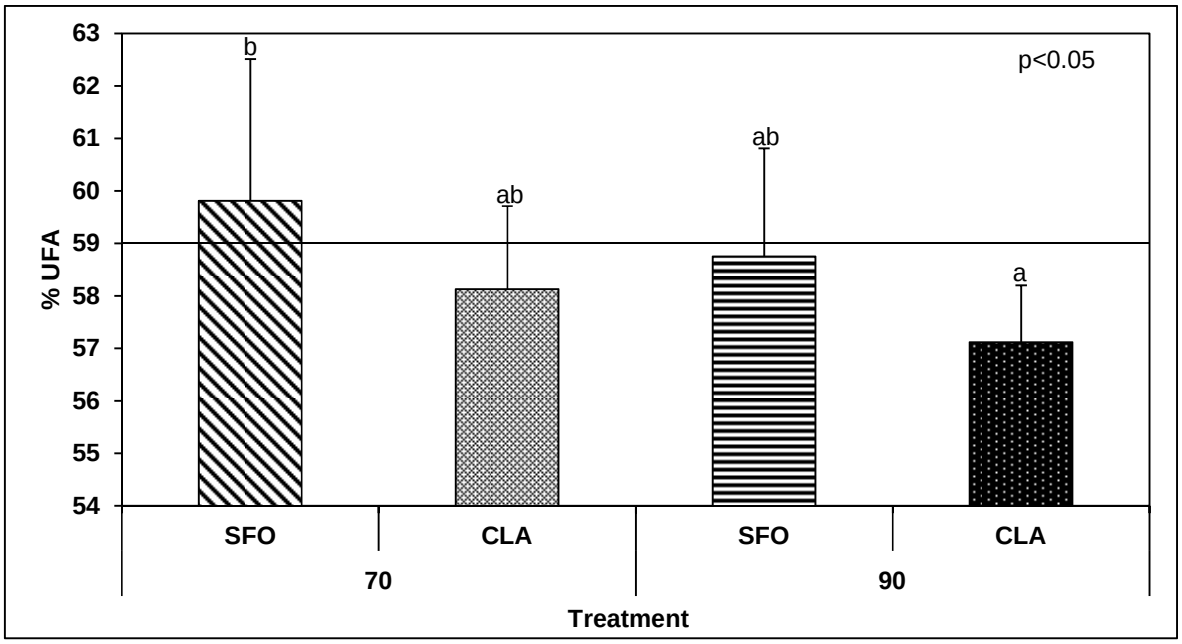
Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.64: Fatty acid ratios of technological and nutritional importance of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Dienoic (%)	Trienoic (%)	Tetraenoic (%)	Hexaenoic (%)	Penta + Hexaenoic (%)	C16:0 + C18:0 (%)	C16:1 + C18:1/ C16:0 + C18:0	C18:0/C18:2	C16:0/C18:2	C18:2/C18:1
70	SFO	14.84 ± 2.32^{b}	0.52 ± 0.14	2.73 ± 0.95	0.44 ± 0.11^{b}	0.44 ± 0.11^{b}	37.48 ± 1.43^{a}	1.09 ± 0.11^{b}	0.85 ± 0.13^{a}	1.80 ± 0.33^{a}	0.39 ± 0.09^{b}
	CLA	13.78 ± 1.65^{ab}	0.44 ± 0.17	2.21 ± 0.55	0.43 ± 0.09^{b}	0.43 ± 0.09^{b}	39.64 ± 1.40^{bc}	1.03 ± 0.04^{a}	0.91 ± 0.12^{a}	2.07 ± 0.31^{ab}	0.36 ± 0.05^{ab}
90	SFO	12.26 ± 2.78^{a}	0.39 ± 0.19	2.03 ± 1.01	0.30 ± 0.12^{a}	0.30 ± 0.12^{a}	38.88 ± 1.14^{b}	1.11 ± 0.09^{b}	1.10 ± 0.23^{b}	2.31 ± 0.54^{bc}	0.30 ± 0.09^{a}
	CLA	11.75 ± 1.65^{a}	0.37 ± 0.08	1.99 ± 0.43	0.41 ± 0.10^{ab}	0.41 ± 0.10^{ab}	40.67 ± 0.80^{c}	1.04 ± 0.05^{a}	1.10 ± 0.16^{b}	2.49 ± 0.37^{c}	0.30 ± 0.06^{a}
Significance level		p<0.05	NS	NS	p<0.05	p<0.05	p<0.001	p<0.1	p<0.01	p<0.01	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

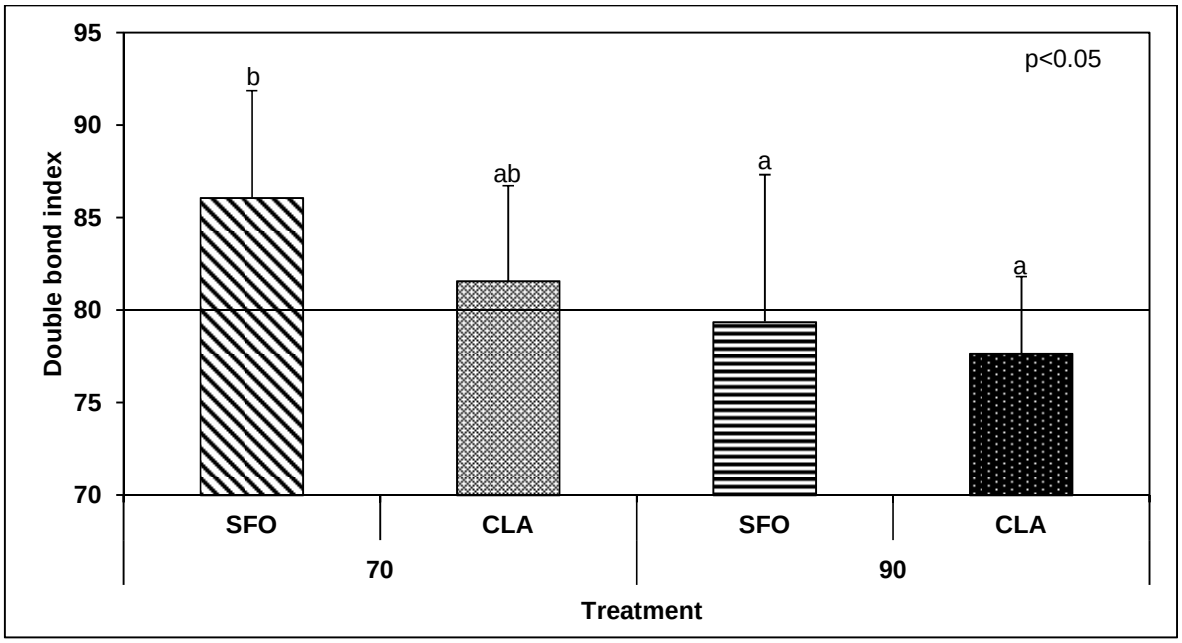
Due to a lack of quality parameters for IMF, the same quality parameters as for backfat and belly fat were used for IMF. For good fat quality, IMF should have a C18:0 content of more than 12% (Lizardo et al., 2002). All the treatment groups had a C18:0 content of more than 12% (Table 4.60). For good fat quality, IMF should have a SFA content of more than 41% (Häuser et al., 1990). Only the CLA supplemented groups had a SFA content of more than 41% (Table 4.63). According to Prabucki (1991) IMF of good quality should have a total UFA content of less than 59%. All the treatment groups except the 70 kg SFO supplemented group had less than 59% UFA. Intramuscular fat from the 90 kg CLA group had significantly ($p<0.05$) lower UFA content compared to the 70 kg SFO group (Figure 4.17). Hur et al. (2007) reported that dietary CLA decreased levels of UFA intramuscularly. Wood et al. (1989) reported that older heavier pigs had a more mature and saturated fat.



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.17: Unsaturated fatty acid content of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Double bond index of IMF of the 90 kg baconer group was significantly ($p<0.05$) lower compared to the 70 kg porker group (Figure 4.18). This is an indication that the IMF from the 70 kg porker group had a more unsaturated fatty acid profile. According to Bruwer et al. (1991), younger, lighter pigs deposit more unsaturated lipids. For good fat quality, IMF should have a DBI of less than 80 (Prabucki, 1991). Only the heavy baconer pigs could conform to this fat quality requirement. Although not statistically significant, the CLA treatment groups had a lower DBI compared to the SFO treatment groups (Figure 4.18). The slightly lower DBI of IMF from CLA supplemented pigs can be attributed to IMF with a more SFA profile (Hur et al., 2007).



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.18: Double bond index of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Intramuscular fat from the 90 kg CLA supplemented group had significantly ($p<0.001$) higher C16:0 + C18:0 ratio compared to the SFO supplemented groups (Table 4.64). Although not statistically significant, a dietary effect was observed for the C16:0/C18:2 ratio in IMF from CLA treatment groups. They generally had higher C16:0/C18:2 ratios compared to IMF from SFO treatment groups (Table 4.64). A significant ($p<0.1$) difference was observed for C16:1 + C18:1/C16:0 + C18:0 with IMF from CLA supplementation groups having lower C16:1 + C18:1/C16:0 + C18:0 ratios compared to IMF from SFO supplementation groups (Table 4.64). For good quality fat, backfat should have a dienoic fatty acid content of less than 10%, a trienoic fatty acid content of less than 1%, a tetraenoic fatty acid content of less than 0.5% and pentaenoic + hexaenoic fatty acid content of less than 1% (Häuser et al., 1991). All of the treatment groups had a dienoic content of more than 10%, a trienoic content less than 1%, a tetraenoic content of less than 0.5% and a pentaenoic + hexaenoic content of less than 1% (Table 4.64).

Table 4.65 indicates that the actual CLA content of *M. longissimus thoracis* was significantly influenced ($p<0.001$) by dietary treatment and not at all by slaughter weight. This is in agreement with the findings of Migdal et al. (2004) and Szymczyk, (2005) who reported that a linear relationship exists between the CLA content in feed and the CLA level in IMF. Table 4.66 indicates that the CLA supplemented gilts had significantly ($p<0.001$) higher amounts of CLA deposited into the IMF compared to the SFO supplemented gilts. This was also depicted in Figure 4.19. The same trend for total CLA was observed for backfat (Table 4.40) and belly fat (Table 4.52). The CLA content of IMF was considerably lower compared to backfat (Figure 4.10) and belly fat

Table 4.65: Analysis of variance (ANOVA) of actual CLA content of *M. longissimus thoracis* for the effect of dietary treatment and slaughter weight

	Diet	Slaughter weight
Actual CLA content:		
C18:2c9,t11(n-6)CLA (mg/100 g)	****	NS
C18:2t10,c12(n-6) CLA (mg/100 g)	****	NS
mg total conjugated linoleic acid (CLA) (mg/100 g)	****	NS
% of RDA of 100 g portion	****	NS

NS = Not significant; CLA = Conjugated linoleic acid; RDA = Recommended daily allowance;* = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

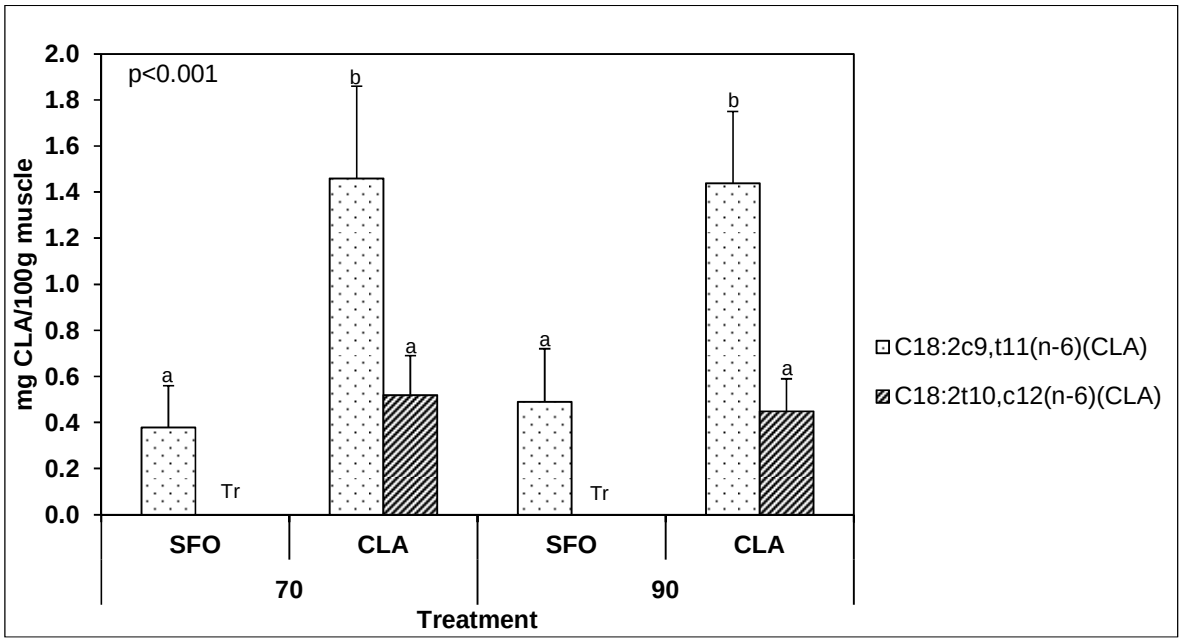
Table 4.66: Actual CLA content of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	mg Total CLA/100 g muscle	% of RDA of 100 g portion
70	**SFO**	0.38 ± 0.18^{a}	0.01 ± 0.01^{a}
	CLA	1.98 ± 0.55^{b}	0.06 ± 0.02^{b}
90	**SFO**	0.49 ± 0.23^{a}	0.01 ± 0.01^{a}
	CLA	1.89 ± 0.42^{b}	0.05 ± 0.01^{b}
Significance Level		p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil; RDA = Recommended daily allowance

(Figure 4.16). This is in agreement with Szymczyk (2005), who reported that dietary CLA isomers were more effectively incorporated into backfat. The lower % EFC of *M. longissimus thoracis* is the reason why muscle contained such low amounts of CLA (Table 4.66). From Figure 4.19 it is clear that the *cis*-9, *trans*-11 isomer was more effectively incorporated into IMF than the *trans*-10, *cis*-12 isomer (Szymczyk, 2005). As indicated in Table 4.66 and Figure 4.19, *M. longissimus thoracis* contains a very small amount of CLA. Consumption of a 100 g portion of meat from CLA supplemented animals will only provide ± 0.05% of the RDA for CLA.

The IMF were separated into neutral-, glyco- and phospholipid fractions by means of solid phase extraction. The fatty acid analyses of these fractions indicated that C18:2 from IMF was mostly deposited into the phospholipid fraction, as also observed for backfat and belly fat. This observation is in agreement with the findings of Wood et al. (2008), who reported that C18:2 was mostly deposited into the phospholipid fraction. According to Table 4.67, both CLA isomers were preferentially deposited in the phospholipid fraction of IMF. This finding is in contrast to those of Wiegand et al. (2002), who reported that it was only the *cis*-9, *trans*-11 CLA isomer that was deposited into the phospholipid fraction. Wiegand et al. (2002) postulated that this was the reason why the *cis*-9, *trans*-11 CLA isomer was the only biologically active CLA isomer. Tous et al. (2013) reported that the *cis*-9, *trans*-11 CLA isomer was deposited at higher levels into the phospholipid fraction compared to the *trans*-10, *cis*-12 CLA isomer. Similar results were obtained in this study (Table 4.67). It can possibly be interpreted that the *cis*-9, *trans*-11 CLA could be more biologically



Bars with different superscripts differ significantly; NS = Not significant; Tr = Trace amounts; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.19: Actual CLA content of *M. longissimus thoracis* of gilts from the experimental treatment groups (n = 10 per treatment)

Table 4.67: Content of different isomers of C18:2 (%) in the neutral-, glycol- and phospholipid fractions of *M. longissimus thoracis* of CLA supplemented gilts of 70 and 90 kg slaughter weight (n = 10 per treatment)

Lipid Fraction	Slaughter Weight	C18:2c9,12 (n-6)	C18:2c9,t11(n-6) (CLA)	C18:2t10,c12(n-6) (CLA)	Total CLA
Neutral Lipid	**70**	5.92 ± 1.27^{b}	0.11 ± 0.07^{ab}	0.01 ± 0.02^{a}	0.11 ± 0.07^{a}
	90	4.34 ± 0.45^{a}	0.12 ± 0.02^{b}	0.01 ± 0.01^{a}	0.12 ± 0.02^{a}
Glycolipid	**70**	6.74 ± 1.18^{b}	0.07 ± 0.07^{ab}	0.01 ± 0.01^{a}	0.07 ± 0.07^{a}
	90	5.26 ± 0.60^{ab}	0.06 ± 0.07^{a}	0.01 ± 0.01^{a}	0.06 ± 0.07^{a}
Phospholipid	**70**	36.02 ± 0.99^{c}	0.28 ± 0.02^{c}	0.07 ± 0.01^{b}	0.32 ± 0.03^{b}
	90	37.00 ± 2.25^{c}	0.22 ± 0.03^{c}	0.06 ± 0.01^{b}	0.29 ± 0.04^{b}
Significance level		p<0.001	p<0.001	p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid

active, since it was deposited in much higher proportions into the phospholipid fraction of IMF, compared to the *trans*-10, *cis*-12 CLA isomer (Table 4.67). An interesting observation is the fact that the *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA isomers was mostly found in the phospholipid fraction of IMF (Table 4.67), as opposed to backfat and belly fat, where it was mostly found in the neutral and glycolipid fractions (Tables 4.41 and 4.53). This can possibly be explained by the fact that *M. longissimus thoracis* contained more red oxidative muscle fibres (De Smet et al., 2004). De Smet et al. (2004) found that red oxidative muscle fibres contain more phospholipids, mainly located in cell membranes. Conjugated linoleic acid isomers are incorporated into these cell

membrane phospholipids. Some of the CLA isomers' biological effects could be due to their effect on membrane composition and function (Subbaiah, Gould, Lal, & Aizezi, 2011).

4.7. Sensory and physical properties of *M. longissimus lumborum*

4.7.1. Physical characteristics of M. longissimus lumborum

The physical characteristics of the *M. longissimus lumborum*, during and after preparation for descriptive sensory analysis, are summarized in Table 4.68. No significant differences in shear force and thawing loss were observed between the treatment groups. This is contradictory to the findings of Jiang et al. (2010), who found that dietary CLA supplementation increased the shear force values. Total cooking loss was significantly influenced by dietary treatment with meat from the 90 kg CLA supplemented gilts having significantly ($p<0.1$) lower total cooking loss compared to meat from the 90 kg SFO supplemented gilts (Table 4.68). Martin et al. (2011) reported that dietary CLA supplementation had no effect on cooking loss. This may be an indication that meat from the 90 kg CLA supplemented group has the potential to produce juicier meat.

Drip loss and evaporation loss were significantly influenced only by slaughter weight (Table 4.68). Meat from the heavier baconer groups had a significantly ($p<0.001$) higher drip and lower evaporation loss compared to the lighter porker groups.

Table 4.68: Physical characteristics of *M longissimus lumborum* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Shear force (kg)	Total Cooking loss (%)	Drip loss (%)	Evaporation loss (%)	Thawing loss (%)
70	**SFO**	5.46 ± 0.69	25.18 ± 0.73^{ab}	5.80 ± 1.09^{a}	19.38 ± 0.77^{b}	2.28 ± 0.77
	CLA	5.19 ± 0.65	25.36 ± 1.39^{ab}	5.78 ± 1.84^{a}	19.58 ± 1.20^{b}	2.11 ± 0.80
90	**SFO**	5.60 ± 0.65	25.76 ± 2.12^{b}	9.17 ± 2.03^{b}	16.59 ± 1.72^{a}	1.57 ± 0.60
	CLA	5.54 ± 0.54	23.81 ± 2.02^{a}	8.28 ± 1.73^{b}	15.53 ± 1.74^{a}	1.63 ± 0.86
Significance Level		NS	p<0.1	p<0.001	p<0.001	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

4.7.1.1. Descriptive sensory analysis of pork M. longissimus lumborum and backfat samples

The results for the descriptive sensory analysis on meat from the experimental treatments are shown in Table 4.69. It indicates that only Piggy (old musty) fat aroma was significantly ($p<0.1$) influenced by dietary treatment. Backfat from pigs receiving SFO supplemented diets showed a trend towards higher Piggy (old musty) aroma, compared to backfat from pigs receiving CLA supplemented diets. Backfat from the 90 kg CLA supplemented gilts had significantly ($p<0.1$) lower Piggy (old musty) fat aroma, compared to backfat from the 90 kg SFO supplemented gilts (Table 4.69). Only the Livery (metallic/bloody) meat aroma was significantly ($p<0.05$) influenced by slaughter weight (Table 4.69). Meat from the 90 kg CLA supplementation group had significantly ($p<0.05$) lower Livery aroma compared to meat from the 70 kg SFO supplementation (Table 4.69).

Table 4.69: Descriptive sensory analysis of pork *M. longissimus lumborum* and fat samples of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	**70**		**90**		**Significance level**
Diet	**SFO**	**CLA**	**SFO**	**CLA**	
Fat Aroma:					
Fresh pork fat	5.41 ± 0.90	5.53 ±0.78	5.49 ± 0.78	5.61 ± 0.82	NS
Roast pork fat (Caramel)	5.23 ± 0.98	5.34 ± 1.02	5.30 ± 1.02	5.41 ± 1.04	NS
Chemical	1.49 ± 0.61	1.37 ± 0.54	1.35 ± 0.54	1.33 ± 0.65	NS
Sour	1.31 ± 0.49	1.29 ± 0.48	1.31 ± 0.49	1.24 ± 0.49	NS
Piggy (Old musty)	1.97 ± 0.82^{bc}	1.81 ± 0.88^{ab}	2.01 ± 0.96^{c}	1.74 ± 0.73^{a}	p<0.1
Meat Aroma:					
Roast pork meat	4.56 ± 0.74	4.63 ± 0.79	4.59 ± 0.90	4.62 ± 0.80	NS
Cooked pork meat (fresh)	5.36 ± 0.82	5.40 ± 0.82	5.51 ± 0.76	5.60 ± 0.72	NS
Musty	1.47 ± 0.64	1.46 ± 0.63	1.45 ± 0.63	1.38 ± 0.65	NS
Livery (metallic/bloody)	1.83 ± 0.65^{b}	1.72 ± 0.65^{ab}	1.71 ± 0.69^{ab}	1.57 ± 0.59^{a}	p<0.05
Juiciness of Meat:					
Initial impression of juiciness	4.73 ± 0.93	4.70 ± 0.98	4.66 ± 1.06	4.61 ± 1.08	NS
Sustained Impression of Juiciness-Meat	4.34 ± 0.77	4.36 ± 0.92	4.11 ± 0.84	4.21 ± 0.98	NS
Meat Texture:					
First bite	5.23 ± 1.00^{bc}	5.28 ± 1.17^{c}	4.95 ± 1.18^{a}	4.98 ± 1.17^{ab}	p<0.1
Tenderness	5.02 ± 0.85^{b}	5.05 ± 0.99^{b}	4.65 ± 1.04^{a}	4.77 ± 0.96^{ab}	p<0.01
Muscle fibre residue & overall tenderness	4.55 ± 0.93^{ab}	4.75 ± 1.02^{b}	4.41 ± 1.14^{ab}	4.36 ± 0.99^{a}	p<0.05
Meat Flavour:					
Typical pork (bland)	4.94 ± 0.81	5.01 ± 0.80	4.94 ± 0.81	4.90 ± 0.89	NS
Metallic (tin/aluminium)	1.84 ± 0.66	1.91 ± 0.64	1.74 ± 0.63	1.77 ± 0.65	NS
Cooked pork	5.48 ± 0.63	5.43 ± 0.71	5.42 ± 0.65	5.44 ± 0.76	NS
Sour	2.17 ± 0.70	2.02 ± 0.78	2.10 ± 0.69	2.01 ± 0.64	NS
After Taste (Off flavour of meat):					
Metallic	1.71 ± 0.61	1.69 ± 0.68	1.64 ± 0.63	1.62 ± 0.65	NS
Sour	2.07 ± 0.67^{b}	1.87 ± 0.61^{a}	1.96 ± 0.63^{ab}	1.88 ± 0.54^{ab}	p<0.1

Means with different superscripts in the same row differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

No significant differences were observed regarding the juiciness of meat (Initial impression of juiciness, as well as sustained impression of juiciness) between treatments (Table 4.69). Texture of meat (First bite, Tenderness and Muscle fibre residue and overall tenderness) was significantly (at least p<0.1) influenced by slaughter weight (Table 4.69). Meat samples for the 70 kg slaughter weight group was perceived to have a significantly (p<0.1) higher, thus better First bite texture score, compared to the 90 kg slaughter weight group. The 90 kg slaughter weight groups' meat was perceived to be significantly (p<0.01) tougher than meat samples from the 70 kg slaughter weight groups. Meat samples from the 70 kg CLA supplemented group had significantly (p<0.05) more Muscle fibre residue and overall tenderness than the 90 kg CLA supplemented group (Table 4.69).

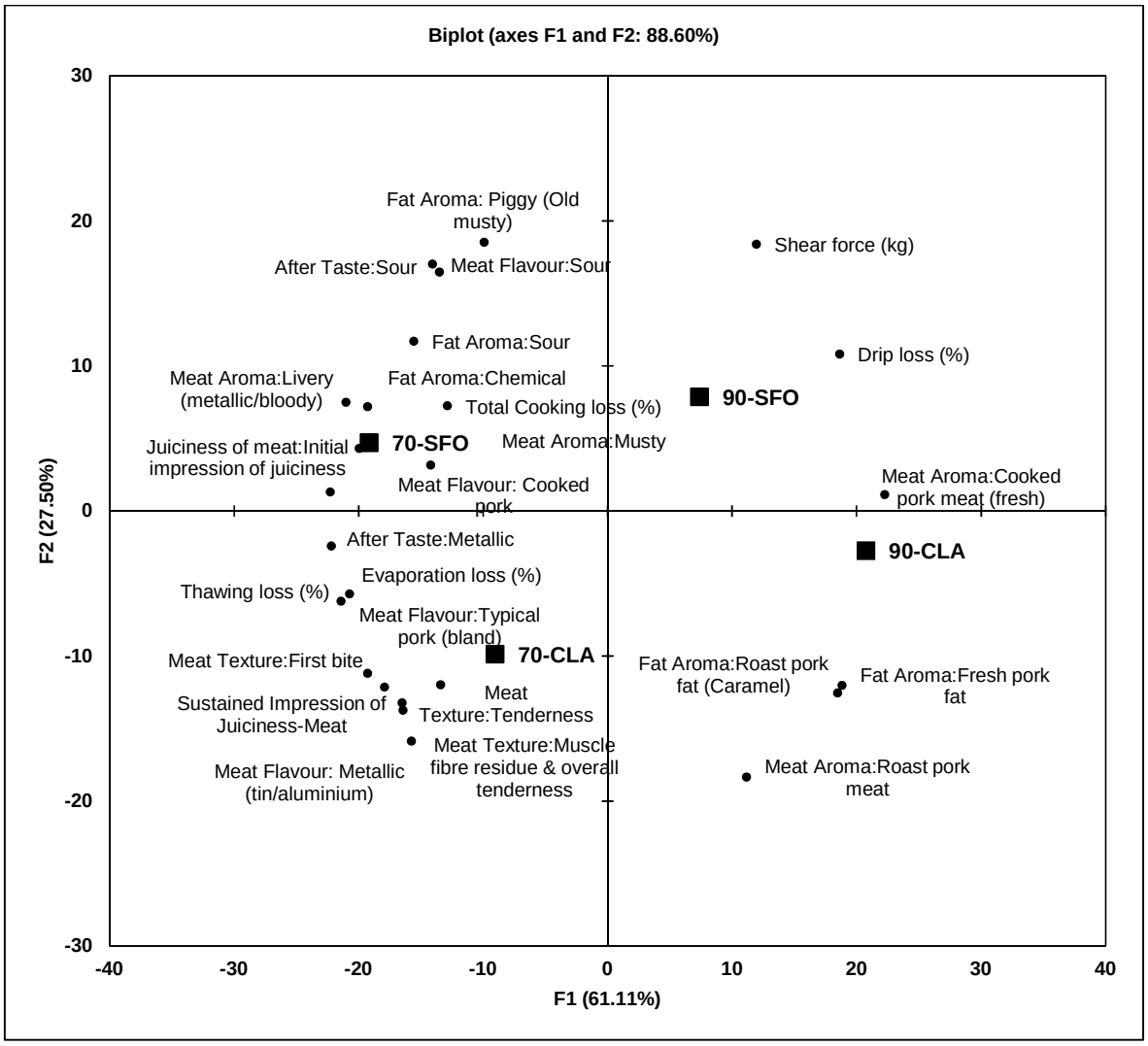
Table 4.69 indicates that the Sour after taste was significantly ($p<0.1$) influenced by dietary treatment with pork from the 70 kg SFO group having a significantly ($p<0.1$) higher score for Sour after taste than pork from the 70 kg CLA group. The general trend was that meat from SFO treatments had a higher score for Sour after taste, compared to meat from CLA treatments. Flavour of meat (Typical pork, Metallic, Cooked pork and Sour) was not significantly influenced by either diet or slaughter weight (Table 4.69). Results from literature regarding the effect of dietary CLA supplementation are somewhat contradictory. According to Dugan et al. (1999), Thiel-Cooper et al. (1999), Wiegand et al. (1999) and Wiegand et al. (2001), dietary CLA had no effect on tenderness, juiciness and flavour intensity, while D'Souza et al. (2002) found that pigs fed CLA had poorer flavour, tenderness, juiciness and overall acceptability.

Physical and descriptive sensory data were visualised in a 2-dimensional space by Principle Component Analysis (PCA) (Figure 4.20). From Figure 4.20 it is clear that dimension 1 explains 61.11% of the variation and that this variation can mostly be attributed to slaughter weight. This implies that slaughter weight had a greater effect on physical and descriptive sensory data than dietary treatment. Attributes like Drip loss, was associated with the 90 kg slaughter weight group, while attributes like evaporation loss and Meat texture: Tenderness was associated with the 70 kg slaughter weight group (Figure 4.20). Dimension 2 (Figure 4.20) indicates that only 27.50% of the variation between treatment groups could be attributed to dietary treatment. Dimension 2 clearly indicates that dietary treatment only had a slight effect on the physical and descriptive sensory properties of meat. Attributes like Fat Aroma: Piggy and After Taste: Sour are associated with fat and meat from SFO supplemented pigs.

4.7.1.2. Consumer sensory analysis of pork M. longissimus lumborum

Table 4.70 shows that the consumer sensory panel consisted out of 68% females and 32% males. The highest proportion of members was in the 20-29 year age groups (40%). The results for the consumer sensory analysis are summarized in Table 4.71. It indicates that general preference ($p<0.1$), taste ($p<0.05$) and tenderness ($p<0.001$) were significantly influenced by dietary treatment. The 90 kg CLA supplemented gilts scored significantly higher in terms of general preference and taste, compared to the 90 kg SFO supplemented gilts (Table 4.71).

From a tenderness point of view, the 70 kg CLA supplemented gilts scored significantly ($p<0.001$) higher compared to the 70 kg SFO supplemented gilts. Although not statistically significant, meat from the 90 kg CLA group also received a higher score for meat tenderness, compared to the 90 kg SFO slaughter weight group (Table 4.71). Although aroma was not significantly influenced by dietary treatment or slaughter weight, samples from the 90 kg CLA supplemented gilts scored higher than the 90 kg SFO supplemented gilts (Table 4.71).



CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.20: Multivariate analysis of physical and sensory characteristics of pork *M. longissimus lumborum* and fat samples of gilts from the experimental treatment groups (n = 10 per treatment)

Table 4.70: Demographic profile of 75 member consumer sensory panel

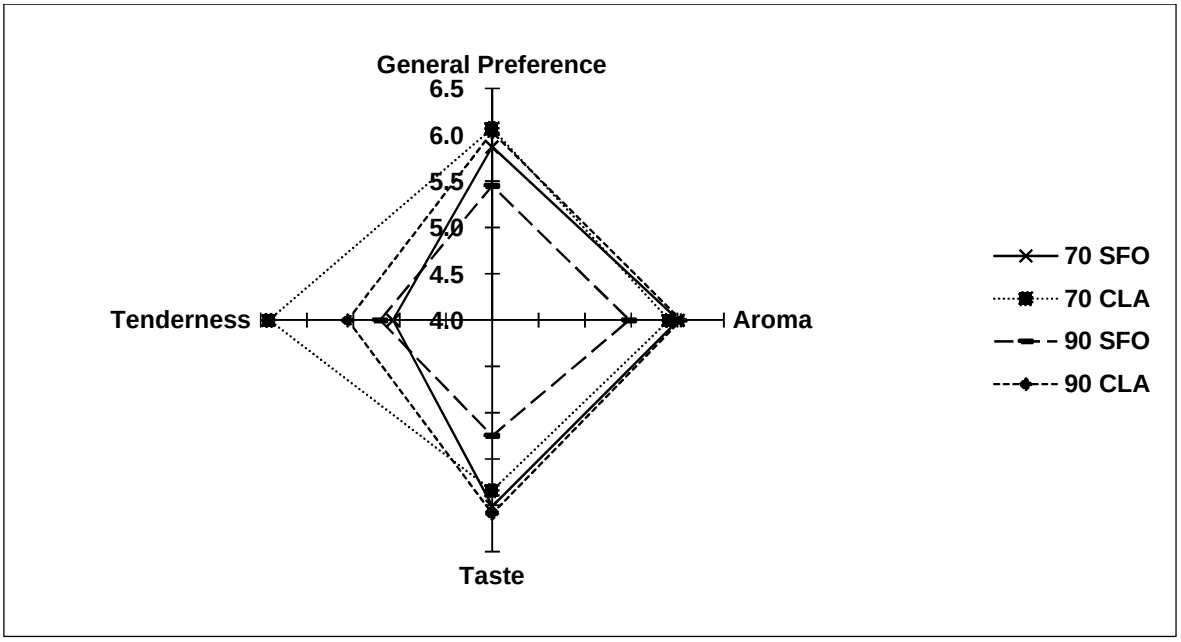
Gender	**% Of Total**	**Age**	**% Of Total**
Female	68	**20 – 29**	40
Male	32	**30 – 39**	22
		40 - 49	16
		50 - 59	18
		>60	4

Figure 4.21 indicates that the sensory attributes from the experimental treatment groups are very much alike. This can be viewed in a positive light, since consumers could not detect the difference between CLA and SFO supplemented pork.

Table 4.71: Consumer sensory analysis of *M. longissimus lumborum* of gilts from the experimental treatment groups (n = 75)

Slaughter weight	Diet	General preference	Aroma	Taste	Tenderness
70	SFO	5.87 ± 1.73^{ab}	6.01 ± 1.68	6.01 ± 1.77^{b}	5.07 ± 1.97^{a}
	CLA	6.07 ± 1.66^{b}	5.91 ± 1.64	5.84 ± 1.88^{ab}	6.41 ± 1.87^{b}
90	SFO	5.45 ± 1.64^{a}	5.48 ± 1.63	5.25 ± 1.83^{a}	5.21 ± 1.89^{a}
	CLA	6.03 ± 1.59^{b}	6.04 ± 1.56	6.09 ± 1.69^{b}	5.56 ± 1.85^{a}
Significance level		p<0.1	NS	p<0.05	p<0.001

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil



CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.21: Spider plot of consumer sensory properties of *M. longissimus lumborum* of gilts from the experimental treatment groups (n = 75)

4.7.2. Histological studies on M. longissimus lumborum

Meat tenderness is a very important meat quality parameter (Joo et al., 2013) and is related to the structural properties of skeletal muscle (Došler, Polak, Žlender, & Gašperlin, 2007). Results of the effect of dietary treatment and slaughter weight on meat tenderness in the current study were inconclusive (Tables 4.69 and 4.71). It was therefore decided to study histological properties such as MFL and muscle fibre types of the meat. Shorter MFL are associated with an increase in tenderness (Došler et al., 2007). One would therefore expect a decrease in MFL over a 5 day storage period, compared to the 2 day storage period illustrated in Figure 4.22. Figure 4.22 (a) illustrates long MFL and Figure 4.22 (b) illustrates short MFL.

According to the descriptive and consumer sensory analysis (Tables 4.69 and 4.71) meat from the 70 kg CLA supplemented gilts obtained higher scores for tenderness related attributes.

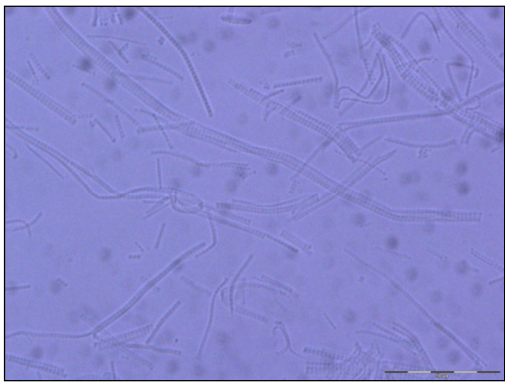
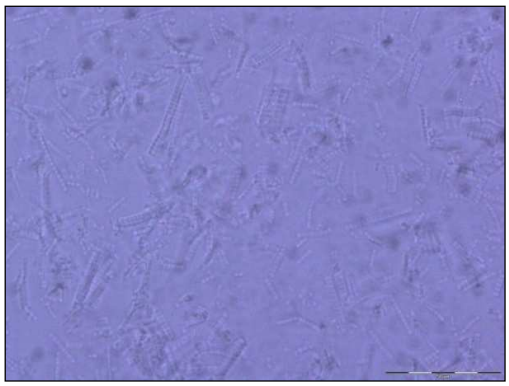
(a)  (b) 

Figure 4.22: (a) Myofibrillar fragment lengths after two days; (b) Myofibrillar fragment lengths after five days

Table 4.72: Myofibrillar fragment lengths of *M. longissimus lumborum* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	AVG DAY2	AVG DAY5
70	**SFO**	28.82 ± 3.14[a]	24.53 ± 2.88[a]
	CLA	38.88 ± 5.49[b]	33.26 ± 4.21[b]
90	**SFO**	40.56 ± 5.24[b]	34.46 ± 4.24[b]
	CLA	37.59 ± 4.75[b]	33.91 ± 4.27 [b]
Significance level		p<0.001	p<0.001

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

The MFL failed to confirm these findings (Table 4.72). In fact, the 70 kg CLA supplemented gilts had significantly ($p<0.001$) longer MFL, compared to the 70 kg SFO supplemented gilts at day 2and day 5 (Table 4.72). For the 90 kg slaughter weight group no significant differences were observed for SFO vs. CLA treatments (Table 4.72). Carcass mass had a more pronounced effect, with MFL of muscle from the 90 kg slaughter weight groups significantly ($p<0.001$) longer than the MFL from the 70 kg slaughter weight groups for both 2 and 5 days of storage. In a further attempt to explain the sensory tenderness preference of meat from the 70 kg CLA supplemented gilts, muscle fibre typing was performed (Figure 4.23). Figure 4.23 (a) and (b) indicates the light cells as white muscle fibres, the greyish cells indicate the intermediate muscle fibres and the dark cells indicate the red muscle fibres. As a rule, the red muscle fibres are surrounded by intermediate muscle fibres (Figure 4.23).

The data in Table 4.73 indicates that muscle fibre type (% red fibre and % white fibre) was significantly influenced by slaughter weight. The 90 kg slaughter weight groups had significantly ($p<0.001$) less red muscle fibres and more white muscle fibres, compared to the 70 kg slaughter weight groups (Table 4.73). This finding is in agreement with Migdal et al. (2004), who reported that increased muscle growth rate and increased carcass weight lead to a decrease in the proportion of red fibres and an increase in the proportion of white fibres, which can result in less

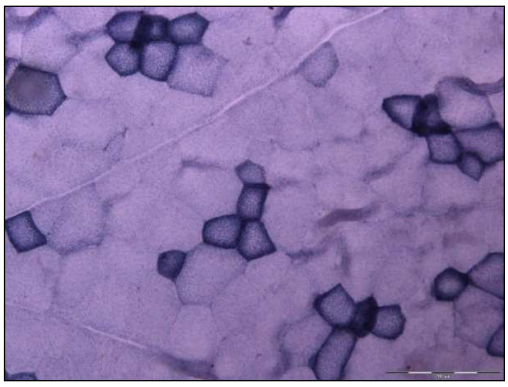
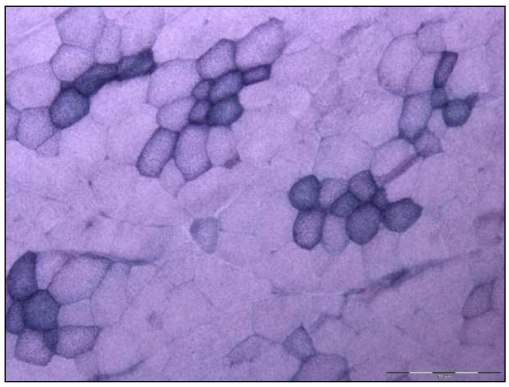
(a)  (b) 

Figure 4.23: (a) Muscle fibre typing of *M. longissimus lumborum* for 70 kg CLA gilts; (b) Muscle fibre typing of *M. longissimus lumborum* for 90 kg CLA gilts

tender and less red meat. According to Joo et al. (2013), a high proportion of red muscle fibres are associated with a high cooked meat flavour. Table 4.69 indicates that the 70 kg slaughter weight group had a slightly higher cooked meat flavour.

Table 4.73: Muscle fibre typing of pork *M. longissimus lumborum* of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	% Red fibre	% Intermediate fibre	% White fibre
70	**SFO**	23.35 ± 1.80^{b}	31.89 ± 3.24	44.76 ± 2.87^{a}
	CLA	22.97 ± 2.46^{b}	31.60 ± 3.07	45.42 ± 3.06^{a}
90	**SFO**	20.43 ± 1.13^{a}	31.12 ± 3.33	49.08 ± 2.55^{b}
	CLA	19.91 ± 2.60^{a}	30.12 ± 2.77	49.97 ± 2.83^{b}
Significance Level		$p<0.01$	NS	$p<0.001$

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

No significant differences in muscle fibre type could be attributed to dietary treatment (Table 4.73). There was, however, a trend for meat from the CLA treated treatment groups to have a lower content of red muscle fibres and a higher content of white muscle fibres (Table 4.73). This trend is in agreement with the findings of Migdal et al. (2004), who found that dietary CLA supplementation increased the number and diameter of white muscle fibres and correspondingly reduced the number and diameter of red fibres. This could explain why the CLA supplemented groups had higher *L**-values. Joo et al. (2013) reported that an increased amount of white muscle fibres resulted in higher *L**-values. Although not statistically significant, the SFO supplemented groups had an increased amount of red muscle fibres (Table 4.73). This increase in red muscle fibres could result in decreased colour stability (Joo et al., 2013).

Pearson correlation analysis was performed to determine the relationship between tenderness related parameters (Table 4.74). Shear force had a significantly ($p<0.1$) positive

Table 4.74: Pearson correlation analysis between selected meat quality parameters

	Shear force (kg)	Live weight (kg)	% IMF	C18:2c9,t11 (n-6) CLA (mg/100 g muscle)	C18:2t10,c12 (n-6) CLA (mg/100 g muscle)	% Red fibre	%Intermediate fibre	% White fibre	MFL Avg DAY2	MFL Avg DAY5
Shear force (kg)	1	0.3109*	0.3337**	-0.0875	-0.0617	-0.09	-0.2569	0.2252	0.1496	0.1052
Live weight (kg)		1	0.2489	-0.0091	-0.0762	-0.5376****	-0.2257	0.6411****	0.3743**	0.4626***
% Fat			1	0.2573	0.0775	-0.269	-0.1221	0.2169	0.1567	0.1201
C18:2c9,t11(n-6) CLA (mg/100 g muscle)				1	0.9302****	-0.155	-0.0316	0.079	0.2426	0.3189**
C18:2t10,c12(n-6) CLA (mg/100 g muscle)					1	-0.095	-0.0298	0.0514	0.3147**	0.3772**
% Red fibre						1	-0.1747	-0.5810****	-0.4319***	-0.4634***
%Intermediate fibre							1	-0.6547****	0.0397	-0.0623
%White fibre								1	0.3484**	0.4319***
MFL Avg DAY2									1	0.8369****
MFL Avg DAY5										1

CLA = Conjugated linoleic acid; IMF = Intramuscular fat; MFL = Myofibrillar fragment lengths; * = p<0.1; ** = p<0.05; *** = p<0.01; **** = p<0.001

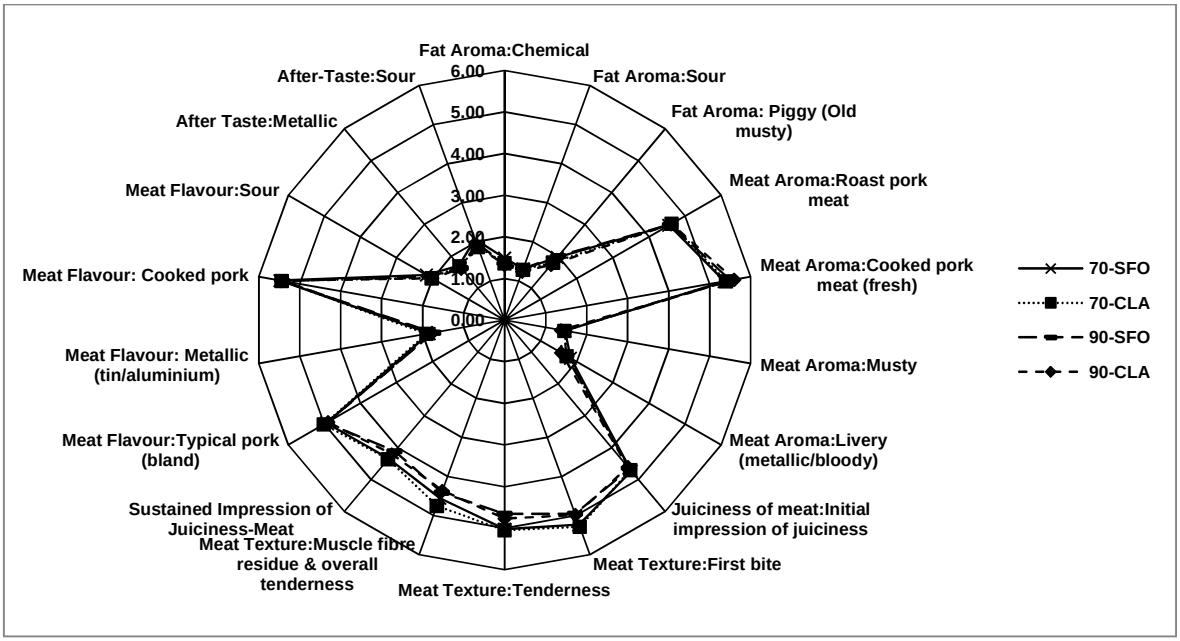
correlation with live weight and % IMF ($p<0.05$) (Table 4.74). That means that heavier animals and meat with higher IMF content had tougher meat. The 90 kg slaughter weight group had the highest amount of IMF (Table 4.58). It is generally accepted that an increased level of IMF has a positive influence on sensory attributes of pork (Fernandez et al., 1999). Live weight had a significantly ($p<0.001$) negative correlation to % red muscle fibres and positively correlated to % white muscle fibres and MFL after two days ($p<0.05$) and 5 days ($p<0.01$) (Table 4.74). Both the CLA isomers (C18:2*c*9, *t*11 and C18:2*t*10, *c*12) had a significantly ($p<0.05$) positive correlation to MFL after 5 days (Table 4.74). Only C18:2*t*10, *c*12 was significantly ($p<0.05$) positively correlated to MFL after 2 days (Table 4.74). It therefore seems that the actual CLA content of the different CLA isomers were linked to the toughness of meat. Myofibrillar fragment lengths after 2 days had a very high significant ($p<0.001$) positive correlation to MFL after 5 day (Table 4.74). Red muscle fibre percentage was significantly negatively correlated to % white muscle fibres ($p<0.001$), MFL after 2 and 5 days ($p<0.01$) (Table 4.74). Intermediate muscle fibre percentage was significantly ($p<0.001$) negatively correlated to % white muscle fibres (Table 4.74). Increased white muscle fibre content (Midgal et al., 2004) and increased MFL after 2 and 5 days (Došler et al., 2007) can lead to tougher meat.

Descriptive sensory analysis (Table 4.69), consumer sensory analysis (Table 4.71) and PCA (Figure 4.20) demonstrated the small effect of dietary treatment on sensory and physical characteristics. In light of this, it was decided to use a spider plot to construct a sensory and physical fingerprint for each treatment group. Figure 4.24 indicates clearly that the fingerprints of sensory and physical characteristics of the treatment groups are very similar. This can be considered as positive, since it illustrates that the inclusion of CLA at the commercial recommended level of 0.5% in pork diets had no effect on the sensory and physical attributes of pork.

4.8. Chemical and oxidative stability studies

4.8.1. Accelerated fat oxidation test

The Rancimat accelerated fat oxidation test was performed on extracted lipid from the backfat of gilts from the experimental treatment groups. This was done to compare the oxidative stability of subcutaneous fat from the different dietary treatments. Table 4.75 clearly indicates that OSI was not significantly influenced by dietary treatment. This table also indicated that backfat from the SFO supplemented groups had numerically higher OSI values, compared to the backfat from the CLA supplemented groups. Backfat from the 90 kg SFO supplemented group had a significantly ($p<0.05$) higher OSI value than the backfat from the 70 kg CLA supplemented group. This is completely unexpected, since backfat from the 70 kg CLA supplemented group had a significantly more saturated fatty acid profile, compared to the backfat from the 90 kg SFO supplemented group (Table 4.34). From Table 4.75 it seems that dietary CLA acted as a pro-oxidant. According to Hur et al. (2007), CLA can act as a pro-oxidant. Szymczyk (2005) stated that oxidation may occur when



CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.24: Graphical presentation by means of a spider plot of the sensory and physical properties of the pork *M. longissimus lumborum* and fat samples of gilts from the experimental treatment groups (n = 10 per treatment)

the concentration of the *cis*-9, *trans*-11 CLA isomer is above 200 µM. According to Figure 4.10, the concentration of the *cis*-9, *trans*-11 CLA isomer was approximately 180 µM.

Table 4.75: Oxidative stability index of backfat of gilts from the experimental treatment groups (n = 10 per treatment)

Slaughter weight	Diet	Oxidative stability index
70	**SFO**	5.18 ± 1.56[ab]
	CLA	4.37 ± 1.80[a]
90	**SFO**	6.50 ± 1.70[b]
	CLA	5.27 ± 2.17[ab]
Significance level		p<0.05

Means with different superscripts in the same column differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

4.8.2. Colour and lipid stability of fresh and frozen pork

The results of a chemical shelf life study, performed on pork chops for 7 days at 4 ℃ and -18 ℃ for 6 months, are shown in Tables 4.76 – 4.79 and Figures 4.25 – 4.26. Table 4.76 indicates that the *L**-value of backfat at day 7 was not significantly influenced by dietary treatment within slaughter weight groups. Backfat from the 90 kg SFO supplemented group had significantly (p<0.05) higher *L**-value compared to the backfat from the 70 kg CLA supplemented group. This indicates a whiter backfat in the 90 kg SFO group. Although no statistical significant, differences

Table 4.76: Backfat colour stability of fresh pork chops from the experimental treatment groups stored at 4 ℃ (n = 10 per treatment)

Slaughter weight	Diet	*L** - value		*a** - value		*b** - value		Chroma		Hue angle	
		Day 0	Day 7	Day 0	Day 7	Day 0	Day 7	Day 0	Day 7	Day 0	Day 7
70	SFO	74.05 ± 2.32^{ab}	70.54 ± 2.16	5.49 ± 1.29^{b}	4.87 ± 0.71^{ab}	7.75 ± 0.78^{b}	7.73 ± 1.10^{ab}	9.52 ± 1.33^{b}	9.16 ± 1.11^{ab}	55.13 ± 4.37^{ab}	57.67 ± 4.43^{b}
	CLA	72.61 ± 2.02^{a}	71.49 ± 1.96	5.54 ± 0.79^{b}	5.40 ± 0.80^{bc}	7.57 ± 0.75^{b}	8.46 ± 0.72^{b}	9.39 ± 1.00^{b}	10.05 ± 0.84^{b}	53.87 ± 2.49^{ab}	57.50 ± 3.88^{b}
90	SFO	75.92 ± 1.58^{b}	71.49 ± 2.01	4.22 ± 0.76^{a}	4.75 ± 0.77^{a}	6.21 ± 0.74^{a}	7.47 ± 0.97^{ab}	7.52 ± 1.00^{a}	8.87 ± 1.10^{a}	55.94 ± 2.71^{b}	57.53 ± 3.66^{b}
	CLA	74.39 ± 2.44^{ab}	72.03 ± 1.88	5.15 ± 0.78^{ab}	5.48 ± 0.51^{c}	6.60 ± 0.75^{a}	7.17 ± 0.76^{a}	8.38 ± 0.98^{ab}	9.03 ± 0.78^{ab}	52.10 ± 3.03^{a}	52.55 ± 3.01^{a}
Significance level		p<0.05	NS	p<0.05	p<0.1	p<0.001	p<0.05	p<0.01	p<0.05	p<0.1	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

were observed within the 70 kg and 90 kg slaughter weight groups for *L** -values. The SFO supplemented groups generally had higher *L**-values at day 0 (Table 4.76). Although no statistical significant differences were observed for *L**-value of backfat after 7 days of storage: backfat from both the 70 kg and 90 kg CLA supplemented groups had numerically higher *L**-values, compared to the backfat from both the 70 kg and 90 kg SFO supplemented groups (Table 4.76). This may be an indication that whiteness of backfat from CLA supplemented groups deteriorates less during refrigerated storage than backfat from the SFO supplemented groups and can be regarded as a positive attribute.

As far as *a**-values of backfat at day 0 were concerned, both the 70 kg slaughter weight groups had significantly ($p<0.05$) higher *a**-values, compared to the 90 kg SFO supplemented group (Table 4.76). After 7 days of storage, the *a**-value of backfat was significantly ($p<0.1$) influenced by dietary treatment, with the backfat from the 90 kg CLA supplemented group having significantly ($p<0.1$) higher *a**-values compared to both of the SFO supplemented groups.

The *b**-values for backfat at day 0 were significantly ($p<0.001$) influenced by slaughter weight (Table 4.76). The 90 kg slaughter weight groups had significantly lower *b**-values compared to the 70 kg slaughter weight groups (Table 4.76). After 7 days of storage at 4 ℃, this trend was continued within the CLA supplemented groups with backfat from the 70 kg slaughter weight group having significantly ($p<0.05$) higher *b**-values compared to the 90 kg slaughter weight group (Table 4.76). Chroma values for backfat at day 0 was significantly ($p<0.01$) influenced by slaughter weight. The 90 kg SFO supplemented group had significantly ($p<0.01$) lower Chroma values compared to the 70 kg CLA and 70 kg SFO supplemented slaughter weight groups (Table 4.76). After 7 days of storage, Chroma value was significantly ($p<0.05$) influenced by slaughter weight and diet. The 70 kg CLA supplemented group had a significantly ($p<0.05$) higher Chroma value compared to the 90 kg SFO supplemented group (Table 4.76). Higher Chroma values for backfat from the 70 kg slaughter weight groups indicate a more pronounced red colour (Table 4.76). Hue angle at day 0 was significantly ($p<0.1$) influenced by dietary treatment within the 90 kg slaughter weight group. The 90 kg CLA supplemented group had a significantly ($p<0.1$) lower Hue angle compared to the 90 kg SFO supplemented group (Table 4.76). This Hue angle difference persisted during refrigerated storage. The Hue angle for backfat from the 90 kg CLA group was still significantly ($p<0.05$) lower than those of backfat from the 90 kg SFO group (Table 4.76). The effect of dietary CLA on the *L**-, *a**- and *b**-value can be attributed to CLA's ability to act as an antioxidant (Szymczyk, 2005).

Lipid stability of backfat, during refrigerated storage of pork chops, was measured by the PV (Table 4.77). As expected, no significant differences were observed during day 0 of refrigerated storage. Lipid stability was only significantly ($p<0.001$) influenced by slaughter weight after 7 days of storage. Backfat from the 90 kg slaughter weight groups had a significantly lower PV compared to the PV of backfat from the 70 kg slaughter weight groups. As indicated in Table 4.25, backfat from the 90 kg slaughter weight group had a more saturated fatty acid profile.

Table 4.77: Backfat lipid stability of fresh pork chops from the experimental treatment groups stored at 4 ℃ (n = 10 per treatment)

Slaughter weight	Diet	PV	
		Day 0	Day 7
70	SFO	1.60 ± 0.17	3.54 ± 1.37[b]
	CLA	1.84 ± 0.60	3.73 ± 1.11[b]
90	SFO	1.64 ± 0.50	1.88 ± 0.49[a]
	CLA	1.47 ± 0.36	1.78 ± 0.28[a]
Significance level		NS	p<0.001

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

These findings confirmed the results of Wood et al. (1989) that backfat from heavier pigs are more mature and has a more saturated fatty acid profile, compared to the backfat of lighter pigs, which is more immature and has a more unsaturated fatty acid profile.

Table 4.78 indicates that muscle *L**-values was significantly (p<0.01) influenced by dietary treatment, especially between the 70 kg SFO and 70 kg CLA supplemented groups. The 70 kg CLA supplemented group had a significantly (p<0.01) higher *L**-value compared to the 70 kg SFO supplemented group at day 0. The lighter muscle colour of CLA supplemented pigs can possibly be attributed to the trend that CLA supplemented pigs had a higher white muscle fibre content (Table 4.73) (Migdal et al., 2004). After 7 days of storage at 4 ℃, no significant differences were observed for *L**-value between the dietary or slaughter weight groups (Table 4.78). Since consumers associate pork quality with a high intensity pink colour (Rosenvold et al., 2003b; Tikk et al., 2008; Joo et al., 2013), researchers are mostly interested in the *a**-value when considering the colour of pork muscle. The *a**-value was significantly (p<0.01) influenced by dietary treatment at day 0 (Table 4.78). Muscle from the 70 kg CLA supplemented group had a significantly (p<0.01) higher *a**-value compared to the 70 kg and 90 kg SFO supplemented groups (Table 4.78). Muscle from the 90 kg CLA supplemented group had a significantly (p<0.01) higher *a**-value compared to the 70 kg SFO supplemented group at day 0. Although not statistically significant, muscle from the 90 kg CLA group also had a higher *a**-value compared to muscle from the 90 kg SFO group at day 0. The significant difference in *a**-value between the 70 kg CLA supplemented group and 70 kg SFO supplemented group at day 0 can be attributed to the trend that the 70 kg SFO supplemented group had a slightly higher red muscle fibre content (Table 4.73). The slightly higher red muscle fibre content of SFO supplemented pigs (Table 4.73) is known to increase the redness and myoglobin content of meat (Joo et al., 2013). An increase in the proportion of red muscle fibres decreases colour stability with a possible shift to a brownish metmyoglobin colour (Joo et al., 2013). The significant (p<0.01) difference between the 70 kg CLA supplemented group and 90 kg SFO supplemented group for *a**-values can be attributed to the possible antioxidant properties of CLA (Szymczyk, 2005). This confirms findings that there is a relationship between lipid and pigment oxidation. After 7 days of storage at 4 ℃, no significant differences were observed for *a**-

Table 4.78: Colour stability of muscle from fresh pork chops from the experimental treatment groups stored at 4 ℃ (n = 10 per treatment)

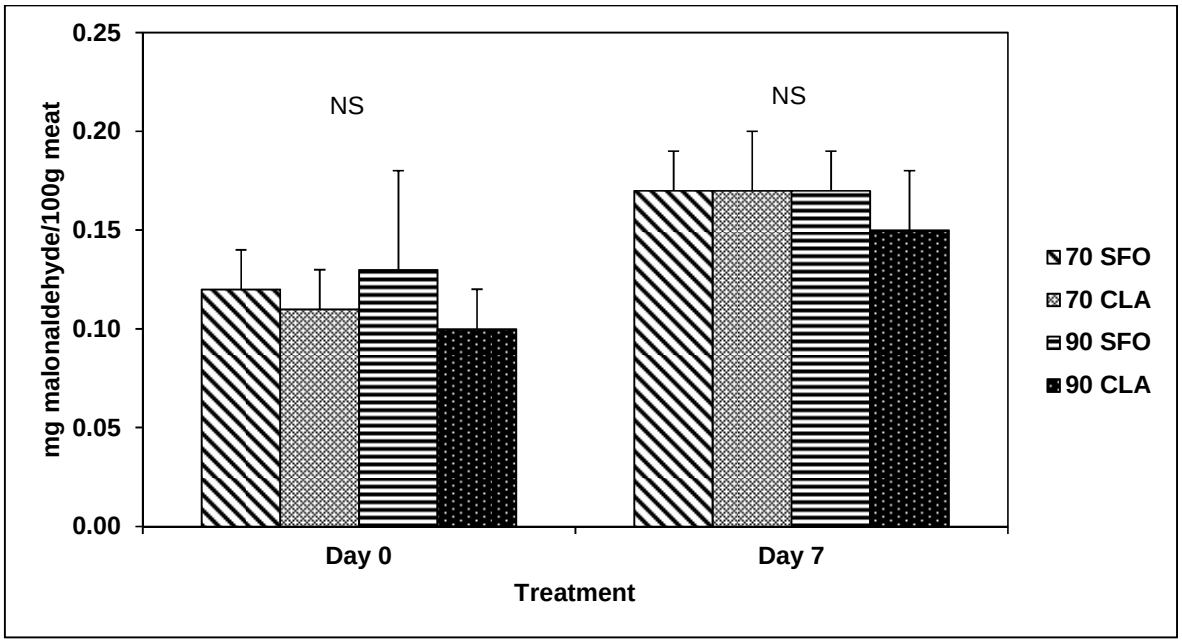
Slaughter weight	Diet	*L** - value		*a** - value		*b** - value		Chroma		Hue angle	
		Day 0	Day 7	Day 0	Day 7	Day 0	Day 7	Day 0	Day 7	Day 0	Day 7
70	SFO	52.59 ± 1.31^{a}	53.12 ± 1.30	7.33 ± 0.88^{a}	5.74 ± 1.00	6.39 ± 0.73^{a}	7.52 ± 1.25	9.73 ± 1.08^{a}	9.47 ± 1.54	41.07 ± 2.33	52.69 ± 3.03
	CLA	56.48 ± 1.65^{b}	53.35 ± 1.94	9.51 ± 1.17^{c}	5.94 ± 0.68	8.17 ± 1.06^{b}	7.48 ± 0.99	12.55 ± 1.45^{b}	9.59 ± 0.83	40.63 ± 2.96	51.37 ± 5.24
90	SFO	54.98 ± 2.96^{ab}	53.43 ± 2.52	8.02 ± 1.26^{ab}	5.38 ± 0.79	7.37 ± 1.30^{ab}	7.18 ± 0.91	10.91 ± 1.72^{ab}	8.99 ± 1.00	42.50 ± 3.27	53.07 ± 4.28
	CLA	55.14 ± 2.64^{ab}	53.65 ± 1.59	8.82 ± 1.35^{bc}	5.81 ± 0.87	8.43 ± 1.53^{b}	7.87 ± 1.05	12.22 ± 1.92^{b}	9.83 ± 0.92	43.52 ± 3.15	53.45 ± 5.86
Significance level		p<0.01	NS	p<0.01	NS	p<0.01	NS	p<0.01	NS	NS	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

value between either the dietary or slaughter weight groups (Table 4.78). Pettigrew, & Esnaola, (2001) reported that CLA was only capable of protecting fat against oxidation for 1 day of storage. Muscle *b**-values at day 0 was also significantly ($p<0.01$) influenced by dietary treatment within the 70 kg slaughter weight group (Table 4.78). The 70 kg and 90 kg CLA supplemented groups had significantly higher *b**-values compared to the 70 kg SFO supplemented group. Although not statistically significant, muscle from the 90 kg CLA group also had higher *b**-values compared to muscle from the 90 kg SFO group at day 0. After 7 days of storage at 4 ℃ nosignificant differences were observed for *b**-values of muscle (Table 4.78). The effect of CLA supplementation on meat colour supports the findings of Szymczyk (2005), who reported that dietary CLA resulted in larger *L**-, *a**- and *b**-values. These results may support the hypothesis that CLA enriched meat has higher oxidative stability. The higher *L**- and *b**-values of muscle of CLA supplemented pigs can possibly be explained by CLA's ability to act as an antioxidant (Szymczyk, 2005) and possibly also by the trend that CLA supplemented pigs had slightly higher white muscle fibre content (Table 4.73) (Migdal et al., 2004).

Lipid stability of muscle during refrigerated storage was determined by TBARS analyses. Figure 4.25 indicates that TBARS was not significantly influenced by dietary treatment or slaughter weight. Although not statistically significant, the CLA supplemented groups had a slightly lower TBARS at day 0 (Figure 4.25). The same trend was observed after 7 days of storage at 4 ℃ for the 90 kg CLA slaughter weight group. The 90 kg CLA supplemented group had a slightly lower TBARS values compared to all the other treatment groups (Figure 4.25). The slightly lower susceptibility towards oxidation of CLA enriched meat can possibly be attributed to the higher SFA content (Table 4.63) of CLA supplemented meat.

Lipid stability of frozen backfat, stored for 6 months at -18 ℃ (Table 4.79), followed the same trend as the lipid stability of fresh backfat (Table 4.77). The PV was significantly ($p<0.05$) influenced by slaughter weight after 3 months of frozen storage (Table 4.79). The 90 kg CLA supplemented group had a significantly lower PV after 3 months of frozen storage compared to the 70 kg CLA supplemented group. This can most probably be attributed to the more saturated fatty acid profile (Table 4.25) for the 90 kg CLA supplemented group (Wood et al., 1989). The decline in PV after 6 months of frozen storage compared to 3 months may be attributed to the breakdown of peroxides and the formation of secondary oxidation products (Table 4.79). After 6 months of frozen storage no significant influence of dietary treatment or slaughter weight was observed in PV of backfat (Table 4.79). Lipid stability of pork chops stored at -18 ℃ was monitored by TBARS analyses (Figure 4.26). Meat from the 90 kg slaughter weight groups had significantly ($p<0.01$) lower TBARS values compared to meat from the 70 kg slaughter weight groups after 3 months of frozen storage This can be attributed to a more saturated fatty acid profile of muscle from the heavier slaughter weight pigs (Wood et al., 1989). Saturated fat is more stable and less prone to oxidation during frozen storage (Wood et al., 2004).



Bars with different superscripts differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.25: Lipid stability of muscle from fresh pork chops from the experimental treatment groups stored at 4 ℃ (n = 10 per treatment)

Table 4.79: Backfat lipid stability of fresh pork chops from the experimental treatment groups stored at -18 ℃ (n = 10 per treatment)

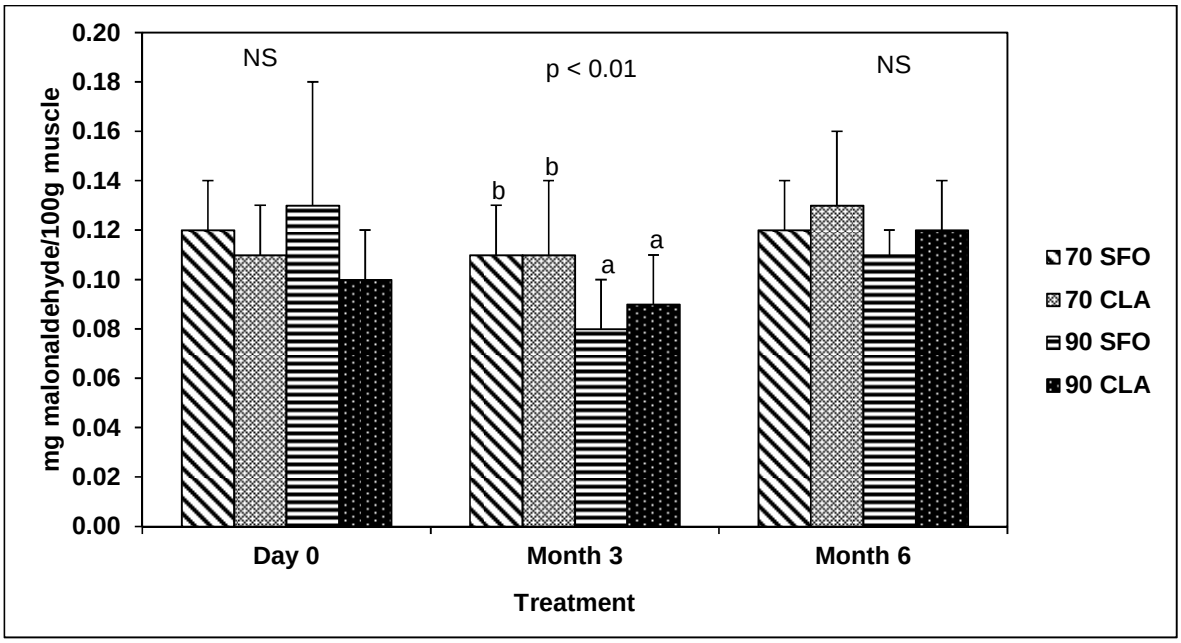
Slaughter weight	Diet	PV		
		Day 0	Month 3	Month6
70	SFO	1.60 ± 0.17	4.77 ± 2.24^{ab}	2.71 ± 0.79
	CLA	1.84 ± 0.60	5.54 ± 1.19^{b}	3.17 ± 0.96
90	SFO	1.64 ± 0.50	3.99 ± 1.64^{ab}	2.34 ± 0.69
	CLA	1.47 ± 0.36	3.39 ± 1.56^{a}	2.38 ± 1.02
Significance level		NS	p<0.05	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Patties, bacon and salami were manufactured from meat from the experimental treatments. Patties were used as an example of a commercial high volume minced meat product. Bacon was used as an example of a high value whole muscle cured meat product. Salami was used as an example of a high value fermented processed meat product.

4.8.3. Oxidative and colour stability of fresh and frozen pork patties

The results of the chemical shelf life study performed on pork patties, for 9 days at 4 ℃ and for 16 weeks at -18 ℃, are shown in Tables 4.80 – 4.82 and Figures 4.27 – 4.28. The colour *L**-value of fresh pork patties were significantly (at least p<0.05) influenced by dietary treatment for days 0,3



Bars with different superscripts differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.26: Lipid stability of muscle from fresh pork chops from the experimental treatment groups stored at -18 ℃ (n = 10 per treatment)

and 6. The 70 kg CLA supplemented group had significantly (at least $p<0.05$) higher *L**-values at days 0, 3 and 6, compared to the 70 kg SFO supplemented group (Table 4.80). This can possibly be attributed to CLA's ability to act as an antioxidant (Szymczyk, 2005). Dietary CLA supplementation resulted in slight, but not statistically significant, increase in white muscle fibres (Table 4.73). Migdal et al. (2004) reported that the increased white muscle fibre content of CLA supplemented pigs may result in increased *L**-values for muscle (Table 4.56). The *a**-value of fresh pork patties was significantly (at least $p<0.01$) influenced by dietary treatment throughout the storage period (Table 4.80). The 90 kg CLA supplemented group had the highest overall *a**-value throughout the storage period, which can possibly be attributed to CLA's ability to act as an antioxidant (Szymczyk, 2005). This is an important finding, since it indicates that dietary CLA supplementation resulted in increased display or shelf life of fresh patties. The consumer will always prefer the product with the brightest red colour. As in the case of *a**-values, the *b**-value of fresh pork patties were significantly (at least $p<0.05$) influenced by dietary treatment throughout the storage period (Table 4.80). The CLA supplemented treatment groups had consistently higher *b**-values, compared to the SFO supplemented groups. Chroma values were also significantly (at least $p<0.05$) influenced by dietary treatment throughout the storage period (Table 4.80). The CLA supplemented groups had a higher Chroma values compared to the SFO supplemented groups. This indicates that patties from the CLA supplemented groups had a more pronounced red colour. Hue angle was also significantly (at least $p<0.01$) influenced by dietary treatment throughout the storage period (Table 4.80). The SFO supplemented groups had higher Hue angle values

compared to the CLA supplemented groups. This indicated that patties from the SFO supplemented groups had a lesser red colour. The effect of dietary CLA on the colour stability of patties corresponds to the colour stability of backfat (Table 4.76) and muscle (Table 4.78). Hur et al. (2007) also reported that dietary CLA supplementation improved the colour stability of pork patties through the inhibition of lipid- and oxymyoglobin oxidation.

Fresh pork patties are extremely susceptible to lipid oxidation because of partial disintegration of the muscle structure during mincing. Mincing facilitates the contact between oxidisable cellular components and pro-oxidants like salt. This leads to the incorporation of air into the tissues, which accelerates the oxidation process. Care has to be exercised when formulating pork patties for long term frozen storage to ensure that oxidation is limited (Hugo et al., 2007).

Table 4.80: Colour stability of fresh pork patties from the experimental treatment groups stored at 4 ℃ (n = 6 per treatment)

Slaughter weight		**70**		**90**		**Significance level**
Diet		**SFO**	**CLA**	**SFO**	**CLA**	
L* **- value**	**Day 0**	60.79 ± 1.39^{a}	63.54 ± 1.37^{b}	61.88 ± 1.38^{a}	62.23 ± 1.32^{ab}	p<0.001
	Day 3	62.65 ± 1.47^{a}	64.85 ± 2.19^{b}	62.95 ± 1.76^{ab}	63.88 ± 1.48^{ab}	p<0.05
	Day 6	64.63 ± 1.77^{a}	66.96 ± 1.35^{b}	65.31 ± 1.58^{ab}	65.78 ± 1.82^{ab}	p<0.05
	Day 9	66.34 ± 1.55	67.35 ± 1.42	66.89 ± 1.57	66.45 ± 1.17	NS
a* **- value**	**Day 0**	5.80 ± 0.40^{a}	6.40 ± 0.64^{ab}	5.91 ± 0.59^{b}	7.48 ± 0.48^{c}	p<0.001
	Day 3	1.79 ± 0.22^{a}	2.08 ± 0.50^{ab}	2.28 ± 0.41^{b}	3.40 ± 0.37^{c}	p<0.001
	Day 6	0.71 ± 0.15^{a}	0.70 ± 0.20^{a}	0.72 ± 0.27^{a}	1.56 ± 0.43^{b}	p<0.001
	Day 9	0.24 ± 0.15^{a}	0.24 ± 0.16^{a}	0.21 ± 0.14^{a}	0.41 ± 0.16^{b}	p<0.01
b* **- value**	**Day 0**	9.63 ± 0.74^{ab}	9.95 ± 0.67^{b}	9.01 ± 0.67^{a}	9.87 ± 0.63^{b}	p<0.01
	Day 3	9.52 ± 0.57^{a}	10.09 ± 0.44^{b}	9.41 ± 0.41^{a}	9.38 ± 0.27^{a}	p<0.01
	Day 6	9.02 ± 0.36^{a}	9.76 ± 0.55^{b}	8.99 ± 0.57^{a}	9.60 ± 0.41^{b}	p<0.001
	Day 9	9.02 ± 0.66^{a}	9.55 ± 0.52^{b}	8.92 ± 0.68^{a}	9.49 ± 0.51^{b}	p<0.05
Chroma	**Day 0**	11.24 ± 0.80^{ab}	11.84 ± 0.86^{bc}	10.78 ± 0.84^{a}	12.39 ± 0.73^{c}	p<0.001
	Day 3	9.69 ± 0.57^{a}	10.22 ± 0.38^{b}	9.69 ± 0.45^{a}	9.99 ± 0.34^{ab}	p<0.05
	Day 6	9.05 ± 0.36^{a}	9.79 ± 0.55^{b}	9.02 ± 0.57^{a}	9.74 ± 0.41^{b}	p<0.001
	Day 9	9.03 ± 0.66^{a}	9.55 ± 0.52^{b}	8.93 ± 0.68^{a}	9.50 ± 0.52^{b}	p<0.05
Hue angle	**Day 0**	58.91 ± 1.44^{c}	57.29 ± 1.67^{bc}	56.78 ± 1.69^{b}	52.86 ± 1.46^{a}	p<0.001
	Day 3	79.34 ± 1.39^{c}	78.38 ± 2.53^{bc}	76.27 ± 2.10^{b}	70.10 ± 1.78^{a}	p<0.001
	Day 6	85.48 ± 0.90^{b}	85.93 ± 1.14^{b}	85.41 ± 1.72^{b}	80.78 ± 2.55^{a}	p<0.001
	Day 9	88.50 ± 0.90^{b}	88.54 ± 0.96^{b}	88.66 ± 0.88^{b}	87.04 ± 1.54^{a}	p<0.01

Means with different superscripts in the same row differed significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Slaughter weight had a significant (p<0.05) effect on the lipid stability of fresh pork patties during the first three days of storage, as measured by PV (Table 4.81). Backfat (Table 4.37) and IMF (Table 4.63) from heavier pigs had a more saturated fatty acid profile and saturated fat is less prone to oxidation (Wood et al., 1989; Wood et al., 2004). Up to 3 days of refrigerated storage, the PV of patties from the 90 kg CLA supplemented group was significantly (p<0.05) lower compared

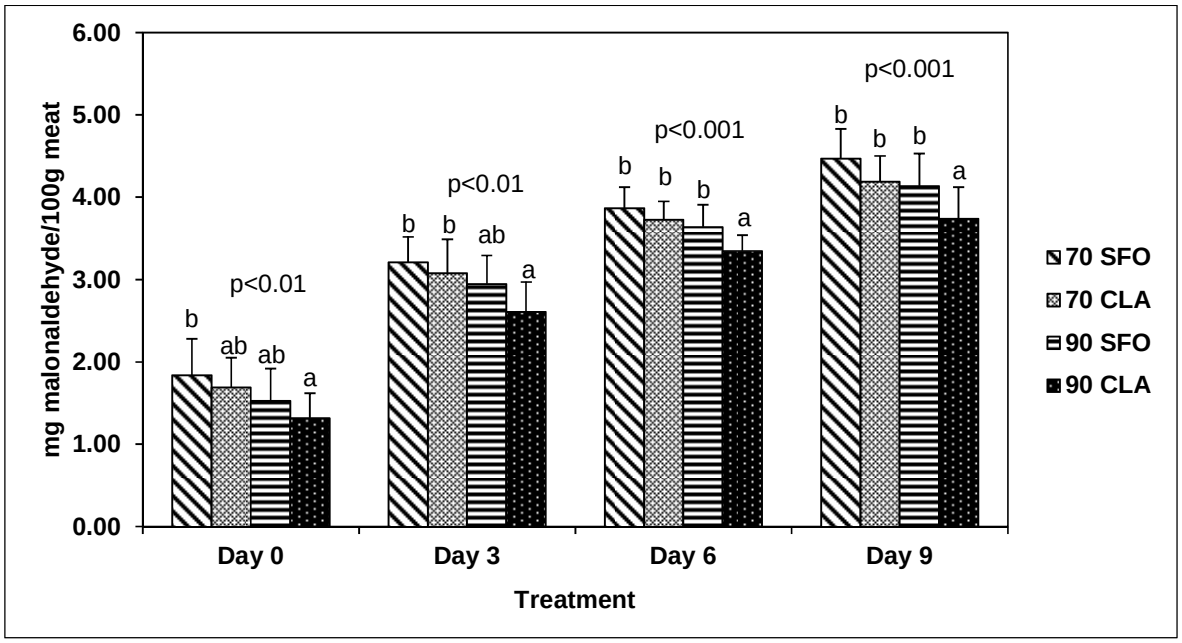
Table 4.81: Lipid stability of fresh pork patties from the experimental treatment groups stored at 4 ℃ (n = 6 per treatment)

Slaughter weight	Diet	PV			
		Day 0	Day 3	Day 6	Day 9
70	SFO	34.19 ± 6.45^{ab}	50.95 ± 10.79^{ab}	56.96 ± 17.67	60.15 ± 15.29
	CLA	38.49 ± 7.84^{b}	52.40 ± 12.49^{b}	56.94 ± 15.62	62.92 ± 16.54
90	SFO	35.09 ± 6.25^{ab}	45.21 ± 11.69^{ab}	53.75 ± 11.52	62.04 ± 16.92
	CLA	29.38 ± 6.57^{a}	38.91 ± 12.08^{a}	45.90 ± 16.67	56.52 ± 20.72
Significance level		p<0.05	p<0.05	NS	NS

Means with different superscripts in the same column differed significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

to the PV of patties from the 70 kg CLA supplemented group (Table 4.81). It seems as if the anti-oxidative, peroxide inhibitory effect of CLA disappears after three days of refrigerated storage, since no significant differences were observed in PV for day 6 and 9 of refrigerated storage.

Figure 4.27 indicates that TBARS values for fresh pork patties were significantly (at least p<0.01) influenced by dietary treatment throughout the storage period. Up to 3 days of storage TBARS values of fresh patties from the 90 kg CLA supplemented group was significantly (p<0.01) lower compared to the 70 kg SFO and 70 kg CLA supplemented group. For days 6 and 9, TBARS values of fresh patties from the 90 kg CLA supplemented group was significantly (p<0.001) lower compared to all other treatment groups (Figure 4.27). There was a general trend throughout the storage period that TBARS values of fresh patties, from both the 70 kg and 90 kg CLA supplemented groups, were lower than their corresponding SFO supplemented counterparts (Figure 4.27). These results support the findings of Hur et al. (2007), who reported that dietary CLA supplementation improved colour and lipid stability of patties, through the inhibition of lipid oxidation and oxymyoglobin oxidation. Lipid stability of frozen pork patties was significantly (p<0.05) influenced by slaughter weight for day 0 with patties from the 90 kg CLA supplementation group having significantly (p<0.05) lower PV values, compared to patties from the 70 kg CLA group. After 8 weeks of frozen storage, the slaughter weight effect disappeared and the only significant effect was that the patties from the 90 kg SFO treatment had significantly (p<0.05) lower PV compared to the patties from the 70 kg CLA group (Table 4.82). This supports the results from the accelerated oxidation test (Table 4.75), which indicates that fat from the 70 kg CLA supplemented group is significantly more prone to lipid oxidation. According to Figure 4.28, TBARS values for frozen pork patties were significantly (at least p<0.01) influenced by dietary treatment at day 0 and after 16 weeks of storage. For day 0, TBARS values of frozen pork patties from the 90 kg CLA supplemented group was significantly (p<0.01) lower compared to the TBARS values of frozen pork patties from the 70 kg SFO supplemented group (Figure 4.28). After 16 weeks of frozen storage, the TBARS values of frozen pork patties from the 90 kg CLA supplemented group was significantly (p<0.001) lower compared to both the 70 kg CLA and 70 kg SFO supplemented groups (Figure 4.28).



Bars with different superscripts differ significantly; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.27: Lipid stability of fresh pork patties from the experimental treatment groups stored at 4 ℃ (n = 6 per treatment)

Table 4.82: Lipid stability of frozen pork patties from the experimental treatment groups stored at -18 ℃ (n = 6 per treatment)

Slaughter weight	Diet	PV		
		Day 0	Week 8	Week 16
70	SFO	34.19 ± 6.45^{ab}	44.25 ± 6.44^{ab}	33.71 ± 10.06
	CLA	38.49 ± 7.84^{b}	47.95 ± 4.40^{b}	34.17 ± 5.51
90	SFO	35.09 ± 6.25^{ab}	39.89 ± 5.82^{a}	32.59 ± 7.48
	CLA	29.38 ± 6.57^{a}	46.26 ± 7.01^{ab}	32.38 ± 5.33
Significance level		p<0.05	p<0.05	NS

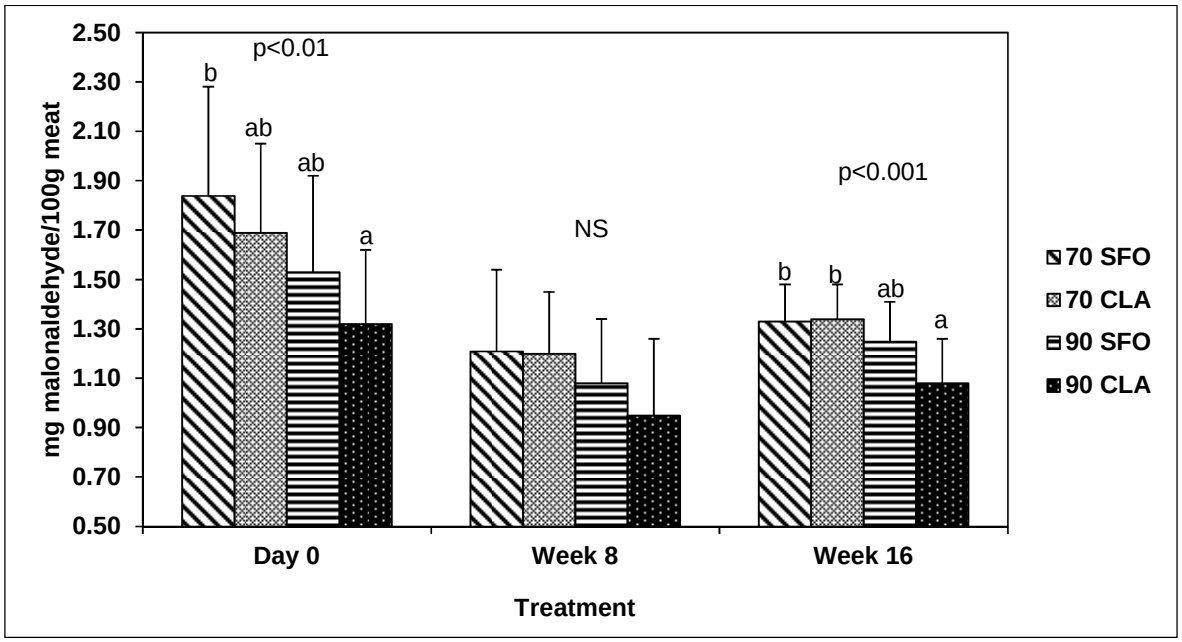
Means with different superscripts in the same column differed significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

This corresponds with findings by Hur et al. (2007), who reported that dietary CLA supplementation improved lipid stability of patties. Patties are often stored in the frozen state.This implies that dietary CLA supplementation may help to extend the chemical stability of such products.

4.8.4. Quality, oxidative stability and consumer preference of bacon

Bacon is a high quality cured whole muscle meat product. For bacon to be of good quality, good quality raw materials should be used. For good bacon quality, the belly fat should be firm and white (Wood, 1984).

Results from this study indicate that belly fat from CLA supplemented pigs was firmer than that of SFO supplemented pigs (Figure 4.11).



Bars with different superscripts differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.28: Lipid stability of frozen pork patties stored from the experimental treatment groups stored at -18 ℃ (n = 6 per treatment)

Belly fat from the SFO supplemented groups had a slightly higher colour *L**-value compared to CLA supplemented groups (Table 4.43). For good quality fat, belly fat should have an IV of less than 70 (Barton-Gade, 1983) and RI of less than 1.4598 (Houben et al., 1983). Only the 90 kg CLA supplemented group had an IV of 60.21 (Figure 4.12) and RI of 1.45945 (Figure 4.13). For good quality fat, the % EFC should be more than 84% (Prabucki, 1991), SFA content should be more than 41% (Häuser et al., 1990), UFA content less than 59% (Prabucki, 1991), MUFA content less than 57% (Lizardo et al., 2002) and PUFA content less than 15% (Houben et al., 1983). None of the treatment groups had an EFC % of more than 84% (Table 4.44). Both the 70 kg and 90 kg CLA supplemented groups as well as the 90 kg SFO supplemented group had a SFA content of more than 41% (Table 4.50). The UFA content followed the same trend as SFA content (Figure 4.14). All the treatment groups had a MUFA content of less than 57% and a PUFA content of less than 15% (Table 4.50). The C18:0 content should be more than 12% (Lizardo et al., 2002) and the C18:2 content should be less than 15% (Enser, 1983) for good quality. Only the CLA supplemented groups conformed to this parameter (Table 4.47). All the treatment groups had a C18:2 content of less than 15% (Table 4.49). The C18:0/C18:1 ratio should be less 1.47 (Enser et al., 1984; Honkavaara, 1989) and the DBI should be less than 80 (Häuser et al., 1990). All the treatment groups had a C18:0/C18:1 ratio of less than 1.47 (Table 4.51). All the treatment groups had a DBI of less than 80, but the CLA supplemented groups had lower DBI (Figure 4.15). Belly fat from the CLA supplemented groups conformed to more fat quality parameters than belly fat from the SFO

supplementation groups. One can therefore conclude that bellies from CLA supplemented pigs would be more suitable for bacon production.

Fat rancidity is usually not a big problem in cured meat products, due to the anti-oxidative action of nitrite (Weiss, Gibis, Schuh, & Salminen, 2010). Freezing of cured products increases the risk of rancidity, regardless of diet, presumably because it increases the concentration of salt, which might act as a pro-oxidant in the remaining unfrozen liquid (Hugo et al., 2007). Bacon contains a larger amount of fat than other pork products and it may therefore be more susceptible to the development of rancidity (Averette Gatlin et al., 2006).

The results of the lipid stability study, performed on bacon for 6 weeks at 4 ℃, are shown in Tables 4.83 – 4.84 and Figure 4.29. The PV of bacon was significantly ($p<0.01$) influenced by slaughter weight only on day 0 (Table 4.83). Bacon from the 90 kg CLA supplemented group had significantly ($p<0.01$) higher PV compared to the 70 kg SFO and 70 kg CLA groups. One would rather expect bacon from the 90 kg slaughter weight groups to have lower PV, because of its more saturated fatty acid profile (Table 4.50). Although the PV for weeks 3 and 6 was not significantly influenced by dietary treatment or slaughter weight, the 90 kg CLA supplemented group had slightly lower PV over this period. This could be an indication that secondary lipid oxidation occurred in the 90 kg CLA supplemented group. It was therefore decided to determine the secondary oxidation products by means of the TBARS and ρ-Anisidine value methods.

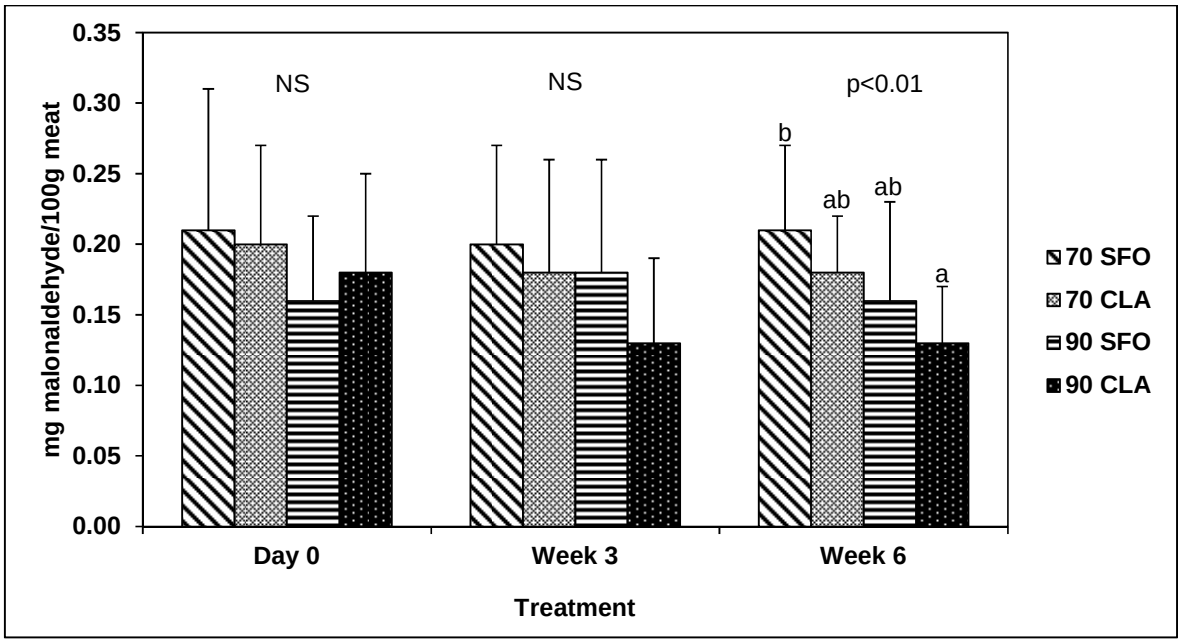
Table 4.83: Lipid stability of bacon from the experimental treatment groups stored at 4 ℃ as measured by PV (n = 10 per treatment)

Slaughter weight	**Diet**	**PV**		
		Day 0	**Week 3**	**Week 6**
70	**SFO**	6.64 ± 2.60^{a}	6.09 ± 2.40	3.97 ± 1.28
	CLA	6.22 ± 1.73^{a}	5.65 ± 1.55	4.50 ± 1.21
90	**SFO**	7.62 ± 4.30^{ab}	6.63 ± 2.79	4.94 ± 0.61
	CLA	11.08 ± 3.91^{b}	4.86 ± 1.26	3.88 ± 1.16
Significance level		$p<0.01$	NS	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.29 indicates that significant differences in TBARS values of bacon were only observed after 6 weeks of storage at 4 ℃. The 90 k g CLA supplemented group had a significantly ($p<0.01$) lower TBARS value, compared to the 70 kg SFO supplemented group (Figure 4.29). Larsen et al. (2009) also reported that dietary CLA supplementation resulted in a slight decrease in TBARS value of bacon.

One of the major advantages of the TBARS method is that its results are highly correlated with sensory evaluation scores (Hugo, Els, de Witt, Van der Merwe, & Fair, 2009). Buckley, & Connolly (1980) found a TBARS value of 1.0 to be a good cut-off point. None of the treatment groups had a TBARS values that even came close to that (Figure 4.29). This indicates that



Bars with different superscripts differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.29: Lipid stability of bacon from the experimental treatment groups stored at 4 ℃ as measured by TBARS value (n = 10 per treatment)

oxidation levels, as it occurred in this experiment, would not have an effect on the sensory profile of bacon.

The ρ-Anisidine value of bacon was significantly ($p<0.05$) influenced by dietary treatment at day 0 and after 6 weeks (Table 4.84). Bacon from the 70 kg CLA supplemented group had a significantly ($p<0.05$) higher ρ-Anisidine value, compared to the bacon from the 70 kg SFO supplemented group at day 0 (Table 4.84). This may be an indication of the early formation of secondary oxidation products in bacon from the 70 kg CLA supplemented group. After 6 weeks of storage at 4 ℃, bacon from the 90 kg CLA supplemen ted group had a significantly ($p<0.05$) higher ρ-Anisidine value compared to bacon from both the 70 kg CLA and SFO supplemented groups (Table 4.84). From the PV (Table 4.83), TBARS (Figure 4.29) and ρ-Anisidine (Table 4.84) results, it is uncertain if CLA acted as an antioxidant or a pro-oxidant. After inspection of the Day 0 values for PV, CLA seems to act as a pro-oxidant (Table 4.83). Inspection of the week 6 TBARS values made CLA act like an antioxidant (Figure 4.29), while inspection of the week 6 ρ-Anisidine values made CLA act like a pro-oxidant (Table 4.84). It has, however, been reported that CLA can act as a pro-oxidant under certain conditions (Hur, et al., 2007; Giua et al., 2013). The inconsistent findings regarding the oxidation status of bacon can possibly be attributed to opposing action of brine ingredients like salt that acts as a pro-oxidant (Hugo et al., 2007) and nitrite that may act as an antioxidant (Weiss et al., 2010).

The sensory profile of bacon from the experimental treatment groups was determined by using an untrained consumer panel. The panel was made up of 81% females and 19% males.

Table 4.84: Lipid stability of bacon from the experimental treatment groups stored at 4 ℃ as measured by ρ-Anisidine value (n = 10 per treatment)

Slaughter weight	Diet	ρ-Anisidine		
		Day 0	Week 3	Week 6
70	SFO	1.96 ± 1.10[a]	1.43 ± 1.04	0.01 ± 0.01[a]
	CLA	3.77 ± 1.89[b]	1.39 ± 1.53	0.01 ± 0.01[a]
90	SFO	2.86 ± 1.09[ab]	1.87 ± 1.40	0.02 ± 0.04[a]
	CLA	2.49 ± 1.19[ab]	1.56 ± 0.85	0.11 ± 0.19[b]
Significance level		p<0.05	NS	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

The highest proportion of panel members was between the age of 20 and 29 years (Table 4.85). No significant differences were observed for taste, texture and general acceptability (Table 4.86). Aroma was, however, significantly (p<0.1) influenced by dietary treatment and slaughter weight. Bacon from the 70 kg SFO supplemented group scored higher for aroma, compared to the bacon from the 90 kg

Table 4.85: Demographic profile of 75 member sensory panel for bacon

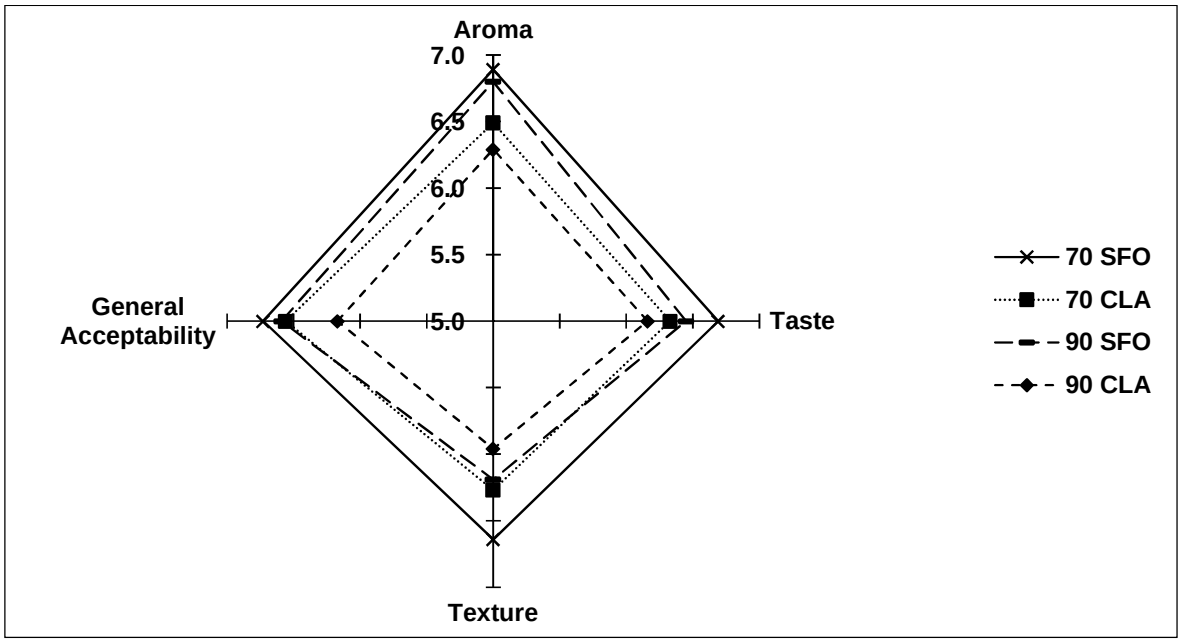
Gender	% Of Total	Age	% Of Total
Female	81	**< 20**	22
Male	19	**20 – 29**	50
		30 – 39	7
		40 - 49	11
		50 - 59	7
		>60	3

Table 4.86: Sensory profile of bacon from the experimental treatment groups at the end of the manufacturing process (n = 75)

Slaughter weight	Diet	Aroma	Taste	Texture	General Acceptability
70	SFO	6.89 ± 1.41[b]	6.69 ± 1.66	6.64 ± 1.67	6.73 ± 1.62
	CLA	6.49 ± 1.43[ab]	6.33 ± 1.75	6.27 ± 1.61	6.56 ± 1.47
90	SFO	6.80 ± 1.34[ab]	6.45 ± 1.65	6.19 ± 1.80	6.59 ± 1.44
	CLA	6.29 ± 1.73[a]	6.16 ± 1.83	5.96 ± 2.03	6.17 ± 1.77
Significance level		p<0.1	NS	NS	NS

Means with different superscripts in the same colum differ significantly. NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

CLA supplemented group (Table 4.86). According to Melton (1990), consumers preferred bacon with a high C18:2 content. Bacon, manufactured from bellies of the 70 kg SFO supplemented group, had slightly higher C18:2 content compared to bellies from the 90 kg CLA supplemented group (Table 4.49). Figure 4.30 indicates that the sensory attributes of bacon from the experimental treatment groups were much the same.



CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.30: Spider plot of consumer sensory profile of bacon from the experimental treatment groups (n = 75)

4.8.5. Quality, oxidative stability and consumer preference of salami

Salami is a high value fermented meat product that must be stable at room temperature. It is also expected to have a long shelf life. The quality of the raw materials (fat and meat) used for the manufacturing of salami are therefore of utmost importance. For good quality, backfat should have a thickness of more than 15 mm (Davenel et al., 1999). Only backfat from the 90 kg slaughter weight groups conformed to this quality parameter. Good quality fat was defined by Wood (1984) as firm and white.

Backfat from the SFO supplemented groups had a slightly higher *L**-value (whiter fat), compared to backfat from the CLA supplemented groups (Table 4.31). Backfat from the CLA supplemented groups was significantly firmer ($p<0.001$) compared to backfat from the SFO supplemented groups (Figure 4.5). For good quality, backfat should have an IV of less than 70 (Barton-Gade, 1983) and a RI of less than 1.4598 (Houben et al., 1983). Both the CLA supplemented groups conformed to the IV quality parameter (Figure 4.6) and only the 90 kg CLA supplemented group conformed to the RI quality parameter (Figure 4.7).

Chemically good quality fat should have an EFC % of more than 84% (Prabucki, 1991), SFA content of more than 41% (Häuser et al., 1990), an UFA content of less than 59% (Prabucki, 1991), a MUFA content of less than 57% (Lizardo et al., 2002) and PUFA content of less than 15% (Houben et al., 1983). Although the CLA supplemented groups had a slightly higher % EFC (Table 4.32), none of the treatment groups had an EFC % of more than 84%. The CLA supplemented groups conformed to the 41% requirement for SFA content, with a SFA content of 44.89% for the

70 kg slaughter weight group and 46.66% for the 90 kg slaughter weight group (Table 4.37). Only the CLA supplemented groups had an UFA content of less than 59%. The 70 kg CLA supplemented group had an UFA content of 55.11% while the 90 kg CLA supplemented group had an UFA content of 53.34% (Figure 4.8). All the treatment groups had a MUFA content of less than 57%, but the CLA supplemented groups had a lower MUFA content (Table 4.37). None of the treatment groups had a PUFA content of less than 15% (Table 4.37).

For good fat quality, the C18:0 content should be more than 12% (Lizardo et al., 2002) and the C18:2 content should be less than 11% (Fischer, 1989b). The 70 kg CLA supplemented group had a C18:0 content of 13.45% and the 90 kg CLA supplemented group had a C18:0 content of 14.58%. None of the treatment groups had a C18:2 content of less than 11%, although the 90 kg CLA supplemented group had the lowest C18:2 content of 14.12%.

Fatty acid ratios of importance are the C18:0/C18:2 and DBI. For good fat quality the C18:0/C18:2 should be less than 1.2 (Enser et al., 1984; Honkavaara, 1989) and DBI should be less than 80 (Häuser et al., 1990). All the treatment groups had a C18:0/C18:2 content of less than 1.2 (Table 4.38). The CLA supplemented groups had the lowest DBI, with 74.58 for the 70 kg CLA group and 69.90 for the 90 kg CLA supplemented group. From this data, it is clear that backfat from the CLA treatment groups, from a fat quality point of view, were more suitable for the manufacturing of salami than the backfat from the SFO treatment groups.

The effect of the experimental treatments on various quality parameters of salami are shown in Tables 4.87 – 4.93 and Figure 4.31. Table 4.87 indicates that the days to 20% moisture loss was significantly ($p<0.001$) influenced by dietary treatment and slaughter weight. Salami manufactured from the 70 kg CLA supplemented group needed a significantly ($p<0.001$) shorter time to reach a 20% moisture loss compared to the salami manufactured from the 70 kg and 90 kg SFO supplemented groups. Salami from the 90 kg CLA supplemented group also a needed significantly ($p<0.001$) shorter time to reach the 20% moisture loss, compared to the salami manufactured from the 70 kg SFO supplemented group (Table 4.87). This increased rate of moisture loss of salami from the CLA supplemented groups could possibly be as a result of the increased drip loss of CLA supplemented meat (Table 4.57). This increased rate of moisture loss could be of economic importance for the salami manufacturing industry. No significant differences were observed for final moisture loss (Table 4.87). Table 4.88 indicates that, directly after manufacturing, FFDM, initial pH and titrateable acidity (TA) were not significantly influenced by dietary treatment or slaughter weight. Moisture % ($p<0.05$), % fat ($p<0.001$) and water activity (a_w) ($p<0.05$) were significantly influenced by dietary treatment. The 70 kg CLA supplemented group had a higher moisture content, compared to the 70 kg SFO supplemented group (Table 4.88). This could probably be as a result of the slightly higher WHC of the 70 kg CLA meat (Table 4.57). Fat content of salami manufactured from the 70 kg CLA supplemented group was significantly ($p<0.001$) lower, compared to salami manufactured from the 70 kg SFO supplemented group (Table 4.88).

Table 4.87: Final moisture loss and number of days to reach final moisture loss (n = 18)

Slaughter weight	Diet	Final moisture loss (%)	Days to 20% moisture loss
70	**SFO**	20.44 ± 0.81	16.33 ±1.28^{c}
	CLA	20.32 ± 0.71	15.00 ± 0.84^{a}
90	**SFO**	20.39 ±0.67	16.00 ±0.84^{bc}
	CLA	20.86 ± 0.90	15.33 ± 0.97^{ab}
Significance level		NS	p<0.001

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

This may be explained by the negative correlation between fat and moisture content. Higher moisture content will result in lower fat content. Water activity was significantly influenced by dietary treatment and slaughter weight (Table 4.88). Salami from the 90 kg SFO supplemented group had a significantly ($p<0.05$) higher a_w compared to salami from the 70 kg CLA supplementation group.

Table 4.89 indicates that, after drying, only moisture content was significantly ($p<0.1$) influenced by slaughter weight. Salami manufactured from the 90 kg slaughter weight groups had a significantly ($p<0.1$) lower moisture content, compared to the 70 kg slaughter weight group. This is in agreement with Bruwer et al. (1991), who found that fat from heavier pigs contained less moisture.

At the end of the drying process, no significant differences were observed for *L**-, *a**- and *b**- as well as Chroma values (Table 4.90). Contradictory findings were reported in literature. According to Szymczyk (2005), CLA supplementation also resulted in significantly higher *L**-, *a**- and *b**-values. Contrary to the findings of Szymczyk (2005), Joo et al. (2002), Tischendorf et al. (2002), Intarapichet, Maikhunthod, & Thungmanee (2008) and Jiang et al. (2010) reported that dietary CLA had no effect on *L**-, *a**- and *b**-values. The lack of a colour effect in the salami, as opposed to a significant effect in the *M. longissimus thoracis* (Table 4.56), where it was found that dietary CLA supplementation resulted in significantly higher *L**-, *a**- and *b**-values, can probably be attributed to the long manufacturing process of salami, in conjunction with the presence of additives with pro- (salt) and antioxidant (nitrite) effects. Salami from the 70 kg SFO supplemented group had a significantly ($p<0.05$) higher Hue angle, compared to salami from the 90 kg CLA supplemented group (Table 4.90). This indicates that salami from the 70 kg SFO supplemented group had a less pronounced red colour. Possible explanations for the lower Hue angle for salami form the 90 kg CLA supplemented group, could be that the 90 kg slaughter weight had significantly ($p<0.001$) higher white muscle fibre contents (Table 4.73). The proportion of white muscle fibres are positively correlated to meat colour (Karlsson, Klont, & Fernandez, 1999). The effect of CLA could be attributed to CLA's ability to act as an antioxidant (Szymczyk, 2005).

Table 4.88: Chemical parameters related to drying rate of salami after manufacturing (n = 9 per treatment)

Slaughter weight	Diet	% Moisture	% Fat	% Fat free dry matter	Initial pH	a_w	TA
70	SFO	58.30 ± 3.55^{a}	14.24 ± 1.17^{b}	23.34 ± 0.70	5.54 ± 0.12	0.92 ± 0.01^{ab}	0.87 ± 0.22
	CLA	61.50 ± 1.10^{b}	11.96 ± 0.92^{a}	24.00 ± 0.94	5.58 ± 0.14	0.91 ± 0.02^{a}	0.89 ± 0.25
90	SFO	59.85 ± 1.46^{ab}	14.61 ± 1.87^{b}	23.34 ± 1.25	5.58 ± 0.15	0.93 ± 0.01^{b}	0.84 ± 0.19
	CLA	61.22 ± 1.24^{b}	13.80 ± 0.96^{b}	23.98 ± 0.74	5.56 ± 0.15	0.92 ± 0.01^{ab}	0.88 ± 0.21
Significance level		p<0.05	p<0.001	NS	NS	p<0.05	NS

Means with different superscripts in the same column differ significantly; NS=Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.89: Chemical parameter related to drying rate after drying (n = 9 per treatment)

Slaughter weight	Diet	% Moisture	% Fat	% FFDM	Final pH	a_w	TA
70	SFO	50.54 ± 2.16^{ab}	19.02 ± 1.24	29.34 ± 1.24	5.02 ± 0.13	0.91 ± 0.01	1.51 ± 0.38
	CLA	52.86 ± 2.95^{b}	17.46 ± 1.76	29.86 ± 1.43	5.01 ± 0.07	0.91 ± 0.01	1.59 ± 0.32
90	SFO	49.54 ± 3.17^{a}	17.95 ± 1.24	29.57 ± 1.92	4.98 ± 0.10	0.91 ± 0.01	1.48 ± 0.37
	CLA	49.59 ± 2.99^{a}	17.99 ± 1.96	29.92 ± 1.22	5.08 ± 0.08	0.91 ± 0.01	1.57 ± 0.30
Significance level		p<0.1	NS	NS	NS	NS	NS

Means with different superscripts in the same column differ significantly; NS=Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Shear force and compression of salami from the experimental treatment groups were significantly (at least $p<0.05$) influenced by dietary treatment and slaughter weight (Table 4.90). Salami from the 70 kg CLA supplemented group had a significantly ($p<0.05$) lower shear force, compared to salami from the 70 kg SFO supplemented group (Table 4.90). This is difficult to explain, since no significant differences were observed in the shear force values of the *M. longissimus lumborum* (Table 4.68). Jiang et al. (2010) reported an increase in shear force as a result of dietary CLA supplementation. Tischendorf et al. (2002) and Intarapichet et al. (2008) reported no effect of CLA supplementation on shear force. The 90 kg CLA supplemented group needed significantly ($p<0.01$) more force to be compressed (Table 4.90). This can be described as an effect of dietary CLA supplementation, which increases fat hardness (Figure 4.5) due to increased SFA content (Table 4.37) with corresponding decreased UFA content (Figure 4.8) (Joo et al., 2002; Wiegand et al., 2002; Lo Fiego et al., 2005a).

As far as lipid stability of salami, after manufacturing, after drying and after 1 month of storage at 4 ℃, are concerned, no significant diff erences were observed for FFA and PV from the experimental treatment groups (Table 4.91 and Figure 4.31). Although no significant differences were observed between the experimental treatments, at a specific point during processing, an expected general increase in FFA and PV were observed towards the end of the manufacturing process (Table 4.91). As far as TBARS values during manufacturing were concerned, the 70 kg SFO supplemented group had a significantly ($p<0.01$) higher TBARS value, compared to the 90 kg SFO supplemented group at the end of drying (Figure 4.31). The CLA supplemented groups did not differ significantly among themselves or from the SFO supplemented groups in terms of TBARS values at any point during manufacturing or after 1 month of storage at 4 ℃.

The sensory analysis on salami was performed at the end of processing by using a 75 member untrained consumer panel. The panel was made up of 75% females and 25% males. Fifty one percent of the panel members were between the ages of 20 and 29 years (Table 4.92).

No significant differences were observed for aroma and firmness between the experimental treatment groups (Table 4.93). Taste and over all acceptability were significantly ($p<0.05$) influenced by slaughter weight (Table 4.93). Salami manufactured from the 90 kg SFO supplemented group scored higher for taste and overall acceptability, than salami manufactured from the 70 kg SFO supplemented group (Table 4.93). Salami from the CLA supplemented groups did not differ significantly amongst each other or from the SFO supplemented groups in terms of taste and overall acceptability (Table 4.93). To visualize the sensory properties of salami, a spider plot was constructed (Figure 4.32). The higher score for overall acceptability of salami from the 90 kg SFO supplemented group, compared to salami from the 70 kg SFO supplemented group, (Figure 4.32) can possibly be attributed to the higher SFA profile of the 90 kg group (Table 4.37). According to Swan et al. (2001), overall acceptability of pork was associated with higher concentrations of SFA.

Table 4.90: Physical properties of salami from the experimental treatment groups at the end of drying (n = 6 per treatment)

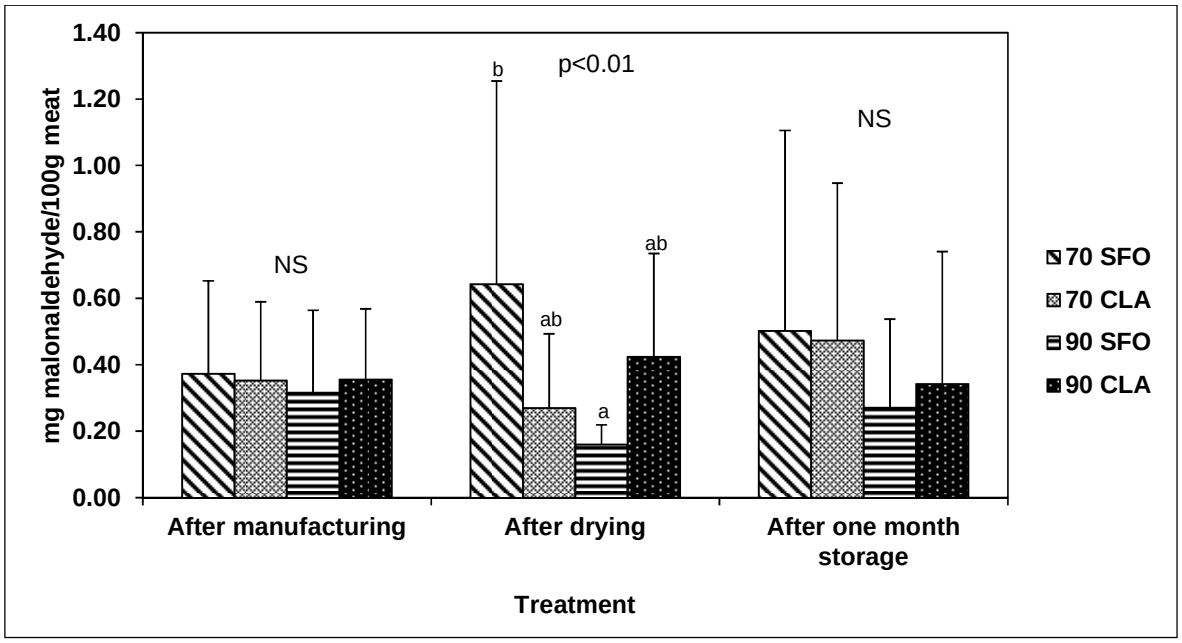
Slaughter weight	Diet	Colour *L** - value	Colour *a** - value	Colour *b** - value	Chroma	Hue angle	Shear	Compression
70	SFO	52.96 ± 2.32	9.75 ± 0.68	8.38 ± 0.47	12.88 ± 0.74	40.99 ± 1.46^{b}	0.36 ± 0.08^{b}	1.22 ± 0.07^{a}
	CLA	53.73 ± 3.30	10.54 ± 0.70	8.18 ± 0.75	13.36 ± 0.96	37.90 ± 1.49^{ab}	0.26 ± 0.02^{a}	1.20 ± 0.07^{a}
90	SFO	52.72 ± 0.98	10.62 ± 1.14	8.50 ± 0.71	13.65 ± 1.05	38.88 ± 3.81^{ab}	0.28 ± 0.05^{ab}	1.25 ± 0.10^{a}
	CLA	51.64 ± 2.31	10.87 ± 0.57	7.84 ± 0.34	13.44 ± 0.45	36.34 ± 2.92^{a}	0.31 ± 0.04^{ab}	1.42 ± 0.12^{b}
Significance level		NS	NS	NS	NS	p<0.05	p<0.05	p<0.01

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Table 4.91: Lipid stability parameter related to salami processing directly after manufacturing, drying and storage for 1 month at 4 ℃ (n = 9 per t reatment)

Slaughter weight	Diet	Directly after manufacturing (Day 0)		After drying (± 16 Days)		After 1 month of storage at 4 ℃	
		FFA	PV	FFA	PV	FFA	PV
70	SFO	2.92 ± 0.76	6.66 ± 4.07	6.92 ± 2.33	8.43 ± 6.98	7.64 ± 1.51	7.76 ± 6.30
	CLA	3.38 ± 1.11	6.67 ± 3.09	6.16 ± 1.74	8.12 ± 6.01	7.52 ± 1.68	7.56 ± 6.00
90	SFO	2.75 ± 0.79	7.95 ± 3.78	5.72 ± 1.91	5.58 ± 3.63	6.98 ± 1.98	6.97 ± 4.40
	CLA	3.08 ± 1.91	7.32 ± 1.99	5.63 ± 2.04	7.75 ± 5.25	6.53 ± 1.37	7.83 ± 4.54
Significance level		NS	NS	NS	NS	NS	NS

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil



Bars with different superscripts differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.31: Thiobarbitutic acid reactive substances analysis of the experimental treatment groups during salami processing (n = 9 per treatment)

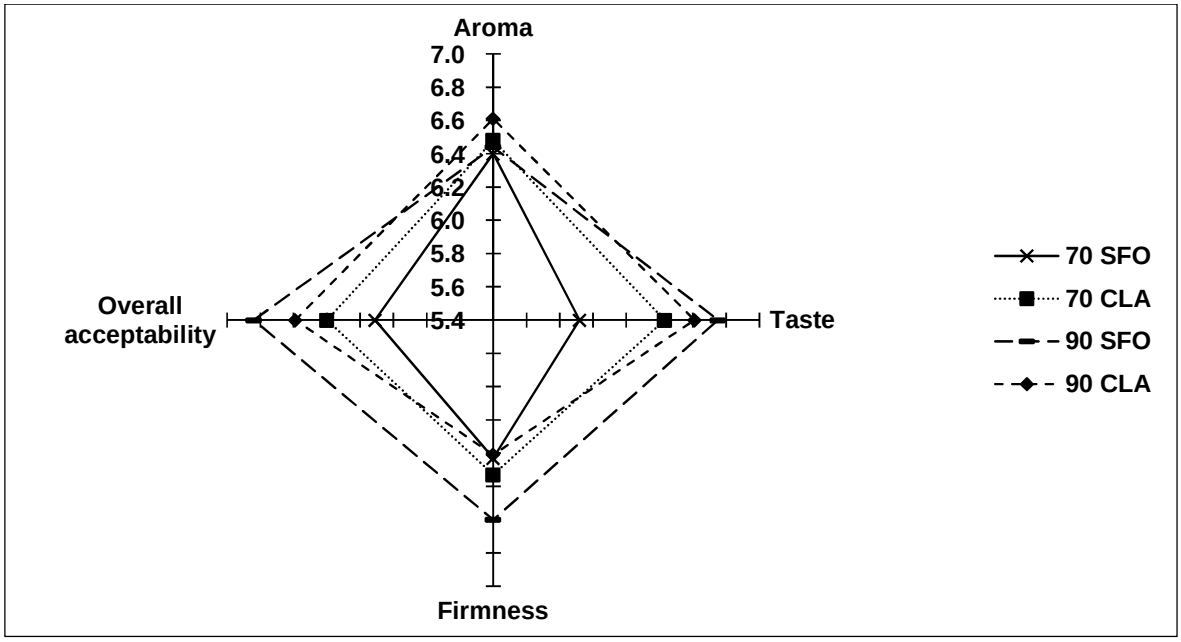
Table 4.92: Demographic profile of the 75 member sensory panel for salami

Gender	% Of Total	Age	% Of Total
Female	75	**< 20**	3
Male	25	**20 – 29**	51
		30 – 39	15
		40 - 49	13
		50 - 59	13
		>60	5

Table 4.93: Sensory properties of salami from the experimental treatment groups at the end of the manufacturing process (n = 75)

Slaughter weight	Diet	Aroma	Taste	Firmness	Overall acceptability
70	SFO	6.40 ± 1.60	5.92 ± 2.03[a]	6.23 ± 1.67	6.11 ± 1.80[a]
	CLA	6.48 ± 1.57	6.43 ± 1.67[ab]	6.33 ± 1.64	6.40 ± 1.59[ab]
90	SFO	6.44 ± 1.64	6.75 ± 1.62[b]	6.60 ± 1.38	6.84 ± 1.39[b]
	CLA	6.61 ± 1.75	6.61 ± 1.90[ab]	6.21 ± 1.88	6.59 ± 1.72[ab]
Significance level		NS	p<0.05	NS	p<0.05

Means with different superscripts in the same column differ significantly; NS = Not significant; CLA = Conjugated linoleic acid; SFO = Sunflower oil



CLA = Conjugated linoleic acid; SFO = Sunflower oil

Figure 4.32: Spider plot of consumer sensory properties of salami from the experimental treatment groups (n = 75)

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

Over the last several decades, consumers have become increasingly aware of a healthy lifestyle and are presently more concerned with the impact of their diets on their health than ever in the past (Verbreke et al., 1999; Morel et al., 2013). Pork was often avoided as consumers considered it to contain an excess of fat, SFA and cholesterol (Hernández et al., 1998). Health conscious consumers prefer pork with high levels of PUFA (Morel et al., 2013). This increased health consciousness among consumers led to significant changes in pig carcass attributes (Scheffler et al., 2007). The global meat industry's response to consumer demands for healthier pork was to produce leaner pigs by aggressively adopting new production technologies to increase both efficiency and production (Blanchard, 1995, Liu et al., 2013). One such an approach, adopted by pig producers, was selection to improve lean growth and carcass yield (Scheffler et al., 2007). This response of the meat industry to meet consumer demands for healthier pork had certain implications. As pigs became leaner, their fat tends to become softer and more unsaturated (Sather et al., 1995). This is good news for health conscious consumers, but may cause serious problems for the meat processor. The increased PUFA content may have detrimental effects on the sensory and technological quality and acceptability of meat products (Houben et al., 1983; Stiebing et al., 1993, Warnants et al., 1998; Teye et al., 2006).

The fatty acid composition of the fat tissue triacylglycerides can be changed by altering the fatty acid composition of dietary fat (Rhee et al., 1990). Adding different lipid products to an animal's diet can therefore successfully alter the fatty acid profile of the tissue of that animal (Wood et al., 1999; Scheerder et al., 2000; Morel et al., 2013). This led to great interest in the manipulation of the fatty acid composition of muscle and fat, to produce meat with desirable nutritional and technological qualities (Teye et al., 2006). Fresh pork and pork products manufactured from such meat can be described as "designer" or "functional" foods (Jiménez-Colomenero et al., 2001; Arihana, 2006). Pork can now be marketed as a nutraceutical (Arihana, 2006). One approach to improve pork quality is dietary supplementation with naturally occurring feed additives, such as CLA in the growing-finishing diet (Wiegand et al., 2002). Numerous positional and geometric isomers of CLA have been reported as components of naturally occurring foods (Lo Fiego et al., 2005a). The *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers appear to be the most biologically active (Kennedy et al., 2010). Conjugated linoleic acid isomers found in meat mainly consists of 90% of the *cis*-9, *trans*-11 isomer and 10% of the *trans*-10, *cis*-12 isomer (Kennedy et al., 2010). Experiments on laboratory animals in human medicine indicated that dietary CLA supplementation had beneficial effects on improving the immune function, preventing

cancer, reducing the incidence of heart disease, improving blood sugar levels, decreasing blood cholesterol and reducing body weight (Migdal et al., 2004; Larsen et al., 2009).

Feeding CLA to pigs improves performance, reduces fat deposition and increase LMC (Swan et al., 2001; Wiegand et al., 2001; D'Souza et al., 2002). Pigs fed CLA had less backfat, more carcass lean, bigger loin muscle area and better feed conversion (Eggert et al., 1998; Ostrowska et al., 1999; Migdal et al., 2004; Larsen et al., 2009; Jiang et al., 2010). With respect to meat quality, CLA increased the SFA/UFA ratio in adipose tissue and IMF and improved belly firmness (Dugan et al., 1999; Eggert et al., 1999; Eggert et al., 2001; Wiegand et al., 2001; Joo et al., 2002). Dietary CLA supplementation had a positive effect on WHC and colour of fresh meat (Migdal et al., 2004; Szymczyk, 2005; Bee et al., 2008; Jiang et al., 2010). No data was found to report on the effect of CLA supplementation on technological properties such as WHC and colour of processed meat and meat products.

In the literature survey of this thesis, an attempt was made to provide an adequate and orderly review of the literature available. The following aspects were explained and discussed: consumption patterns of meat, particularly pork, pork quality in general and the factors affecting pork quality. The effect of dietary CLA supplementation on pig production efficiency, carcass composition, pork quality itself, fatty acids and sensory analysis of pork. Available information on the effect dietary CLA supplementation may have on animal performance and meat quality was also discussed. Conclusions regarding the effect of CLA on the carcass quality, FA composition and sensory data vary among researchers. The author believes that this literature review has made a contribution in that it has summarized and highlighted the most recent literature on the effects of CLA supplementation on animal performance and meat quality.

The practical work of this thesis focused on the influence of a commercial dietary CLA feed supplement on the production and meat quality parameters of pigs under commercial production conditions as well as on the chemical and sensory stability of processed meat products manufactured from such animals. There is currently a lot of interest in supplementing pig diets with CLA (Eggert et al., 1998; O'Quinn et al., 2000; Wiegand et al., 2002; Migdal et al., 2004; Szymczyk, 2005; Averette Gatlin et al., 2006; Bee et al., 2008; Jian et al., 2010; Han et al., 2011; Matak et al., 2013) and the subsequent manufacturing of processed meat products (Joo et al., 2002; Hur et al., 2007; Martin et al., 2008; Larsen et al., 2009; Han et al., 2011). In the first practical part of this thesis, a production study with two slaughter weights (70 kg and 90 kg) and three genders (boars, barrows and gilts) were performed to determine the effect of a 0.5% CLA inclusion on production efficiency and carcass quality.

This production study demonstrated that there were no differences in the digestibility between the SFO and CLA supplemented feed. From this, the author could conclude that all effects observed were as a result of experimental treatments and not due to confounded effects like digestibility differences. The first hypothesis that there is no difference in the digestibility of SFO and CLA in pigs was therefore accepted. Conjugated linoleic acid was also found to

demonstrate antioxidant properties in animal feed. That is an important finding, since some of the synthetic antioxidants currently used in animal feeds are suspected carcinogens.

Many pig production, growth performance, feed efficiency and carcass characteristics were influenced by dietary treatment, gender and slaughter weight. Boars had the lowest FCR, followed by gilts, with an intermediate FCR and barrows with the highest FCR. Pigs from the 90 kg slaughter weight group had a higher FCR than pigs from the 70 kg slaughter weight group. This study demonstrated that CLA supplementation had a positive effect on pig production efficiency, since animals receiving the CLA diet had improved FCR. Pigs on the CLA diet needed 0.10 kg less feed to increase 1 kg in weight, representing a 3.26% improvement in feed efficiency. This is of practical significance if one takes into consideration that 2.6 million pigs are slaughtered annually in South Africa. Pig producers are reluctant to adopt technologies without the assurance that improved production will mean more money in their pockets if they weigh it up against the cost of the technology. Pigs from commercial production systems vary widely and often differ from those in research herds, thus the benefits of new technologies may even be more profound in practice than in research herds (Liu et al., 2013). The hypothesis that dietary CLA supplementation will have no effect on pig production efficiency was therefore rejected.

Carcass quality was significantly influenced by diet, gender and slaughter weight. Barrows generally had the best carcass quality, followed by gilts, with intermediate carcass quality and boars had the poorest carcass quality. The 90 kg slaughter weight group had better carcass quality compared to the 70 kg slaughter weight group. A negative effect linked to dietary CLA supplementation was a decrease in WHC and pH_{45min}. Lean classification of pigs improved as a result of CLA supplementation. In this study, 89% of the 70 kg slaughter weight group pigs on the CLA diet obtained a P and O classification, compared to 81% of pigs on the SFO diet. For the 90 kg slaughter weight group, 61% of the pigs on the CLA diet obtained a P and O classification, compared to 53% of the pigs on the SFO diet. This finding is of practical significance for the South African pig producer, since more pigs being classified as P and O means more profitable pig production. The hypothesis that 0.5% dietary CLA supplementation had a positive effect on carcass quality of lighter and heavier pigs could therefore not be accepted or rejected. The reduction in WHC and pH_{45min} could be considered negative, while the lower backfat thickness of CLA supplemented pigs, compared to SFO supplemented pigs, could be considered as positive.

Backfat quality from pigs in this study was significantly influenced by diet, gender and slaughter weight. Boars had a more unsaturated fatty acid profile, gilts an intermediate and barrows had a more saturated fatty acid profile. The 90 kg slaughter weight group had a more saturated fatty acid profile, compared to the 70 kg slaughter weight group. Dietary CLA supplementation resulted in backfat with a lower IV and RI and thus a more saturated fatty acid profile. From the growth performance, feed efficiency, carcass characteristics and backfat quality, it could be concluded that gilts had intermediate meat and fat quality, as previously reported by Barton-Gade (1987) and Xue et al. (1997). The second part of this thesis focused on advanced

meat quality and processed meat products and was therefore only conducted on gilts from the different dietary and slaughter weight groups.

Many of the physical and chemical properties of backfat, belly fat and *M. longissimus thoracis* were influenced by dietary treatment and slaughter weight. Backfat and belly fat from the 90 kg slaughter weight group had better physical and chemical properties, compared to backfat from the 70 kg slaughter weight group. Dietary CLA supplementation increased back- and belly fat firmness. Firmer backfat is more suitable for the manufacture of high value processed meat products like bacon and salami (Häuser et al., 1990). The IV of back- and belly fat from the 70 and 90 kg CLA supplemented groups were reduced by dietary CLA supplementation. The IV of backfat from the CLA supplemented groups were reduced below 70, compared to the IV of the SFO groups with IV values above 70. This indicates that only the CLA supplemented pigs could conform to the IV of less than 70 proposed for good fat quality (Barton-Gade, 1983). Although the IV of belly fat from the CLA supplemented groups were lower, compared to IV of belly fat from the SFO supplemented groups, all the treatment groups conformed to the quality parameter for good quality fat with an IV of less than 70 (Barton-Gade, 1983). Refraction index values of both the back- and belly fat for both the CLA supplemented groups were reduced. Only the 90 kg CLA supplemented group for both back- and belly fat had a RI of less than 1.4598 considered as the maximum for good fat quality (Houben et al., 1983).

Mixed results were obtained for the effect of slaughter weight and dietary treatment on the chemical and physical properties of *M. longissimus thoracis*. Drip loss was higher for *M. longissimus thoracis* from the 90 kg slaughter weight group, compared to the 70 kg slaughter weight group. The IV of the IMF from the 90 kg slaughter weight group was lower, compared to the IV of IMF from the 70 kg slaughter weight group. This was regarded as positive. Lightness, *a**- and *b**-values of *M. longissimus thoracis* from the CLA supplemented groups were higher compared, to the SFO supplemented groups. Water-holding capacity of the 70 kg and 90 kg CLA supplemented groups were higher, compared to the WHC of the SFO supplemented groups.

Dietary CLA supplementation caused similar changes in the fatty acid profile of lipids from backfat, belly fat and *M. longissimus thoracis.* Dietary CLA supplementation resulted in a significant increase in SFA and a decrease in UFA and MUFA content in backfat, belly fat and *M. longissimus thoracis*. Backfat from CLA supplemented pigs had a higher C14:0, C15:0, C16:0, C17:0 and C18:0 content and lower C18:1*c*9, C18:1*c*7, C18:2, C20:2, C20:3 and C20:4. Belly fat had a higher C14:0, C16:0 and C18:0 content and lower C16:1*c*9, C18:1*t*9, C18:1*c*9, C18:1*c*7, C20:1, C18:3*n*-3, C20:2 and C20:4 content. Lipid from *M. longissimus thoracis* had a higher C14:0, C15:0, C16:0 and C20:0 content and lower C16:1*c*9, C18:1*t*9, C18:1*c*9, C18:2, C18:3*n*-3, C20:2 and C22:6 content. This increase in SFA content can be ascribed to decreased $^{\Delta}$9 desaturase index of back- and belly fat of CLA supplemented pigs. Back- and belly fat from the CLA supplemented groups conformed to most of the fatty acid related quality parameters for good fat quality.

From a nutritional and health point of view, higher UFA content of fat tissue is preferred. For improved health properties, the SFA content, *n*-6 and *n*-6/*n*-3 ratio should decrease, while UFA, MUFA, the MUFA/SFA ratio, PUFA, *n*-3 and the PUFA/SFA ratio have to increase (Honkavaara, 1989; Muchenje et al., 2009). Backfat from both the CLA supplemented pigs had increased SFA, *n*-6, *n*-6/*n*-3 ratio and AI, while UFA, MUFA, the MUFA/SFA ratio, PUFA, *n*-3 and PUFA/SFA ratio decreased. Belly fat from the CLA supplemented groups had increased SFA, PUFA, *n*-6, *n*-3, and AI, while UFA, MUFA, as well as the ratios of MUFA/SFA, *n*-6/*n*-3 and PUFA/SFA decreased. Lipid from the *M. longissimus thoracis* from the CLA supplemented groups showed increased SFA content and AI, while UFA, MUFA, the MUFA/SFA ratio, PUFA, *n*-6, *n*-3 and PUFA/SFA ratio decreased. The positive effects of CLA supplementation (improving the immune function, preventing cancer, reducing the incidence of heart disease, improving blood sugar levels, decreasing blood cholesterol and reducing body weight) reported in literature, should be weighed against the negative effects of CLA on nutritional and health properties reported in this thesis. All fatty acid ratios concerned with fat firmness and fat quality improved as a result of dietary CLA supplementation or slaughter weight. Double bond indexes were consistently lower for the backfat, belly fat and IMF of CLA supplemented pigs. The hypothesis that 0.5% dietary CLA supplementation would improve nutritional, health and technological properties could not be accepted or rejected. The increase in SFA content results in improved technological properties, but it also results in decreased nutritional and health properties.

A very novel aspect of this research was the lipid fractionation of the backfat, belly fat and IMF from CLA supplemented pigs. The purpose of the work was to determine where the different C18:2 isomers were deposited in CLA supplemented pigs. For back- and belly fat, both CLA isomers were deposited into the neutral- and glycolipid fractions. More of the *cis*-9, *trans*-11 isomer was deposited, compared to the *trans*-10, *cis*-12. For IMF, both CLA isomers were successfully deposited into the phospholipid fraction. The *cis*-9, *trans*-11 isomer was also deposited at a higher level compared to the *trans*-10, *cis*-12 isomer. This can possibly be used to further explain the numerous health properties of CLA. Knowing into which lipid fraction CLA are deposited can possibly shed some light on the complex metabolism of CLA in pigs and possibly humans too.

Since little is known about the implications of the use of CLA supplemented lean and fat tissue in meat products, this study extensively researched the effect of dietary CLA supplementation on the chemical and sensory stability of fresh and processed pork. An accelerated oxidation test, performed on extracted lipid from backfat, could not prove that dietary CLA supplementation protect backfat against oxidative breakdown. Backfat from 70 kg CLA supplemented pigs had a significantly decreased OSI value, compared to backfat from the 70 kg SFO group. In this case, CLA acted as a pro-oxidant (Hur et al., 2007). Fresh pork chops, form CLA supplemented pigs, had improved colour stability and in the case of the 90 kg CLA supplemented group, improved TBARS values over the storage period. Lipid stability of frozen pork chops demonstrated the same trend as fresh pork chops. Chops from the 90 kg CLA

supplemented group had improved TBARS values. Descriptive sensory analysis, consumer sensory analysis and principal component analysis demonstrated only small differences between SFO and CLA supplemented pork in the sensory and physical characteristics of fresh pork. These findings can be considered as positive, since it illustrates that the inclusion of CLA, at a commercial recommended level in pork diets, is unlikely to have a negative effect on consumer perceptions of the product.

It was found that fresh pork patties manufactured from CLA supplemented pork had improved colour stability over the 9 day storage period. Patties from the 90 kg CLA supplemented group had improved lipid stability over the 9 day refrigerated storage, as well as 16 week frozen storage period. Results of the lipid stability of bacon during refrigerated storage for 16 weeks were inconsistent. These inconsistent findings can possibly be attributed to opposing action of brine ingredients like salt that acts as a pro-oxidant (Hugo et al., 2007) and nitrite, that may act as an antioxidant (Weiss et al., 2010). The sensory analysis of bacon indicated that consumers preferred the aroma of bacon from the 70 kg SFO supplemented group. Salami manufactured form the CLA supplemented groups reached the desired percentage moisture loss within a shorter time. This can be considered an advantage for manufacturers of salami. No significant differences could be observed between the different dietary treatments for colour stability, lipid stability and sensory acceptability. As in the case of bacon, the presence of nitrite may have had an equalizing effect. The hypothesis that a 0.5% inclusion of CLA in pig diets would have no effect on fat oxidation in processed meat products like bacon and salami must be accepted but can be rejected for products like patties, where CLA did reduce fat oxidation.

Findings from this research offer a solution for the dilemma of the inverse relationship between the health and technological qualities of fat tissue. This research indicates that CLA, being a PUFA, can be used to increase the health and technological properties of fat tissue simultaneously.

A possible future research project could be to investigate the effect of the individual CLA isomers (*cis*-9, *trans*-11 and *trans*-10, *cis*-12) on production efficiency and meat quality of pigs. The effects of these individual isomers are not clear at this moment. The inconsistent effect of CLA on the antioxidant properties, of especially the cured meat product, observed in the current study could possibly be better explained with the use of individual CLA isomers. Another possible research project could be a study on the effect of direct addition of synthetic CLA into processed meat products and a study on the quality of such products.

CHAPTER 6

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CHAPTER 7

SUMMARY

The objectives of this study were to determine the effects of a commercial dietary CLA feed supplement on the production and meat quality parameters of pigs under commercial production conditions. It included the study of the chemical and sensory stability of processed meat products manufactured from the meat of such animals. One hundred and forty four Landrace x Large White crossbred pigs, weighing ± 30 kg, were randomly divided into two groups of seventy two pigs each, that were assigned to one of two dietary treatments. Diets consisted of a control diet supplemented with 1% SFO and the experimental diet where 0.5% SFO was replaced with 0.5% CLA. Each dietary group was further divided into three gender groups (boars, barrows and gilts) that consisted of twenty four pigs each. Each gender group was further divided into two slaughter weight groups (70 kg and 90 kg) consisting of twelve pigs each. Pigs were fed until the average live weight of the pigs was ± 70 kg for the porkers and ± 90 kg for the baconers.

Growth performance (weight increase, ADG and FCR) and carcass characteristics (warm and cold carcass mass, dressing percentage, carcass length, shoulder and buttock circumference, pH, backfat thickness, eye muscle thickness and LMC) were assessed. Animals receiving the CLA diet had improved FCR and carcasses with thinner backfat and higher LMC, compared to animals on the SFO diets. This resulted in a higher frequency of P and O classification of carcasses from CLA supplemented pigs.

Backfat, belly fat and *M. longissimus thoracis* quality of the dietary treatment and slaughter weight groups were compared. Baconers had improved technological properties compared to porkers. Dietary CLA supplementation resulted in improved technological properties of backfat and belly fat, demonstrated by decreased IV; RI; DBI; UFA; MUFA; PUFA; MUFA/SFA ratio; PUFA/SFA ratio; $^{\Delta}$9 desaturase index; C16:1 + C18:1/C16:0 + C18:0 ratio and increased C18:0; *cis*-9, *trans*-11; *trans*-10, *cis*-12; SFA; AI; C16:0 + C18 and ratios of C18:0/C18:2; C18:2/C18:1; C16:0/C18:2. *M. longissimus thoracis* from CLA supplemented pigs had higher *a**-values, drip loss and WHC. Dietary CLA supplementation resulted in a decrease of health and nutritional properties of *M. longissimus thoracis*, demonstrated by increased SFA content and AI, while UFA, MUFA, PUFA, *n*-6, *n*-3 and ratios of MUFA/SFA and PUFA/SFA decreased. Technological and health properties were inversely related. The decreased health properties must be weighed against the numerous health benefits, ranging from improved immune function to prevention of cancer that can be attributed to CLA supplementation.

Conjugated linoleic acid isomers were deposited into the neutral- and glycolipid fraction of subcutaneous adipose tissue and into the phospholipid fraction of IMF. Processed products

(patties, bacon and salami) were manufactured from meat from the experimental treatment groups. The chemical stability and sensory properties of fresh meat and processed products manufactured from the experimental treatment groups were compared. Conjugated linoleic acid also demonstrated antioxidant properties in animal feed. Sensory analysis indicated the small effect of dietary CLA supplementation on the sensory properties of fresh and processed pork products. In the case of fresh pork chops and pork patties, dietary CLA supplementation had a stabilizing effect on the *a**-value of the products. The lipid stability of pork patties was improved by dietary CLA supplementation as indicated by TBARS values. Salami from the CLA groups was firmer. That could be ascribed to the fat hardening effect of CLA. Pork and pork products enriched with CLA can be considered functional foods and even “nutraceuticals” with positive effects on human health. South African pig producers may therefore consider marketing CLA enriched pork products as a health food. The potential advantages and the premium that can be earned on such meat has to be balanced against the reality of increased feed cost.

Keywords: conjugated linoleic acid, pig production, feed efficiency, pig, subcutaneous, intramuscular, fatty acids, processed meat products, sensory, stability.

OPSOMMING

Die doelwitte van die studie was om die uitwerking van ‘n kommersiële mengsel van gekonjugeerde linoleïensuur (CLA) voeraanvulling op die produksie en vleiskwaliteits parameters van varke onder kommersiële produksieomstandighede te bepaal. Dit het ook die chemiese en sensoriese stabiliteit van geprosesseerde vleisprodukte, vervaardig van die vleis van hierdie varke, bestudeer. Een honderd vier en veertig, Landras X Groot Wit kruisgeteelde varke met ‘n gemiddelde massa van 30 kg, is ewekansig in twee groepe verdeel, met twee en sewentig varke elk. Een van twee dieët behandelings het bestaan uit ‘n kontrole dieët wat aangevul is met 1% sonneblom olie (SFO) en die ander was die eksperimentele dieët, waar 0.5% SFO vervang is met 0.5% CLA. Elke dieëtgroep is verder verdeel in drie geslagsgroepe (bere, burge en sôe) en het bestaan uit vier en twingtig varke elk. Elke geslagsgroep is verder verdeel in twee slagmassas (70 kg en 90 kg), bestaande uit twaalf varke elk. Varke is gevoer totdat die gemiddelde lewende massa ± 70 kg vir die vleisvarke en ± 90 kg vir die spekvarke was.

Groeiprestasie (gewigstoename, gemiddelde daaglikse toename en voeromsetverhouding) asook karkas eienskappe (warm en koue karkasmassa, uitslagpersentasie, karkaslengte, skouer- en boudomtrek, pH, rugvetdikte, spierdikte en maervleisinhoud) is beoordeel. Varke wat die CLA dieët gevoer is, het ‘n verbeterde voeromsetverhouding, dunner rugvetdikte en ‘n hoër spierdikte, in vergelyking met varke wat die SFO dieët gevoer is, getoon. Die CLA dieët het tot gevolg gehad dat meer varke ‘n P en O klassifikasie ontvang het.

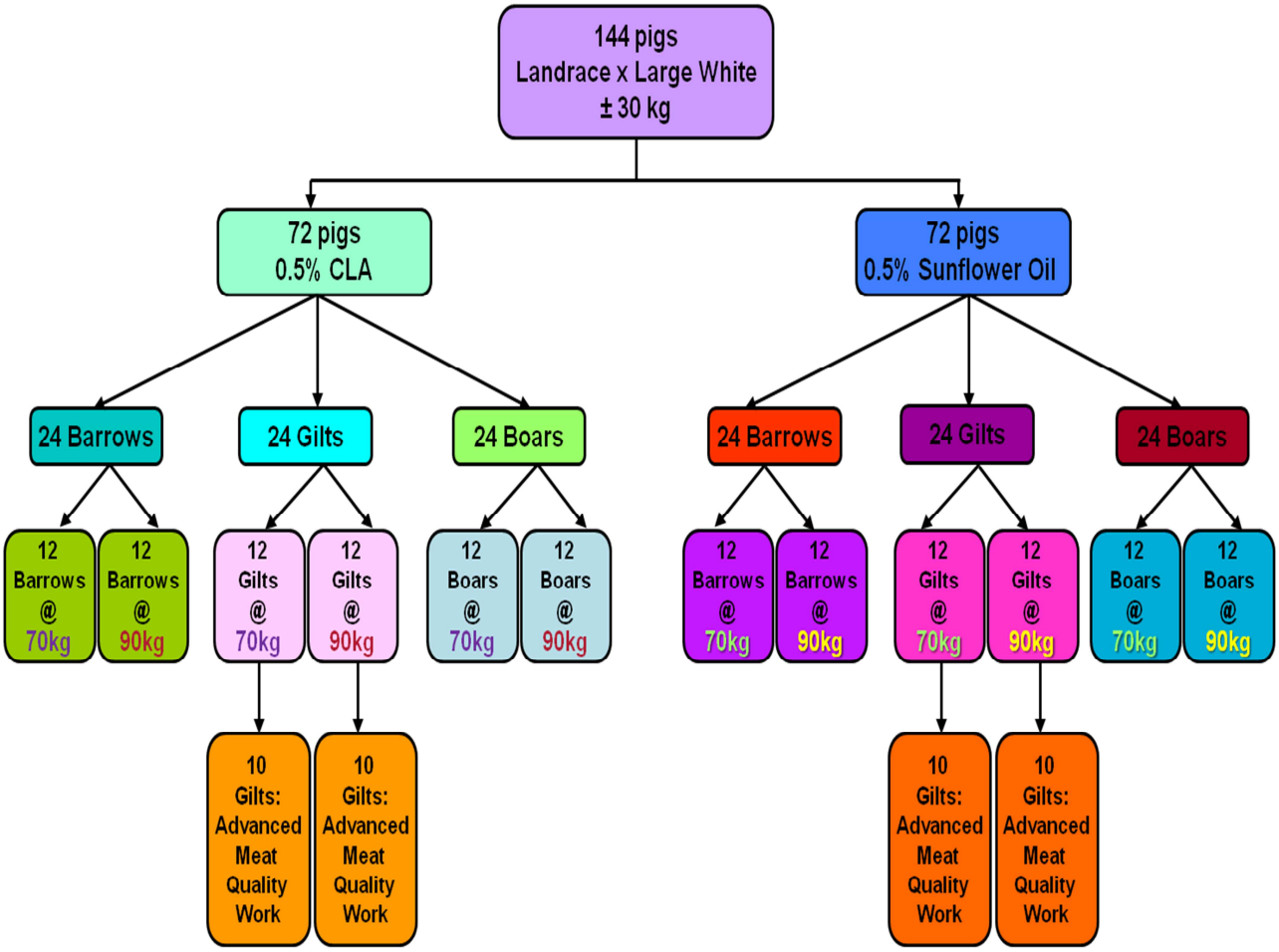
Die uitwerking van dieëtbehandeling en slagmassa is bepaal vir rugvet, buikvet en *M. longissimus thoracis*. Spekvarke het verbeterde tegnologiese eienskappe, in vergelyking met vleisvarke getoon. Gekonjugeerde linoleïensuur het gelei tot verbeterde tegnologiese eienskappe vir rug- en buikvet van varke. Dit is bewys deur die verlaagde jodiumwaarde; refraksie indeks; dubbel bindings indeks (DBI); totale onversadige vetsure (UFA); mono-onversadig vetsure (MUFA); poli-onversadige vetsure (PUFA) en verhoudings van MUFA/SFA; PUFA/SFA); $^{\Delta}9$ desaturase indeks; C16:1 + C18:1/C16:0 + C18:0 verhouding en verhoogde C18:0; *cis*-9, *trans*-11 en *trans*-10, *cis*-12; SFA, arterogenetiese indeks (AI) en die verhoudings van C16:0 + C18:0; C18:0/C18:2; C18:2/C18:1; C16:0/C18:2. Die *M. longissimus thoracis*, van varke op die CLA dieët, het hoër *a**-waardes, drupverlies en waterhouvermoë getoon. CLA aanvulling in vark diëte het gelei tot ‘n afname in die gesondheids- en voedingseienskappe van *M. longissimus thoracis*. Die afname is waargeneem deur ‘n verhoogde SFA en AI inhoud, terwyl die UFA, MUFA, MUFA/SFA verhouding, PUFA, *n*-6 vetsure, *n*-3 vetsure en PUFA/SFA verhouding ook afgeneem het. Daar is ‘n omgekeerde verwantskap tussen tegnologiese en gesondheidseienskappe van vet. Die afname in gesondheidsvoordele moet teen die talle positiewe gesondheidseienskappe, wat wissel van verbeterde immuunfunksie tot voorkoming van kanker, van CLA opgeweeg word.

Beide die *cis*-9, *trans*-11 en *trans*-10, *cis*-12 CLA isomere word in die neutrale- en glikolipied fraksies van onderhuidse vetweefsel deponeer. Die isomere word in die fosfolipied

fraksie van binnespierse vet gedeponeer. Die vleis van die verskillende behandelingsgroepe is gebruik om Hamburgerkoekies, spek en salami te vervaardig, as voorbeelde van verwerkte vleisprodukte. Chemiese stabiliteits- en sensoriese eienskappe van vars vleis en verwerkte vleisprodukte van die verskillende behandelingsgroepe is vergelyk. Die CLA aangevulde voer het laer TBARS waardes gehad. Dit dui op die anti-oksidant eienskappe van CLA. Sensoriese analise het daarop gedui dat CLA dieëtaanvullings ‘n beperkte uitwerking gehad het op die sensoriese eienskappe van vars en verwerkte produkte. Vars varktjops vanaf diere wat die CLA aangevulde diet gevoer is, het hoër *a**-waardes, in vergelyking met vars varktjops van diere wat die SFO aangevulde dieët gevoer is, getoon. Dit dui daarop dat CLA aanvulling beter kleurstabiliteit tot gevolg gehad het. Hamburgerkoekies, vervaardig van die vleis van varke wat die CLA aangevulde dieët ontvang het, het beter lipied stabiliteit gehad, soos die laer TBARS waardes aangedui het. Salami, vervaardig van die vleis en vet van diere wat die CLA aangevulde dieët gevoer is, was fermer. Dit kan toegeskryf word aan die vetverhardingseffek van CLA. Gekonjugeerde linoleïensuur verrykte vleis en vleisprodukte kan beskou word as funksionele voedsel en selfs ‘n “nutraseutiese produk”, wat ‘n positiewe uitwerking op die gesondheid van die mens het. Suid-Afrikaanse varkprodusente kan dus oorweeg om CLA verrykte varkvleis te bemark as a gesondheidsvoedsel. Die potensiële voordele en die premie wat op sodanige vleis verdien kan word, moet opgeweeg word teen die realiteit van verhoogde voerkoste.

Sleutelwoorde: gekonjugeerde linoleïensuur, varkproduksie, voerdoeltreffendheid, vark, onderhuidse vetweefsel, binnespierse vet, vetsure, verwerkte vleis produkte, sensoriese, stabiliteit.

ANNEXURE 1


144 pigs
Landrace x Large White
± 30 kg
72 pigs
0.5% CLA
72 pigs
0.5% Sunflower Oil
24 Barrows
24 Gilts
24 Boars
24 Barrows
24 Gilts
24 Boars
12 Barrows @ 70kg
12 Barrows @ 90kg
12 Gilts @ 70kg
12 Gilts @ 90kg
12 Boars @ 70kg
12 Boars @ 90kg
12 Barrows @ 70kg
12 Barrows @ 90kg
12 Gilts @ 70kg
12 Gilts @ 90kg
12 Boars @ 70kg
12 Boars @ 90kg
10 Gilts: Advanced Meat Quality Work
10 Gilts: Advanced Meat Quality Work
10 Gilts: Advanced Meat Quality Work
10 Gilts: Advanced Meat Quality Work

ANNEXURE 2

Sensory evaluation of CLA PORK and PORK FAT

Name:…….. Date…….. Session……. Sensory Code…….

Read instructions carefully

Please complete form i.e. name, date code etc.

1. **AROMA**: Smell the pork fat by lifting the foil closure at least half way off the glass container and inserting your nose into the top part of the glass beaker. Smell the fat.

2. **FLAVOUR, TEXTURE, JUICINESS AND AFTERTASTE**: Now bite through the meat, evaluate first bite the chew and swallow. Be cognisant of the mouth-feel and aftertaste while tasting. The aftertaste should be judged as the flavour in the mouth immediately after swallowing the product.

FAT AROMA	**Bland**					**Intense**		
	None	**Hint**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
Fresh pork fat	1	2	3	4	5	6	7	8
Roast pork fat (caramel)	1	2	3	4	5	6	7	8
Chemical	1	2	3	4	5	6	7	8
Sour	1	2	3	4	5	6	7	8
Piggy (Old Musty)	1	2	3	4	5	6	7	8
MEAT AROMA	**Bland**					**Intense**		
	None	**Hint**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
Roast pork meat	1	2	3	4	5	6	7	8
Cooked pork meat (fresh pork)	1	2	3	4	5	6	7	8
Musty	1	2	3	4	5	6	7	8
Livery (metallic/bloody)	1	2	3	4	5	6	7	8
JUICINESS OF MEAT	**Dry**					**Juicy**		
	None	**Hint**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
Initial impression of juiciness	1	2	3	4	5	6	7	8
MEAT	**Tough**					**Tender**		
	Extremely	**Very High**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
First bite	1	2	3	4	5	6	7	8
Tender	1	2	3	4	5	6	7	8
TEXTURE – MEAT	**Abundant**					**Practically**		
Muscle fibre & overall Tenderness (tough)	**Extremely**	**very**	**Excessive**	**slight**	**Moderate**	**Trace**	**none**	**none**
	1	2	3	4	5	6	7	8
JUICINESS OF MEAT	**Dry**					**Juicy**		
	None	**Hint**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
Sustained impression of juiciness – meat	1	2	3	4	5	6	7	8
FLAVOUR – MEAT	**Bland**					**Intense**		
	None	**Hint**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
Bland	1	2	3	4	5	6	7	8
Metallic (tin/aluminium)	1	2	3	4	5	6	7	8
Cooked pork	1	2	3	4	5	6	7	8
Sour	1	2	3	4	5	6	7	8
AFTER TASTE	**Bland**					**Intense**		
(Off flavour of meat)	**None**	**Hint**	**Slight**	**Weak**	**Moderate**	**High**	**Very High**	**Extremely**
Metallic	1	2	3	4	5	6	7	8
Sour	1	2	3	4	5	6	7	8

ooOoo