IMPROVEMENT OF SUBCUTANEOUS FAT QUALITY OF PIGS BY MEANS OF DIETARY MANIPULATION

by

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Opgedra aan my ouers

"Baie dankie vir die ondersteuning en geleenthede wat julle my gebied het."

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(This thesis has been written according to the typographical style of Meat Science)

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LIST OF ABBREVIATIONS

Abbreviation	Description
a^*	Colour redness value
ANOVA	Analysis of variance
b^*	Colour yellowness value
ca.	Approximately
CLA	Conjugated linoleic acid
DFD	Dark, firm and dry
FAME	Fatty acid methyl ester/s

Individual FAME:

Abbreviation	Common name	Complete Formula	Systematic (IUPAC) name
C10:0	Capric	C10:0	Decanoic
C11:0	Hendecanoic	C11:0	Undecanoic
C12:0	Lauric	C12:0	Dodecanoic
C13:0	Tridecoic	C13:0	Tridecanoic
C14:0	Myristic	C14:0	Tetradecanoic
C15:0	Pentadecylic	C15:0	Pentadecanoic
C16:0	Palmitic	C16:0	Hexadecanoic
C16:1	Palmitoleic	C16:1c9	cis-9-Hexadecenoic
C17:0	Margaric	C17:0	Heptadecanoic
C17:1	Heptadecenoic	C17:1c10	cis-10-Heptadecenoic
C18:0	Stearic	C18:0	Octadecanoic
C18:1c9	Oleic	C18:1c9	cis-9-Octadecenoic
C18:1c7	Vaccenic	C18:1c7	cis-7-Octadecenoic
C18:1t9	Elaidic	C18:1t9	trans-9-Octadecenoic
C18:2	Linoleic	C18:2c9,12(n-6)	cis-9,12-Octadecadienoic
C18:3n-3	α –Linolenic	C18:3c9,12,15(n-3)	cis-9,12,15-Octadecatrienoic
C19:0	Nonadecanoic	C19:0	Nonadecanoic
C20:0	Arachidic	C20:0	Eicosanoic
C20:1	Eicosenoic	C20:1c11	cis-11-Eicosenoic
C20:2	Eicosadienoic	C20:2c11,14(n-6)	cis-11,14-Eicosadienoic
C20:3n-3	Eicosatrienoic	C20:3c11,14,17(n-3)	cis-11,14,17-Eicosatrienoic
C20:3n-6	Eicosatrienoic	C20:3c8,11,14(n-6)	cis-8,11,14-Eicosatrienoic
C20:4	Arachidonic	C20:4c5,8,11,14((n-6)	cis-5,8,11,14-Eicosatetraenoic
C20:5	Eicosapentaenoic	C20:5c5,8,11,14,17(n-3)	cis-5,8,11,14,17-Eicosapentanoic
C21:0	Heneicosanoic	C21:1	Heneicosanoic
C22:0	Behenic	C22:0	Docosanoic

Abbreviation	Description

Individual FAME:

Abbreviation	Common name	Complete Formula	Systematic (IUPAC) name
C22:1	Erucic	C22:1c13	cis-13- Docosanoic
C22:2	Docosadienoic	C22:2c13,16(n-6)	cis-13,16-Docosadienoic
C22:5n-3	Docosapentaenoic	C22:5c7,10,13,16,19(n-3)	cis-4,7,10,13,16-Docosapentaenoic
C22:5n-6	Docosapentaenoic	C22:5c7,10,13,16,19(n-6)	cis-4,7,10,13,16-Docosapentaenoic
C22:6	Docosahexaenoic	C22:6c4,7,10,13,16,19(n-3)	cis-4,7,10,13,16,19-Docosahexanoic
C23:0	Tricosanoic	C23:0	Tricosanoic
C24:0	Lignoceric	C24:0	Tetracosanoic
C24:1	Nervonic	C24:1c15	cis-15-Tetracosenoic

g	Gram
kg	Kilogram
L^*	Colour lightness value
LDL	Low density lipoprotein
m	Meter
mg	Milligram
ml	Milliliter
mm	Millimeter
MUFA	Mono unsaturated fatty acid/s
n-3	Omega-3 fatty acid/s
n-6	Omega-6 fatty acid/s
PSE	Pale, soft and exudative
PUFA	Polyunsaturated fatty acid/s
SFA	Saturated fatty acid/s
UFA	Unsaturated fatty acid/s

CHAPTER 1

INTRODUCTION

The modern consumer requires pork to be healthy, lean, juicy, fresh, tender and tasty (Bredahl & Andersson, 1998). Presently, consumers are more aware of diet, health and nutritional concerns than ever in the past (Rhee, Davidson, Knabe, Cross, Ziprin, & Rhee, 1988a; Verbeke, Van Oeckel, Warnants, Viaene, & Boucqué, 1999). Pork meat was often controversial in the past because consumers considered it to contain an excess of fat, saturated fatty acids (SFA) and cholesterol (Hernández, Navarro, & Toldrá, 1998). Consumers were advised to maintain a ratio of polyunsaturated fatty acids (PUFA) to SFA of at least 0.5 in their diet (Levnedsmiddelstyrelsen, 1986; Enser, Hallett, Hewitt, Fursey, & Wood, 1996). Currently, consumers are advised to reduce the ratio of omega-6 to omega-3 (n-6/n-3) fatty acids in their food (Okuyama, 1997). The concern of consumers about the health status of meat are best illustrated by a consumer survey done in the UK that revealed that although consumers were aware of the decrease in palatability of leaner meat, they were willing to sacrifice some degree of palatability for their desire for increased leanness (Sather, Jones, Robertson & Zawadski, 1995).

The global meat industry responded to the consumer demand for leaner and healthier pork, by utilizing modern breeding, feeding as well as altered management techniques to produce leaner pigs (Morgan, Noble, Cocchi & McCartney, 1992; Blanchard, 1995; Cannon, Morgan, McKeith, Smith & Meeker, 1995). According to the Meat and Livestock Commission in the United Kingdom, the average P2 backfat thickness of slaughter pigs in the United Kingdom has decreased from 17.4 mm in 1977 to 11.1 mm in 1996 (Sharlach, 1998). The same trend regarding leanness is currently observed in South Africa. The percentage of pigs in the P classification group (pigs with a backfat thickness of less than 12 mm) increased drastically over the last 6 years, from 17.5 % in 1993 to 34.3 % of all pigs merchandized at South African auction markets during 2001 (SAMIC, 2002). During 2001, 74.7 % of all pigs merchandized at South African auction markets were classified as P and O (less than 18 mm backfat thickness) carcasses (SAMIC, 2002). The low backfat thickness of pigs in South Africa are often the result of a very low slaughter weight. During 2001, 39.0 % of all the pigs which were slaughtered and sold at South African markets, had a carcass weight of less than 55 kg while 85.3 % of the slaughtered pigs had a carcass weight of less than 71 kg (SAMIC, 2002).

The response of the meat industry to the consumer demand for healthier pork has certain

implications. As pigs become leaner, their fat tends to become softer and more unsaturated (Sather et al., 1995). This is good news for the health conscious consumer but may cause serious problems for the meat processor (Affentranger, Gerwig, Seewer, Schwörer & Kunzi, 1996). Increased levels of PUFA in the thin backfat of lean pigs can have detrimental effects on the sensory and technological quality and acceptability of meat products (Houben & Krol, 1983; Metz, 1985; Stiebing, Kühne, & Rődel, 1993; Warnants, Van Oeckel & Boucqué, 1998). This compositional changes of pig adipose tissue may manifest in technological problems like lack of consistency (Whittington, Prescott, Wood & Enser, 1986; Rhee, Ziprin, Ordonez & Bohac, 1988b; Fischer, 1989) and poor oxidative stability (Houben & Krol, 1983; Davenel, Riaublanc, Marchal & Gandemer, 1999). Processed meat products containing these adipose tissues, often called "soft fat" may show defects such as insufficient drying, oily appearance, rancidity development and lack of cohesiveness between muscle and adipose tissue on cutting (Bailey, Cutting, Enser, & Rhodes, 1973). When fresh meat with high concentrations of unsaturated fatty acids (UFA) is cooked it becomes dry and tasteless (Wood, 1983).

The decrease in backfat thickness observed in British pigs resulted in meat handling problems and decreased quality of meat cuts (Kempster, Dilworth, Evans & Fisher, 1986; Wood, Jones, Francombe & Whelehan, 1986; Warkup, 1994; Sharlach, 1998). According to Stiebing et al. (1993), a loss of quality in the fatty tissue of pigs has also been observed in recent years in Germany. European countries like Switzerland are already focusing on fat quality to such an extent that they incorporated it into their payment system for pig meat (Häuser & Rhyner, 1991). The iodine value of the fat is used to determine the quality of the pig fat at the slaughtering plants. Iodine values higher than a set value causes the profit margin of the producers to drop considerably (Affentranger et al., 1996).

According to Bruwer (1992) the South African meat industry is unaware or unconcerned about fat quality and the contribution of fat quality to meat quality in both fresh and processed meats. In an attempt to obtain an overview of the situation regarding fat quality of pigs in South Africa a survey on the backfat quality of South African pigs was conducted by Hugo and Roodt (2002) during which backfat samples from 2107 pig carcasses were collected and analyzed. Backfat iodine values showed a significant decrease with increased backfat thickness and decreased lean meat content (Hugo & Roodt, 2002). Only the C, U and S classification groups had average iodine values lower than the 70 proposed by Barton–Gade (1983; 1987) as the maximum value for good fat quality. The average iodine values of the P group (76.95 ± 5.15), the O group (73.01 ± 4.61) and the R group (70.65 ± 4.20) was higher than the maximum proposed by Barton–Gade (1983; 1987). The average iodine

value (72.42) of all 2107 pigs sampled was higher than 70. Hugo and Roodt (2002) concluded that South African pigs in general but especially those in the P and O classification groups have poor backfat quality. This is of special importance because it was earlier mentioned that 74.7 % of all pigs merchandized at South African auction markets during 2001 were classified as P and O carcasses (SAMIC, 2002). Due to the demand for the carcasses of leaner pigs in South Africa, higher prices per kg are generally paid for carcasses from the P and O classes than from the R, C, U and S classes (i.e. those with thicker backfat). It is unlikely that the South African meat processing industry will start paying a premium for good fat quality. It is also more economical for the pig farmer to produce lean pigs because fat is only deposited at the end of the growth cycle when feed conversion ratios are not so good. Farmers are not interested in producing fat tissue because it is a more expensive tissue to produce than lean meat, and meat processors do not want to buy fat if they cannot sell it at a good profit margin (Phelps, 1991). It will, therefore, be very difficult to convince the South African pig producers to start producing more pigs in the R, C, U and S classification groups. The only viable solution would be to improve the backfat quality of pigs in the P and O classification groups (Hugo & Roodt, 2002).

In pigs and other monogastric animals, the fatty acid composition of the fat tissue triglycerides (particularly in subcutaneous fat) can be changed by altering the fatty acid composition of dietary fat, since fatty acids are absorbed intact from the small intestine and incorporated directly into fat tissue (Friend & Cunningham, 1967; Koch, Pearson, Magee, Hoefer, & Schweigert, 1968; Bowland, 1972; Castell & Falk, 1980; Rhee, Davidson, Cross, & Ziprin, 1990). This means that it is possible to modify the fatty acid composition of pigs by the strategic use of specific dietary fat sources (Morgan, et al., 1992). This implies that dietary manipulation may be used to solve the problem of soft and low quality fat of pigs, and that is the approach that will be followed in this study in an attempt to improve the fat quality of South African pigs. It is known that inclusion of feed ingredients like barley (rich in the SFA acid palmitic acid) produces harder (more saturated) fat (van der Merwe, 1985; van der Merwe & Smith 1991). By including ingredients like barley in pig diets, it may be possible to produce more pigs in the P, O or R classification groups with acceptable fat quality. Barley is unfortunately not freely available all over South Africa. It is however possible that there may be other more freely available feedstuffs with the same potential to improve fat quality.

The aim of this study will, therefore, be to:

1. Provide a review of the literature explaining the importance of fat quality in meat

technology. In the literature survey the position of fat quality within the total concept of meat quality will be established. Fat quality will be defined and the importance of fat quality in meat technology will be discussed. Any meat quality parameter must be measurable, therefore the different ways of monitoring fat quality will be explained. Fat oxidation and the significance of pork fat quality in human nutrition will be considered. Factors affecting fat quality will also be discussed.

2. To identify feed ingredients with the potential to improve fat quality of pigs. A questionnaire will be sent out to major companies involved in the formulation, mixing, and supply of pig feeds in South Africa to identify individual feed ingredients available as well as typical inclusion levels of such ingredients. All the available lipid containing feed ingredients will then be analyzed for iodine value and fatty acid composition. From this data, individual feedstuffs with the potential of improving fat quality will be identified. Diets will then be formulated with the aim of improving fat quality of South African pigs cost effectively.

3. To illustrate experimentally whether it is possible to produce baconer pigs in the P and O classification groups with good fat quality, a feeding trial will be performed by utilizing the diet optimized for fat quality against a commercial diet. At ± 95 kg live mass the pigs will be slaughtered. Fat quality characteristics (colour, firmness, iodine value, refraction index, extractable fat content and fatty acid profile) of the subcutaneous fat of the two treatments will be compared.

CHAPTER 2

LITERATURE SURVEY

INTRODUCTION

As the competition among the various animal protein sources (poultry, beef and pork) increased, meat quality became an important criterion relative to the marketability of meat cuts. Meat quality is especially important in pork as the pork industry attempts to increase its presence in the global market and as it faces increased competition with other red meat species (Cannon et al., 1996). Meat quality is becoming increasingly important to meat processors and consumers. "Providing the customer with what he requires, at an affordable price, is the most important task of the meat industry" (de Jong, 1992). Until recently, pig breeding programmes were essentially devoted to the improvement of growth rate, feed conversion efficiency and carcass quality. With the exception of problems related to the halothane susceptibility gene, meat quality was not taken into account (Bidanel, Ducos, Gueblez, & Labroue, 1994).

What is meat quality? Many definitions for meat quality have been proposed in scientific literature. Ingr (1989) considered the following as the ten most important meat quality features: morphological structure, chemical composition, physical properties, biochemical condition, microbial contamination, sensory properties, technological properties, hygienic condition, nutritional value and culinary properties. Other definitions include: "fitness for use, the ability to satisfy a need, meeting specified demands, the degree of excellence at a reasonable price, and the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs" (Gray, Gomaa & Buckley, 1996).

Meat quality can also be defined as the totality of all properties and characteristics of the meat that are important to its nutrient value, acceptability, human health and the processing of the meat or even shorter and more general "quality is the sum of all quality factors" (Hofmann, 1973). According to their practical importance, the different quality factors of meat may be divided into four groups: sensory, nutritive, hygienic – toxicological and technological factors (Hofmann, 1990; 1993; 1994). The effect of fat and fat composition on sensory and nutritive properties of meat is evident. The presence of trans fatty acids (Khosla & Hayes, 1996) and fat oxidation products (Halliwell & Gutteridge, 1990) can easily be added to hygienic and toxicological factors. The importance of fat

and fat composition as a technological meat quality property will become clear in this literature survey.

The fatty acid composition of the pig carcass may influence pork flavour, storage stability of body fat, consistency of adipose tissue and the quality of meat products (Gustincic, Kramer, & Prabucki, 1976; Enser, Dransfield, Jolley, Jones & Leedham, 1984; Hertzman, Göransson & Rudérus, 1988; Rhee et al., 1988b). Fat quality is as important as any other meat quality parameter. However, requirements placed on fat quality for processing into meat products vary and are also dependent on the type of product to be manufactured (Fischer, 1989). The global trend towards leaner pigs and associated meat quality problems brought fat quality to the foreground (Kempster et al., 1986; Wood et al., 1986; Häuser & Rhyner, 1991; Bruwer; 1992; Stiebing et al., 1993; Warkup, 1994; Affentranger et al., 1996; Sharlach, 1998; Hugo & Roodt, 2002).

In this literature survey, fat quality will be defined and the importance of fat quality in meat technology will be emphasized. Different ways of monitoring fat quality will be explained. The significance of pork fat quality in human health, nutrition, fat oxidation and specific meat products will be considered. Factors affecting fat quality will also be discussed.

FAT DEPOSITION IN THE PIG

The maintenance of a fine balance between energy intake and energy materialization results in the deposition of adipose tissue as well as the maintenance of an energy balance (Mersman, 1991; Jenkins, 1993). Fat deposition may be in one of the following depot sites: subcutaneous (the major fraction in pigs), inter-muscular, in the body cavity or as intra-cellular fat droplets. These depots are composed mostly of localized clusters of identifiable adipose cells. These cells are primarily filled with triacylglycerides and their main function is to serve as energy reserves (de Jong, 1992). Therefore, fat deposition is the difference between fat synthesis and energy metabolism and depends on the energy intake and the intake of essential nutrients (Madsen, Jakobsen & Mortensen, 1992). As the digestible energy ratios increase, the rate of fat deposition will increase as well (Chiba, Lewis & Peo, 1991).

Glucose that is consumed by the pig is the main precursor of lipids (Christensen & Goel, 1972). *De novo* synthesis is responsible for converting carbohydrates to lipids (Secondi et al., 1992). The *de novo* cycle produce SFA and mono-unsaturated fatty acids (MUFA) (Coutron-Gambotti, Gandemer

& Casabianca, 1998). The main fatty acids in adipose tissue of pigs are synthesized in the tissue. They are the long-chain fatty acids palmitic (C16:0), stearic (C18:0) and oleic (C18:1c9). If the medium chain fatty acids like lauric (C12:0) and myristic (C14:0) are present in the feed, they will be deposited to a limited extent in depot fat (Christensen, 1962; 1969). High concentrations of dietary fat decrease the *de novo* fatty acid synthesis activity (Chilliard, 1993).

There are some essential fatty acids like linoleic (C18:2) and linolenic acids (C18:3n-3) that pigs are not able to synthesize. This is the reason why their concentrations in subcutaneous fat are well correlated with their concentrations in the feed or diet (Madsen et al., 1992). The requirement for dietary C18:2 for normal growth rate, feed efficiency, nitrogen and energy metabolism, is only 0.26 % of the metabolizable energy (Christensen, 1985). According to Jakobsen (1990) the dietary requirement for C18:2 is not more than 1 % of dietary energy. Pigs are also unable to synthesize the n-3 PUFA such as eicosapentaenoic acid (C20:5) and docosahexaenoic acid (C22:6) with the *de novo* fatty acid cycle (Irie & Sakimoto, 1992). Fatty acids like C22:5n-3 is a metabolite from dietary C18:3n-3 or dietary C20:5 and is further metabolized to C22:6. Docosopentaenoic (C22:5n-6) is a metabolite from dietary C18:2 and is the end product in this metabolic chain (Hertzman et al., 1988).

Fat in pigs are deposited in a fixed order, that being: subcutaneous, inter-muscular and intra-muscular (Osterhoff, 1988). This means that the intra-muscular depots are usually the last to receive lipid deposition (Buttery et al., 1997). Subcutaneous fat accounts for ± 61.5% of all fatty tissue on a carcass while intra-muscular fat accounts for ± 30.8 % and fair or leaf fat for ± 7.7 % (Fischer, 1989). The depot fat of pigs is very susceptible to dietary changes as fatty acids are incorporated unchanged into body fat. (Mortensen, Madsen, Bejerholm & Barton, 1983; Flachowsky, Schone, Schaarmann, Lubbe, & Bomhme, 1997). Koch et al. (1968) reported that the inter-muscular fat from the *M. longissimus dorsi* muscle was less affected by a change in diet than that of leaf fat or backfat. This implies that subcutaneous fat is the main site of fat synthesis and deposition in the pig (Camara, Mourot & Fevrier, 1996).

Major fatty acids such as C16:0, C18:0, C18:1c9, palmitoleic (C16:1) and C18:2 show a site preference pattern meaning that these fatty acids were present in higher concentrations in certain anatomical positions on the carcass. Other fatty acids like C12:0, C14:0, pentadecanoic (C15:0), heptadecanoic (C17:0), heptadecenoic (C17:1), C18:3n-3 and arachidonic (C20:4), are minor fatty acids and did not show a site preference pattern (Sink, Watkins, Ziegler & Miller, 1964). According to Leat, Cuthbertson, Howard and Gresham (1964), saturated fat is usually produced

biosynthetically, and is to a lesser extent derived from the diet. These fats are most of the time deposited inter-muscularly. The lipid synthesis potential is influenced by the location of the tissue. The lipogenic activities were higher in backfat, lower in liver and intermediate in *M. longissimus dorsi* muscle (Camara et al., 1996). Subcutaneous fat is, therefore, the main site for fatty acid synthesis via the *de novo* fatty acid cycle. That is the reason why SFA are preferentially deposited in leaf fat rather than in subcutaneous fat. Saturated fats are also rather deposited within the inside of the subcutaneous fat layer rather than within the outside layer (Marchello, Cook, Slanger, Johnson, Fischer & Dinusson, 1983). Marchello et al. (1983) observed an opposite pattern when looking at the UFA. Other researchers also observed the outer layer of the backfat to contain more UFA than the inner layer (Madsen et al., 1992; Dean & Hilditch, 1933). This may be one of the factors causing an increase in the C18:2 percentage with decreasing backfat thickness, which resulted in softer backfat (Madsen et al., 1992). Camara et al. (1996) also stated that the inner layer of the backfat might be more sensitive to changes in the dietary fat than the outer layer, this may also be a factor which contributes to a difference in saturation between the two backfat layers.

Not all of the fatty acids are deposited in the same amounts in the pig. Poly-unsaturated fatty acids, especially C18:2 are preferentially deposited by the pig (de Jong, 1992). Linoleic acid is initially stored in depot fat at the expense of C18:1c9 (Leat et al., 1964; Brooks, 1967; 1971). When the dietary level of C18:2 is high, C16:0 (Leat et al., 1964; Brooks, 1967; 1971), C16:1 (Brooks, 1967; 1971) and C18:0 acid is replaced by C18:2 (Leat et al., 1964). The incorporation of C22:5n-3 is very effective in both backfat and intra-muscular fat (Hertzman et al., 1988).

FAT COMPOSITION OF THE PIG

Mature pig fat tissue contains 70-90 % crude fat, 5-20 % water and approximately 5 % connective tissue (Nürnberg & Ender, 1990). The main components of connective tissue are the two connective tissue proteins namely collagen and elastin (Fischer, 1989).

Pork fat (lard) is composed of an average of 43 % SFA, 47% MUFA and 10 % PUFA (INRA, 1987). Pork fat is a combination of one glycerol molecule with three fatty acid molecules attached to the glycerol molecule. According to their chemical structure, animal fats can therefore be considered triglycerides. The fatty acid parts of the triglyceride are made up of about 35 different fatty acids (Fischer, 1989). Approximately 90% of these fatty acids is made up of C14:0, C16:0, C18:0, C16:1, C18:1c9 and C18:2 (Fischer, 1989; Nürnberg & Ender, 1990). Odd-numbered fatty acids make up

only a few percent of the total fatty acids. They play, however, an important role because they may affect fat characteristics like softness and fluidity of the fat (Johnson, Purchas & Birch, 1988). The majority of the odd-numbered fatty acids C11, C13, C15 and C17 occur in the phospholipid fraction (Allen, Bray & Cassens, 1967).

As already mentioned, the major fatty acids follow a site preference deposition pattern (Dean & Hilditch, 1933; Leat et al., 1964; Sink et al., 1964; Marchello et al., 1983; Madsen et al., 1992; Camara et al., 1996). Pig fat has a saturated to unsaturated ratio of more or less 50:50 in leaf fat, and approximately 40:60 in backfat (Fischer, 1989). Perirenal fat contains a lower UFA content than backfat (Leat et al., 1964; Sink et al., 1964; Marchello et al., 1983). According to Jeremiah (1982), back fat samples have lower percentages of C16:0 and C18:0 as well as total SFA than belly fat. Backfat also has higher percentages of C18:1c9 and C18:2 fatty acids as well as PUFA and total UFA when compared to belly fat samples (Jeremiah, 1982). According to Barton-Gade (1983) changes in anatomical location cause a change in iodine value and this change was caused particularly by C16:0, C18:0 and C18:1 fatty acids.

A detailed description of the differences in the fatty acid composition between the two backfat layers of pigs were given by Malmfors, Lundström and Hansson (1978). The outer layer of backfat contains more UFA, such as C16:1, C18:1c9, C18:2 and C18:3 acids, than does the inner layer of the backfat. The outer layer of the backfat also contains lower percentages of SFA such as C16:0 and C18:0 (Sink et al., 1964; Koch et al., 1968; Malmfors et al., 1978). Malmfors et al. (1978) also reported that fatty acids with odd carbon numbers also occurred in higher percentages in the outer layer than the inner layer.

FACTORS AFFECTING FAT QUALITY OF THE PIG

Gender

Gender has an effect on the quantitative deposition of fat (Allen & Bray, 1964). Barrows produce the most fat and gilts are intermediate (Bruwer, Heinze, Zondagh & Naude, 1991; Enser, 1991). Castration of male pigs cause a decrease in the conversion of feed into lean meat and increased fat deposition (Wood, 1983). Barton-Gade (1987) found that boars had 5 % less extractable fat, 1 % more protein and 4 % more water in backfat compared to castrates. Wood, Enser, Whittington, Moncrieff, & Kempster. (1989) reported that the backfat from male pigs contained higher

concentrations of water, collagen and lower concentrations of lipids than that of females.

Fat from castrates also contains lower proportions of PUFA than that of boars (Malmfors et al., 1978). Fat from gilts also have lower proportions of total UFA than that of boars (Smithard, Smith, & Ellis, 1980). Malmfors et al. (1978) reported that boar carcasses contained higher proportions of C18:2, less C16:0 and less C18:1c9 in their backfat than castrates. They found no difference in the C18:0 acid contents in the backfat of the castrates and the boars. They concluded that boars contained higher proportions of total UFA and PUFA in their backfat. They also found that the gilt carcasses had intermediate percentages of various of these fatty acids in their backfat (Malmfors et al., 1978). Wood et al. (1989) found that the entire males and females differed in the C18 UFA (C18:2 and C18:3), the males having higher concentrations of the PUFA and lower concentrations of C18:1c9. Barton-Gade (1987) found that boar fat had higher concentrations of C18:2 causing boar fat to have higher iodine values when compared to gilts and castrates.

Fat from boars is also softer than that of other sexes (Barton-Gade, 1987; Reid, 1983; Warnants, Van Oeckel & Boucque, 1996). Boars also had a higher incidence of splitting (Reid, 1983). The backfat of barrows is also lighter than that of gilts which is more yellow (Warnants et al., 1996). It can, therefore, be concluded that boars have higher concentrations of UFA followed by barrows and then gilts. The fat of boars are therefore of poorer quality when compared to gilts and castrates.

Backfat thickness

The fat composition of backfat will alter with a change in backfat thickness. Experiments done by Wood et al. (1989) showed the collagen percentage to decrease from 53% to 46% as the fat thickness increased from 8 mm to16 mm P2. Wood et al. (1989) also found that the concentration of water decreased with 59 % as the P2 increased from 8 mm to 16 mm and the lipid content increased with 18 % as the P2 value increased with the same margin. Fatty acid concentrations also changed as the backfat thickness increased. The concentrations of C16:0 ,C18:0 and C18:1c9 increased, while the concentrations of C18:2 and C18:3 will decrease. The C18:2 fatty acid content decreased with 4.3 % as the P2 backfat thickness value increased from 8 mm to 16 mm (Wood et al., 1989). Wood et al. (1989) showed that the PUFA to SFA ratio was 0.41; 0.33 and 0.28 in the 8 mm, 12 mm and 16 mm P2 backfat thickness groups, respectively. This means that the fatty acid profile of the backfat will become more saturated as backfat thickness increases (Wood et al., 1989). These changes will cause the melting point of the fat to decrease and the softness of the backfat to increase as the P2

value decreases (Wood et al., 1986).

Slaughter weight / age

The deposition of fat in pigs varies as the pig grows. Fat deposition is low at birth but it increases as the pig mature (Madsen et al., 1992). As pigs grow older, the fat composition change. According to Duncan and Garton (1966) the concentration of C16 fatty acids will decline between birth and the age of 184 days but C16:0 will decrease at a slower rate than C16:1. This will lead to an increase in saturation. The concentrations of both C18:0 and C18:1c9 increased to 184 days but there was no overall change in their ratio. The concentration of C18:2 increased fast between birth and day 3 due to the fact that the colostrum has high levels of this fatty acid and because of the preferential deposition of these fatty acids. This fatty acid declined from day 3 until day 184 due to a fall in its concentration in the sow's milk and the increasing role that the *de novo* fatty acid synthesis plays in fat deposition. The fact that C18:2 is entirely derived from the diet was already discussed (Madsen et al, 1992).

The combined increase in the saturated C16 and C18 fatty acids during the growth period, leads to an increase in the firmness and the melting point as the pig ages (Wood et al., 1978). Age will also have an effect on the relative proportions of lipid, water and connective tissue. Young fat tissue is made up of small cells that contain high proportions of water and low proportions of lipid. Young fat also has high percentages of connective tissue. As the animal gets older and dietary energy is diverted more and more into growth, the cell size increases and consequently the proportion of lipids increases, therefore, the proportion of connective tissue and water decrease (Aberle, Etherton & Allen, 1977). In older tissue the fat cells contain more lipid and the cells are also packed more closely together which contributes to the firmer feel of such fat. Separation between fat and muscle occurs more easily in young tissue. The gray colour of the fat from young pigs is the result of higher concentrations of connective tissue, which lower the whiteness value of the fat (Mac Dougall & Disney, 1967). The fact that older and heavier pigs tend to deposit more SFA, causes the fat to become harder and firmer, which is how the butchers and processors prefer it (Bruwer et al., 1991).

An exception to the general trend for more saturated fat with better fat quality with increased weight and/or age was observed under restricted feeding conditions. Malmfors et al. (1978) found that if slaughter weight was raised from 110 to 130 kg under restricted feeding conditions, the relative content of C18:2 increased. At the same time, the proportion of C18:1c9 continued to increase,

though to a lesser extent than earlier, while the content of major SFA was unaffected or decreased slightly. This pattern was observed in all three layers of backfat in the Landrace pigs. Feed restriction may cause some reduction in the rate of backfat deposition in the interval 110 – 130 kg (Hansson, Lundström, & Malmfors, 1975), and might explain the relative increase in PUFA in the pigs after ca. 110 kg live weight. Callow (1935) suggested that the degree of saturation is influenced by the rate of fat deposition; the slower the deposition rate, the more unsaturated the fat. Hilditch, Lea and Pedelty (1939) found that the fat produced on a restricted diet was softer, owing to an increase in the proportion of C18:2 together with some increase in C18:1c9. These results agreed with work done by Vold (1975) who also found no significant difference in lipid saturation with increased slaughter weight under restricted feeding conditions. Many other studies have shown that the deposition of SFA increased with increasing slaughter weight and age under ad libitum feeding conditions (Sink et al., 1964; Johns, 1941; Staun, 1970; Martin, Fredeen, Weiss, & Carson, 1972; Cameron, Warris, Porter & Enser, 1990).

Genetic factors

It was noted in Britain that pig's fat tends to be softer than before the second world war, and the implication was that this was the result of genetic changes (Lea, Swoboda & Gatherum, 1970). It was found that the more the Hampshire breed was represented in a cross, the more likely the carcasses were to have softer fat (Lea et al., 1970). Cameron and Enser (1991) also found that Duroc pigs have higher concentrations of SFA and MUFA and lower concentrations of PUFA in subcutaneous fat than that of Landrace pigs.

Breeding leaner pigs caused a decrease in the adipose tissue mass which is accompanied by a decrease in the ratio between fat cell mass and connective tissue mass (Metz, 1985). Levels of UFA, especially C18:2, were higher in genetically leaner pigs compared to genetically fatter pigs (Wood, 1973). Genetically fatter pigs accumulated more saturated fat than genetically leaner ones even at the same level of feed intake. Wood (1973) proposed two reasons for this difference. Firstly, there may be a difference in the mechanism of fat deposition between the genetically lean pigs and the genetically fat pigs. Secondly, the lean pigs may have a smaller amount of fat deposition, with a smaller contribution from the usually saturated *de novo* fatty acid syntheses, to the total fat deposition than in genetically fatter pigs at the same level of feed intake. Metz (1985) postulated that the difference in fatty acid saturation is most probably a variation in the rate of fat deposition, that affects the ratio between the incorporation of dietary fatty acids and the incorporation of *de novo*

synthesized fatty acids into the body fat. There is no indication that there is a difference between genetically lean and fat pigs in the ability to digest or to incorporate dietary fat (Metz, 1985). This means that genetically leaner pigs incorporate less fatty acids from the *de novo* fatty acid syntheses because the fat deposition is lower. Fatty acids from vegetable fat which is present in pig rations, are usually more unsaturated than those of fatty acids from the *de novo* fatty acid syntheses. This means that the breeding of leaner pigs will lead to the deposition of more UFA unless the dietary fat is saturated (Metz, 1985).

This decreasing ratio between the fat deposition and lean deposition, brought about by the breeding of a leaner pig, affected fat quality negatively in two ways. Firstly, the smaller contribution of the *de novo* fatty acid syntheses to the total fat deposition cause the adipose tissue to be less saturated, and secondly the amount of lipids inside the adipose tissue decreased, causing separation between the tissues (Metz, 1985).

Growth stimulants

There are two types of growth stimulants that are of interest namely somatropin and beta-adrenergic agonists. By using somatropin it is possible to increase the protein content of the pig with as much as 16 % and reduce the fat content by as mush as 36 %. This reduction of fat content can also cause the backfat thickness to reduce between 20 and 45% (Cannon et al., 1995). Pigs treated with somatropin usually have a reduction of cell size and the number of the fat cells and the concentration of the PUFA are increased (Rehfeldt, Nürnberg & Ender, 1994; Nürnberg, Kuhn, Nürnberg, Rehfeldt & Ender, 1995).

The second group of growth promoting compounds is the beta-adrenergic agonists like ractopamine. Ractopamine is effective in increasing lean growth rate, decreasing the amount of carcass fat and improving feed efficiency. Ractopamine decrease the amount of fat in cuts up to 25 %, thus increasing the carcass-cutting yield. This reduction in fat content is primarily due to a reduced subcutaneous and inter-muscular fat content because intra-muscular fat is not altered significantly by ractopamine (Stites, McKeith, Singh, Bechtel, Mowrey & Jones, 1991).

Effect of the PSE and DFD conditions

The fact that the lipid composition of carcasses differed significantly among muscle quality groups

(PSE or DFD), is of considerable importance, since it implies that stress factors that produce differences in muscle quality may also significantly influence the fatty acid composition and thereby the physical properties of the carcass lipids (Jeremiah, 1982). Jeremiah (1982) compared the effects of the DFD (dark, firm and dry) and PSE (pale, soft and exudative) conditions on the fatty acid composition of pigs. The DFD carcasses had lower percentages of C16:1, C18:2 and total PUFA in their backfat than PSE carcasses. A comparison between DFD carcasses and normal carcasses revealed that DFD carcasses had higher percentages of C14:0, C18:0 and long chain SFA (≥C18), while they had lower percentages of C16:0 and C16:1 fatty acids than normal carcasses in their backfat. The bellyfat samples of the DFD carcasses had lower percentages of C16:1, C18:2 and PUFA than normal and PSE carcasses.

Dietary effects

In monogastric animals like pigs, the SFA and UFA from the diet pass directly through the digestive system and are deposited in the different depots without change. Lipids in various tissues strongly reflect the major dietary fatty acids (Nürnberg, Kracht & Nürnberg, 1994a; Nürnberg, Kracht & Edner, 1994b; Kracht, Jeroch, Matzke, Nürnberg, Ender & Schumann, 1996).

Commonly used feedstuffs for pig feeding in South Africa are fishmeal, maize, sunflower oilcake, soyabean oilcake and wheaten bran (van der Merwe, 1985). The fat components of these feeds are largely made up of UFA, which have the potential to produce unsaturated soft subcutaneous fat tissue (Viljoen & Ras, 1991). Several experiments indicated the effect of these feedstuffs on the fat composition of pigs.

Leat et al. (1964) did an experiment where pigs were fed maize oil, which contained 54 % C18:2 and 29 % C18:1c9. In these pigs the C18:2 content of depot fat rose to 25 - 30 % at the expense of C18:1c9, C16:0 and C18:0. The highest concentration of C18:2 was found in the outer layer of the subcutaneous fat. It was concluded that dietary inclusion of maize caused an increase in the UFA content of pig fat. Hartman, Costello, Libal and Wahlstrom (1985) reported that the fat of pigs that were fed high levels of sunflower seeds was less saturated as indicated by an increase in the iodine value as well as an increase in the amount of total UFA. The fatty acid profile of the subcutaneous fat of the pigs showed a decrease in the concentrations of C14:0, C16:0, C18:0, C16:1 and C18:1c9. There was also an increase in the concentration of C18:2. The backfat of pigs receiving sunflower seed were also classified as soft. Lauridsen, Andersen, Andersson, Danielsen, Engberg and Jakobsen

(1999) found that the addition of fish oil to the diet of pigs increased particularly the concentrations of C20:5, C22:5n-3 and C22:6 in muscle as well as the fat tissue. They also reported a decrease in the n-6/n-3 ratio of fat tissue of pigs that received fish oil. This means that the addition of fish oil to pig diets will cause the fat to become more unsaturated. The addition of soya oil to the diets of pigs also had a significant effect on the fatty acid profiles of pigs. Monahan, Buckley, Morrissey, Lynch and Gray (1992) showed that the addition of soya oil to pig feed significantly lowered the levels of C14:0, C16:0, C16:1 and C18:1c9 while it significantly increased the levels of UFA such as C18:2 and C20:4 in subcutaneous fat. This soya oil diet also increased the ratios of UFA/SFA and C18:2/C18:1c9 significantly compared to that of pigs fed tallow. Flachowsky et al. (1997) reported that the incorporation of oilseed like soya beans into pig diets result in a significantly increased UFA content in body fat.

It is clear that the addition of feedstuffs commonly used in South Africa such as maize, soya products, sunflower products and fishmeal, will decrease the saturation of the pig fat. From the previous sections it is clear that an increase in UFA in the diet will definitely result in an increase in UFA in the subcutaneous fat of the pig. It is, therefore, important to control the amount of particularly PUFA present in the diet of the pig. High levels of PUFA in the subcutaneous fat of pigs will have a negative effect on the processing and storage stability of pig fat. That is why pig diets should not contain more than 50 g PUFA/kg to prevent problems with particularly oxidation during storage of the subcutaneous fat (Bryhni, Kjos, Ofstad & Hunt, 2002).

Van der Merwe and Smith (1991) stated that the addition of feedstuffs like barley and sorghum, rich in SFA, to the diet of a pig, should increase saturation of the pig fat. Siebrits, Kemm and Ras (1987) compared the subcutaneous fatty acid profiles of pigs fed maize with pigs fed wheat. They found that pigs which were fed the maize based diet had a higher concentration of C18:2 (11.0 %), when compared to pigs fed the wheat based diet which had a C18:2 concentration of 9.4 %. The iodine value and the refraction index also supported these results. These findings were also supported by the findings of Ericson, Miller, Hill, Black, Bebiak and Ku (1980) who found that the replacement of maize by wheat in pig diets resulted in pig fat with higher concentrations of SFA. This more saturated fat was firmer and less susceptible to oxidation.

It was also found that exposure time to a specific finishing diet had an effect on the concentration of the fatty acids in the pig fat (Hertzman et al., 1988). Fat deposition in pigs is also highly sensitive to the increase of protein supplements (Madsen et al., 1992). If the dietary energy to protein ratio is

low and no fat is added, the fat deposition of the pig will also be low (Moran, 1986). Certain amino acids also have an affect on fat deposition, for instance fat deposition decreased as the lysine: digestible energy ratios increased up to 3.00 g lysine/Mcal digestible energy (Chiba et al., 1991). Certain minerals also have an effect on the fatty acid profile of pigs. Such an element is copper, the addition of copper to pig diets is used to promote growth in pigs, and the copper is added at levels of about 250 ppm. At this concentration, copper promoted the deposition of soft fat (Moore, Christie, Braude & Mitchell, 1969; Elliot & Bowland, 1968). Soft fat which is caused by copper supplementation usually showed an increase in the amount of C16:1 as well as C18:1c9 and a decrease in the amount of C16:0 and C18:0 in the depot fat of the pig (Elliot & Bowland, 1968; Moore et al., 1969). Copper in the form of copper sulfate is added to pig diets in South Africa at concentrations of 125 to 250 ppm (Van Der Merwe & Smith, 1991).

Environmental factors

There exists an inverse relationship between the temperature of the environment and the degree of saturation of the depot fat of pigs. The degree of unsaturation of the fat stores of the pigs is also inversely related to the temperature of the tissue in which the fat is embedded (Henriques & Hansen, 1901; Dean & Hilditch, 1933). MacGrath, Van der Noot, Gilbreath and Fischer (1968) also confirmed that the exposure of pigs to cold temperatures cause the backfat of the pigs to become more unsaturated than pigs in a warm environment. Hugo and Roodt (2002) also demonstrated that there is a seasonal change in the saturation of the backfat of the pigs. They found that pigs had a significant increase in the saturation of the backfat during the summer and a decrease during winter.

FAT QUALITY AND ITS MEASUREMENT

Visual appearance is an important aspect of meat quality and consumers therefore, prefer the subcutaneous fat to be white and firm (Enser, 1983). Fat tissue that is not fully solidified appears relatively gray or yellowish (Wood, 1983). Furthermore, the softer more unsaturated fats may develop an orange colour resulting from early rancidity (Barton-Gade, 1983; Santoro, 1983). Good quality fat can therefore be defined as firm and white and poor quality fat as soft, floppy, oily, gray and wet (Wood, 1983).

According to Santoro (1983) poor quality fat has the following characteristics:

- The connective tissue protein of immature fat still needs to develop.
- The cut surface is granular and not smooth.
- The fat has a greater tendency to oxidize, resulting in off-flavour and odour.
- The colour of the oxidized fat turns from light yellow to intense brownish-orange.
- The rancid flavour can be transmitted to the meat.

Consistency of adipose tissues is related to the physical state of the lipids which depends on the fatty acid composition and the position of fatty acids in the triglyceride (Perrin, Dinis, Rousseau & Vidal, 1990). The firmness is related to the concentration of fatty acids like C16:0, C18:0 and C18:3n-3 (Enser et al., 1984; Whittington et al., 1986; Rozenbauer, Honical, Muller, & Przytulla, 1998). Wood et al. (1989) also stated that a close relationship exists between the concentrations of the C18:0 and C18:2 fatty acids and the firmness of fat. Wood and Enser (1989) indicated that C18:0 is one of the constituents most closely related to good fat quality and C18:2 is one of the constituents most negatively related to bad fat quality.

According to Prabucki (1991) good quality fat should conform to the following criteria:

- The backfat should not be less than 18mm thick in the middle of the back.
- The lipid content of the fat tissue should be no less than 84 - 90 %.
- The double bond index (DBI) of good fat tissue should be less than 80.
- The sum total of all the UFA should not exceed 59% of the total amount of fatty acids.

Low lipid concentrations and high water concentrations lead to softer fat tissue (Nürnberg & Ender, 1990). According to Lea et al. (1970), good quality saturated fat can have an iodine value of 65 or less, and soft fat an iodine value of 70 or more. Barton-Gade (1983; 1987) proposed a maximum iodine value of 70 for good fat quality. Good quality fat should have a refraction index of no higher than 1.4598 (Hart, 1956)

Good quality fat should contain no less than 12 % C18:0 (Davenel et al., 1999). Problems with soft fat also arises when the C18:2 content of the fat is higher than 15% of the total fatty acids (Wood, 1984). Warnants et al. (1996) recommended a PUFA level of 22 % as a maximum for fresh and frozen fat. However, for meat processing, demands could be more severe (Warnants et al., 1996). Whittington et al. (1986) proposed a C18:2 content of 15 % as the maximum concentration which is

acceptable for good quality bacon. Roberts and Enser (1988) reported that firmness of fat is better correlated with C16:0 and C18:2 concentrations than with the concentration of C18:0. Warnants et al. (1996) proposed that the PUFA concentration should not exceed 15 % for good quality fat. Prabucki (1980) proposed that the concentration of PUFA should not exceed 12 % in the fat. Wenk, Häuser, Vogg-Perret and Prabucki (1990) proposed that this level should not surpass 13 %.

According to Enser (1984) the combinations of fatty acids associated with fat firmness are C16:0 + C18:0 and C16:0/C18:2. Lea et al. (1970) suggested that the MUFA/SUFA and C16:1 + C18:1c9 / C16:0 + C18:0 ratio might be a measure of fat firmness and melting point. Honkavaara (1989) reported that a good measure for fat hardness would be the C18:0/ C18:2 ratio. A ratio of above 1.2 would be considered good quality firm fat and a ratio of below 1.2 would be considered soft fat. Enser et al. (1984) reported that a C18:0/C18:2 ratio of more than 1.47 would indicate good fat quality.

Häuser and Prabucki (1990) proposed the following additional criteria for good quality fat:

SFA	> 41% of the total fatty acids
MUFA	< 57% of the total fatty acids
Dienoic fatty acids	< 10% of the total fatty acids
Trienoic fatty acids	< 1% of the total fatty acids
Tetraenoic fatty acids	< 0.5% of the total fatty acids
Pentaenoic + hexaenoic fatty acids	< 1% of the total fatty acids

There is a need for a rapid instrumental method for measuring fat quality (Enser et al., 1984). An instrument that could be used in determining the quality of pig fat, is the refractometer. This measurement still involves a time consuming lipid extraction step. Studies had been devoted to the evaluation of physical characteristics of lipids such as melting point or slip point (Lea et al., 1970; Wood et al., 1978). Fatty tissue does not have a fixed melting point but rather a melting range (Townsend, Witnauer, Rilloff, & Swift, 1968). Unfortunately, these two methods are considered too tedious to be used for selecting adipose tissues on a factory line (Davenel et al., 1999). The methods mentioned above, have the following additional problems: the equipment needed for these evaluations are expensive, running costs of the methods are too expensive to perform on a routine base and these methods are too time consuming to perform on line in the meat processing industry (Anderson, Borggaard, Nishida, & Rasmussen, 1999).

As mentioned before, appearance is an important aspect of quality. Consumers prefer fat to be white (Barton-Gade, 1983; Enser, 1983). Bryhni, Kjos, Qverland and Sorheim (1999) used a Minolta Chromometer to determine the lightness, redness and yellowness values in fat. Warnants et al. (1996) used a Hunter Labscan to determine the colour of the fat. Irie and Sakimoto (1992) found significant differences in the colour values amongst anatomical location, but not between the fat of pigs fed different diets, indicating that colour measurement would not be suitable for routine quality control of subcutaneous fat.

Another test which is often used by bacon manufacturers, is the finger-pressure test to select carcasses of satisfactory consistency. This is a very subjective test and not very reliable. As a result, many packets of bacon with soft fatty tissue are still produced (Enser et al., 1984). Because of the difficulty and inconsistency of the subjective finger pressure test, producers turned to a mechanical puncture technique (Dransfield & Jones, 1984; Enser et al., 1984). The puncture test is strongly related to SFA proportion in adipose tissue, and is mainly related to C18:0 rather than to the C18:2 content (Enser et al., 1984; Wood, Jones, Bayntun & Dransfield, 1985). The puncture technique is, however, weakly influenced by water and collagen content (Whittington et al., 1986; Enser et al., 1984).

According to Davenel et al. (1999) "one of the simplest ways to characterize the physical state of lipids is to measure their solid fat content by H-Nuclear Magnetic resonance spectroscopy (NMR)". This method gives a determination of the solid fat content at 20 °C. The solid fat content of adipose tissue at a temperature of 20 °C is strongly related to the concentrations of two main SFA, namely C16:0 and C18:0 (Davenel et al., 1999). The solid fat content of soft adipose tissue at 20 °C should be less than 15 % and hard ones should have a solid fat content of higher than 18 % at 20 °C. This method could be used in slaughterhouses because it is a quick and easy method (Davenel et al., 1999).

A near infrared reflectance spectroscopy (NIR) filter based instrument for on-line measurements of fat quality in pork has been developed. This measuring system is able to detect soft fat problems in pork carcasses. This is a handheld instrument that could be used anywhere on the slaughter line. If the fat of the carcass gives a reading of higher than 2.5, the carcass are classified as being too soft, readings below 1.5 are classified as being firm and of good quality. In tests that were done on a total of 580 carcasses, only 14 were mis-classified (Anderson et al., 1999).

French meat technologists/slaughterhouses presently select adipose tissue using an indirect method based on carcass lean meat content (< 57 %) and backfat thickness (> 15 mm) (Davenel et al., 1999). This method is based on observations that adipose tissue with the lowest thickness lack consistency because it has the highest proportion of PUFA and the lowest proportion of SFA (Lea et al., 1970; Villegas, Hedric, Veum, McFate, & Bailey, 1973; Wood, 1973). Although this method limits the selection of pig carcasses with soft fat (Rampon, Davenel, Riaublanc, Marchal, & Gandemer, 1994), it does not guarantee quality because many soft adipose tissue may escape detection. This approach may have some potential for use in South Africa, but because the South African pig classification differs from the French system, the cut-off points for backfat thickness and lean meat content will have to be recalculated.

FAT QUALITY REQUIREMENTS FOR SPECIFIC MEAT PRODUCTS

During processing in a commercial meat processing plant, the selection of the correct fatty tissue for various meat products relies on experience and the use of empirical data, plant-specific conditions and quantities of various types of fatty tissue typically yielded in processing (Fischer, 1989).

Fresh meat

Wood (1983) stated that meat that is very lean could become dry. Meat fat, especially the marbling fat, is very important for the taste of the meat (Hofmann, 1994). Meat markets today will reject meat with inferior subcutaneous fat quality as well as meat with too little marbling (Affentranger et al., 1996). According to De Vol, Meckeith, Bechtel, Novakofski, Shanks and Carr (1988), pig meat should contain at least 2.5 to 3.0 % intra-muscular fat. Pork chops with less than 2.5 % intra-muscular fat was less tender than meat with more than 2.5 % intra-muscular fat. The amount of intra-muscular fat also has an effect on the flavour, tenderness and juiciness of the meat (Schwörer & Morel, 1987). As mentioned before, the selection for genetically leaner pigs lead to the production of carcasses with fat quality inferior to those of genetically fatter pigs (Metz, 1985). The fat of these pigs will also spoil more easily (Affentranger et al., 1996). More butcheries are using modified atmosphere packaging to improve the quality of their products, this means that the meat is exposed to higher levels of oxygen for longer times. This can also lead to higher oxidation levels (Morrissey, Sheehy, Galvin, Kerry & Buckley, 1998). High proportions of UFA will also cause flavour and taste defects (Madsen et al. 1992). Warnants et al. (1996) also recommended that the PUFA levels should not surpass a level of 22 % in pork meat for consumption.

The eating quality of pig meat is also affected by the fatty acid profile of the pig fat. The eating quality of the meat decreases as the concentrations of PUFA increase (Cameron & Enser, 1991). Abnormal flavour was positively correlated with C18:2 and C18:3 (Cameron et al., 1990). Garcia-Macias et al. (1996) also reported that C18:2 had a negative effect on the eating quality of meat. Saturated fatty acids and MUFA are generally associated with better eating quality in pig meat (Cameron & Enser, 1991). Abnormal flavour is generally less prominent in the presence of higher concentrations of C16:0 (Cameron et al., 1990).

Cooked sausage and scalded sausages

Sausages like liverwurst has a fat content of between 30 – 60 % and jellywurst can have a fat content of between 10 – 40 % (Wirth, 1973). Soft fatty tissue is processed into finely comminuted cooked sausages, while firm fat is used for finely cut products (Fischer, 1989). Hammer (1980) tested the processability of various fatty tissues in the pig carcass for instance fat from chine, back, shoulder, ham, belly, belly sides and leaf fat, for finely ground liverwurst. He found no differences between the various fatty tissues. Fat intended to be used as insertion material (showpieces) must be of firm consistency. The reason for this is that the tissue undergoes heavier heat stress because the general practice is to put the fat through a double heat treatment during the processing of these products (Fischer, 1989). According to Fischer (1989) fat for these products should not be selected based on the firmness or softness of the fat, but rather the fat content of the final product.

Fat tissue used for scalded sausages must be "hefty" and "gritty". Backfat, belly, nape and jowl fat are fat that have these qualities. These qualities of the fat are due to the higher melting points of these fats (which indicates a higher SFA profile) and a greater quantity of connective tissue (Wirth, 1973; Tändler, 1984). In applications where fatty tissue undergoes coarse cutting and where inclusions are specified, the requirements mentioned above are very important (Fischer, 1989). Rozenbauer et al. (1998) indicated that sausages that were prepared from soft fat showed the formation of wrinkles, by losing oil through the surface. The product also showed a smeared cross section and a soft crumbly consistency. The products were also oily and had a pungent taste.

Hard and spreadable raw sausages

Solid, gritty, firm pork fat (like fat from the nape or back) should be used for firm-cutting, uncooked

sausages like certain salamis. These types of fat can be in short supply and that is why fat from pork bellies, fatty top layers from hams and shoulders and leaf and flare fat are also used. The use of soft fatty tissue in firm cutting raw sausages can cause the following problems: the soft fat is more susceptible to oxidation causing it to become rancid very easily. Oxidation can also lead to degradation of the product's colour; smearing during the cutting process. Formation of a film around the meat particles may prevent gel formation and water release and in turn result in an obscure cutting surface and poor binding giving rise to undesirable firm cutting. Soft fat can also perspires out during smoking and ageing (Fischer, 1989). This may occur at temperatures of 15 °C when fatty tissue has an iodine value of 66 and a C18:2 content of more than 11 % (Ten Cate, 1968). To prevent problems like these, the use of unsuitable raw materials in the manufacture of firm-cutting uncooked sausage must be avoided, for instance fat used should not have an iodine value of more than 60 (Fischer, 1989).

Salami made from fat with high concentrations of PUFA develops fishy off-flavours. High levels of PUFA in salami causes the product to be soft. Salami with very soft texture can cause smearing when attempts are made to cut the product. High levels of PUFA also causes discolouration of the product which will be observed as excessive darkening as the product ages. Backfat intended for salami manufacturing should contain less than 20 % PUFA. The salami itself should contain less than 14 % PUFA (Warnants et al., 1998).

For finely cut varieties of spreadable raw sausages, softer fatty tissue is also appropriate. It is possible that temperatures can rise above 18 °C during storage and during the smoking process. It is, therefore, possible that soft fatty tissue can liquefy leaving an oily film of fat on the sausage's outer casing (Fischer, 1989).

Cooked and uncooked cured whole muscle meat products

In the production of products like bacon, inferior fat quality such as the fat from lean pigs with intrinsic softness and a tendency to split, could give rise to a greater degree of end-product defects (Reid, 1983; Houben & Krol, 1983; Whittington et al., 1986). Firm fat is particularly important in the production of vacuum-packed bacon rashers. Soft fat in a vacuum pack appears as a single squashy mass and the definition of individual rashers is lost (Enser et al., 1984). Enser et al. (1984) compared samples of soft vacuum-packs of rindless bacon with hard samples. They found that the unsatisfactory packs contained higher concentrations of UFA and had a lower mean melting point

and slip point. The melting point of soft unsatisfactory bacon was 30.2 - 47.6 °C and hard bacon had a melting point of 45.0 - 52.4 °C). Unsatisfactory bacon had 44 % less C16:0, 15 % less C18:0 and 22 % more C18:2 than satisfactory bacon. Unsatisfactory bacon as well as the pork from which it was made had a concentration of C18:2 in excess of 9.2 % or a ratio of C18:0 to C18:2 of less than 1.47 (Enser et al. 1984). The physical softness of low quality fat also negatively affects the ease of cutting the bacon (Dransfield & Jones, 1984). Higher concentrations of UFA enhance the risk of oxidation when producing bacon. The reason is that both the brine and smoke contain oxidative components (Madsen et al., 1992).

High C18:1c9 percentages in the fat of dry hams are responsible for flavour development of the hams (Ruiz, Lopez-Bote, Antequera, Tejeda, Timon & Cava, 1996). That is why the pig meat that is used for dry-cured hams have high concentrations of C18:1c9 and low concentrations of SFA (Cava, Lopez-Bote, Martin, Garcia, Ventanas, & Antequera, 1997; Ruiz, Cava, Antequera, Martin, Ventanas & Lopez-Bote, 1998). Lipolysis and lipid oxidation are the major processes in flavour development during the production of dry cured ham (López-Bote, Antequera, Corboda, Garcia, Asensio & Ventanas, 1990).

The fat requirements for uncooked cured meat products, is inter-muscular as well as subcutaneous fatty tissue with a white colour and firm consistency. These products might be exposed to high temperatures (approximately 28 °C) during storing and smoking for long periods of time, that is why the fat used in this product must not be easily susceptible to spoilage, and the fat must also have low fat transpiring tendencies (Fischer, 1989).

FAT OXIDATION

Fats rich in PUFA with a soft consistency are very sensitive to oxidation (Houben & Krol, 1983). The oxidative deterioration of food lipids involves primarily autoxidation reactions. These reactions are accompanied by various secondary reactions having oxidative and non-oxidative qualities. The primary lipids involved in oxidation are C18:1c9, C18:2 and C18:3 fatty acids (Labuza, 1971). There are a number of factors that influence the oxidative potential of fatty acids. One of these factors depends on the number of double bonds, varying from one to six (Flachowsky et al., 1997). Holman (1954) specified oxidative relations of 0,025:1:2:4:6:8 for double bonds varying from one to six. The following proportions of disposition for oxidation between C18:0, C18:1c9, C18:2 and C18:3 amounting to 1:100:1200:2400 was given by Grosch (1970). From these results it is clear that fats

with more double bonds in the fat will have a stronger tendency towards oxidation, resulting in shorter induction times (Flachowsky et al., 1997). The oxidation process leads to discolouration, drip losses, off-odour and off-flavour development and the production of potentially toxic compounds (Morrissey, Buckley, Sheehy & Monahan, 1994; Gray et al., 1996). The fact that the softer fat is more susceptible to oxidation can cause problems for the major retailers who are increasingly moving towards centralized butchery and modified atmosphere packaging. Both these processes lead to meat products being exposed to higher levels of oxygen for a longer period of time prior to retail (Morrissey et al., 1998). Oxidation is also a major problem in the development of new convenience meat products and processes (Gray & Pearson, 1987).

HEALTH AND NUTRITIONAL ASPECTS OF FAT QUALITY

With the population becoming more diet/health conscious, it has become of considerable importance for the meat industry to produce red meat products that are more in line with recent thinking on health (Rhee et al., 1988a, Honkavaara, 1989). From a human nutritional point of view, consumers are advised to increase their intake of PUFA to give a ratio of PUFA/SFA of at least 0.45 - 0.5 (Levnedsmiddelstyrelsen, 1986; Honkavaara, 1989). This meant that producers had to move from pig meat with a SFA profile to meat with a more UFA profile. For the carcass fat in pigs, such a ratio would increase the iodine value (indicating softer fat) and would decrease storage stability (Madsen et al., 1992).

It should be known that pigs with too high a content of PUFA might also pose health risks. Gammel, Carroll and Plunkett (1976) and King and Spector (1978) reported that ingestion of large quantities of PUFA promote carcinogenesis. Sturdevant, Pearce and Dayton (1973) reported the development of gallstones as a consequence of ingestion of too much PUFA.

It is generally believed that the ingestion of SFA increases the concentration of plasma low density lipoprotein (LDL) cholesterol (Mattson & Grundy, 1985). Although the ingestion of SFA has not been positively linked with coronary heart disease, high levels of LDL cholesterol has been correlated with coronary heart disease. It is possible that not all SFA plays the same role in increasing the LDL cholesterol. The inclusion of MUFA such as C18:1c9 actually lowers the LDL cholesterol levels in the blood (Mattson & Grundy, 1985; Grundy, 1986; Rhee et al., 1988a; 1988b). Bonanome and Grundy (1988) indicated that C18:0 and C16:0 are just as effective in lowering plasma cholesterol levels as C18:1c9. It is now believed that only two of the SFA, namely C12:0 and

C14:0, cause the rise of blood cholesterol levels. Saturated fatty acids are also less likely to undergo oxidation and cause the formation of poisonous substances (Morrissey at al., 1994). Currently the emphasis is moving away from PUFA and consumers are advised to rather reduce the ratio of n-6 to n-3 fatty acids in their foods than to only increase their consumption of PUFA (Okuyama, 1997). According to Okuyama and Ikemoto (1999) the major risk factor for atherosclerosis and coronary heart disease is the n-6/n-3 ratios. Okuyama (1997) proposed a n6/n3 ratio of 2:1 for good health while Verbeke et al. (1999) proposed a ratio of 6:1.

Currently there is a lot of interest in conjugated linoleic acid (CLA). Conjugated linoleic acid is made up of isomeres of C18:2 which contain conjugated cis, trans double bonds (Enser, Scollan, Choi, Kurt, Hallet & Wood, 1999). Conjugated linoleic acid has anticarcinogenic and antioxidative properties in animals and is produced by *Butyrivibrio fibrisolvens* rumen bacteria in ruminant animals as a first intermediate in the biohydrogenation of dietary C18:2 (Lee, Park, Ha, Shin, Joo, & Park, 1999). Ruminant meat, therefore, contains higher concentrations CLA than non-ruminant meat. It is possible to increase the concentration of CLA in pork loins via dietary supplementation (Lee et al., 1999). One would expect a similar increase in subcutaneous fat as well as a deterioration in fat quality with increased CLA levels.

CONCLUSIONS

In the first part of this literature survey fat deposition and fat composition of the pig were discussed. A number of factors were identified that may influence the fat composition of the pig. They were gender, backfat thickness, slaughter weight and age, genetic factors, growth stimulants, effect of the PSE and DFD conditions, environmental influences and dietary effects. It is usually a combination of these factors that determine the fat quality of the pig.

From a processing point of view, good quality fat should be firm and white. Selecting pigs with good quality fat is critical during the production of products like bacon, which can show a number of defects if poor quality fat is used. Ways of determining fat quality were also discussed. There are a number of methods available but a method that will be suitable to use in an online slaughter situation is still lacking. There are, however, methods like the NIR method that shows great potential for solving this problem. The fat quality requirements for specific meat products such as fresh meat, cooked sausage, hard and spreadable raw sausage and cooked and uncooked whole muscle meat products were discussed.

It was concluded that the easiest way of changing the fatty acid composition of a pig to a desired profile is by changing the fatty acid composition of the feed. It was indicated that barley, sorghum and feed wheat might be used to increase the saturation of pig fat. It therefore, seems perfectly possible to increase the saturation and quality of the pig fat by means of dietary manipulation.

It was demonstrated in this literature survey that fat content or condition may have an effect on all the important meat quality properties namely, sensory properties, nutritional value, technological properties and hygienic and toxicological status of meat and meat products. Fat quality is as important as any other meat quality parameter. Requirements placed on fat quality for processing into meat products vary and are also dependent on the type of product to be manufactured.

CHAPTER 3

MATERIALS AND METHODS

Survey on feed ingredients

In an attempt to identify feed ingredients with the potential to improve fat quality of pigs, a questionnaire was sent to the 23 major companies involved in the formulation, mixing and supply of pig feeds in South Africa. The names of the companies, addresses and the name of a contact person at each company was supplied by the Amalgamated Feed Manufacturers Association (AFMA). The purpose of this survey was to identify individual pig feed ingredients available, to determine how often each is used and to determine typical inclusion levels of such ingredients. An example of the covering letter, background information and questionnaire supplied to each feed company are depicted in Appendixes 1 and 2.

Collection of feed samples

From the 23 questionnaires sent out, 17 companies responded. Of these the following 9 companies were personally visited by the researcher for feed sample collection: Braak Piggery (Pretoria), Epol (Roodepoort), Kanhym (Middelburg); Meadow Feeds (Welkom), Nolko (Bethlehem), Nutri Needs (Bloemfontein), OTK (Middelburg), Senwesko Feeds (Viljoenskroon) and Silgro Feeds (Pretoria). Samples of ± 250 g of all feedstuffs used in pig feeding, available on the premises, were collected in impermeable, marked, plastic zip lock bags. Samples were transported to Bloemfontein and stored in the dark until analyzed.

Feed analysis

Fat extraction

Extraction of total lipid from feed ingredients was performed quantitatively by means of a Soxhlet extraction (AOAC, 2000) using diethyl ether as solvent. Of the total lipid extracted, ± 10 mg was weighed into a glass vial and stored under a blanket of nitrogen at -20 °C for fatty acid analysis.

Fat analysis

Total lipid (± 10 mg) was methylated to prepare fatty acid methyl esters (FAME) for gas chromatographic analysis by using methanol–BF3 (Slover & Lanza, 1979). Fatty acid methyl esters were quantified using a Varian GX 3400 flame ionization gas chromatograph , with a fused silica capillary column, Chrompack CPSIL 88 (100 m length; 0.25 mm ID; 0.2 μm film thickness). Column temperature was 40 – 230 °C (hold 2 minutes; 4 °C/minute; hold 10 minutes). Fatty acid methyl esters in hexane (1 μl) were injected into the column using a Varian 8200 CX Autosampler with a split ratio of 100:1. The injection port and detector were both maintained at 250 °C. Hydrogen was used as the carrier gas at 45 psi and nitrogen was the makeup gas. Chromatograms were recorded using Varian Star Chromatography software. Identification of sample FAME was made by comparing the relative retention times of FAME peaks from samples with those of standards obtained from SIGMA (189–19). The relative percentage of each individual fatty acid was expressed as percentage of all fatty acids present. Fatty acid data was used to calculate the following fatty acid ratios: total SFA, total MUFA, total PUFA and total UFA. Hanus iodine value of extracted lipids was done according to the AOAC (2000).

Database on fat quality of feedstuffs

The total fat content, fatty acid profiles and iodine value of each feedstuff was entered into an Excel database. The average value, minimum value, maximum value, standard deviation and number of samples for each parameter for each feedstuff was calculated. The average values were later used as an aid in selecting feedstuffs with the potential to improve fat quality of pigs.

Diets

As guidelines in the formulation of a diet with the potential to improve the fat quality of pigs, it was decided by the researcher that a feedstuff or feedstuffs used in such a diet must adhere to the following requirements:

1. It should be readily available in South Africa.
2. The fatty acid profile has to be largely saturated.
3. The degree of variation in the saturation of the fatty acid profile from one batch to the next had to be minimal.

4. It should not inhibit feed intake of animals.
5. Its consumption should not retard the growth of the pig.
6. It should not cost more than the feedstuffs that are currently used. Its inclusion should not increase the cost of the total diet significantly.

In order to identify a feedstuff or feedstuffs which adhere to these requirements, information obtained from the questionnaire as well as the results from the fatty acid profiles and iodine values of individual feedstuffs, were utilized. Literature available on the subject was also considered. Major factors which had to be considered was whether the feedstuff's fatty acid profile was saturated enough and whether the feedstuff had a high enough fat content to have a sufficient effect on the fatty acid profile of a diet as a whole. To accomplish this, an Excel program was written to indicate what changes would take place in the iodine value and fatty acid profile of a diet as a whole, if one feedstuff was replaced with another. The Excel program used the average values for fat content, iodine value and fatty acid content stored in the database of feedstuffs in combination with the % of each feedstuff proposed for a diet to do this calculations. An animal feed company (NOLKO) agreed to do the preliminary formulation, final formulation and upscaling of the control and experimental diets.

Based on information obtained from the questionnaire, a preliminary control diet was formulated by NOLKO. The feedstuffs most commonly used and at typical inclusion levels (as indicated by respondents to the questionnaire) were included in this control diet. By using the guidelines and requirements discussed above in combination with the Excel program, six preliminary experimental diets were also formulated by NOLKO. The preliminary control and experimental diets were mixed on a small scale in the laboratory. All seven diets were chemically analyzed for fatty acid content and iodine value as described under Feed analysis on p. 27-28 of this thesis. The diet which had, from a fatty acid point of view, the most potential to improve the fat quality of pigs, and which was the most suitable for use in the pig feed industry, was then selected as the experimental diet.

Barley (Puma cultivar) was obtained from GWK in Modderrivier and poultry byproduct from Country Bird in Botshabelo. After the final control and experimental diets were formulated, the barley and poultry byproduct was transported to NOLKO in Bethlehem where 1800 kg of each of the control and experimental diets were mixed. Feed was packed in 50 kg bags and transported to Bloemfontein where it was stored in the dark at summer room temperature until used. Chemical analysis on the control and experimental diets was performed in duplicate on samples from six

randomly selected bags of feed from each treatment as described under Feed analysis on p. 27-28 of this thesis.

Animals

Fourteen Large White X Duroc gilts, approximately 2 months old, were purchased from J.D Havenga & Son from Petrusville in the Northern Cape. Only gilts were used to prevent any influence that sex may have on the fatty acid composition of the pigs (Koch et al., 1968). The pigs weighing on average ± 43 kg, were randomly divided into 2 groups of 7 pigs each. The groups were then randomly assigned to each of the control and experimental diets. The mean initial weight of the control group was 43.30 kg and that of the experimental group was 43.33 kg. The pigs were individually penned in a facility of the Animal Science Department of the University of the Free State in Bloemfontein. Pigs were provided *ad libitum* access to feed and water. The feed intake of each of the pigs was monitored on a daily basis by determining the difference between feed given and feed refused. The pigs were weighed once every week. Pigs were fed until the average live-weight of the pigs was ± 95 kg. The carcass growth rate was expressed as average daily gain and calculated as live-weight gain at the end of the trial divided by days in the trial. Feed conversion ratio was calculated as total feed intake divided by total live-weight gain. The experiment was approved by the Control Committee on Animal Experiments of the University of the Free State.

Slaughter and carcass measurements

After a 55 day feeding period and a mean weight of 96.79 kg for pigs in the control group and 95.36 kg for pigs in the experimental group, the pigs were slaughtered. Feed was removed approximately 12 hours before slaughter. Pigs were transported to Bloemfontein abattoir where they were humanely slaughtered. All animals was electrically stunned (400 V @ 60 Hz), stuck, scalded (61 °C) and dressed, following commercial procedures. An Intrascope was used to measure backfat thickness, 4.5 cm off the carcass midline, between the second and third last rib, within 30 - 40 minutes of stunning. The percentage lean meat content of each carcas was calculated according to the formula currently used by the South African meat industry (Bruwer, 1992): Lean meat content = 74.4367 - (0.4023 x backfat thickness). Commercial warm carcass weights were also obtained at this time. After a 16 hour chilling period at 4 °C, cold carcass weight was recorded and carcasses were transported to the meat technology laboratory of the University of the Free State.

Physical fat quality measurements and tissue sampling

After hanging for 24 hours in a cold room at approximately 1 °C, heads were removed, carcasses were split and the left and right loin portion from each carcass (last three ribs) were removed. Firmness of the subcutaneous fat was measured, using a Fat Hardness Meter MK2, on the cross sectional surface at the position between the second and the last rib after the fat was shaved and smoothed. Fat hardness meter values were obtained from the average of three readings, adjusted to 1 °C using the equation: FHM= M - 18(1 °C -T °C) where FHM is the temperature corrected meter reading, M is the actual meter reading and T is the actual fat temperature (Sather et al., 1995). The colour of the backfat (L*, a*, and b* values) was determined at the same position with a Minolta CR-200 tristimulus colour analyzer. The L* values represent the measurement of the lightness of the fat, the a* values represent the measurement of the redness of the fat and the b* values represent the measurement of the yellowness of the fat.

Twenty four hours after slaughter, subcutaneous fat samples (± 5 g) were removed from a position as close as possible to the middle of the areas marked A, C, D, E, F and G as illustrated in Figure 1 from both sides of all carcasses. A core sample of both layers of backfat (position B) was taken 45 mm from the mid-dorsal line between the second and third last rib. Samples intended for lipid extraction were stored in Nunc cryotubes in liquid nitrogen.

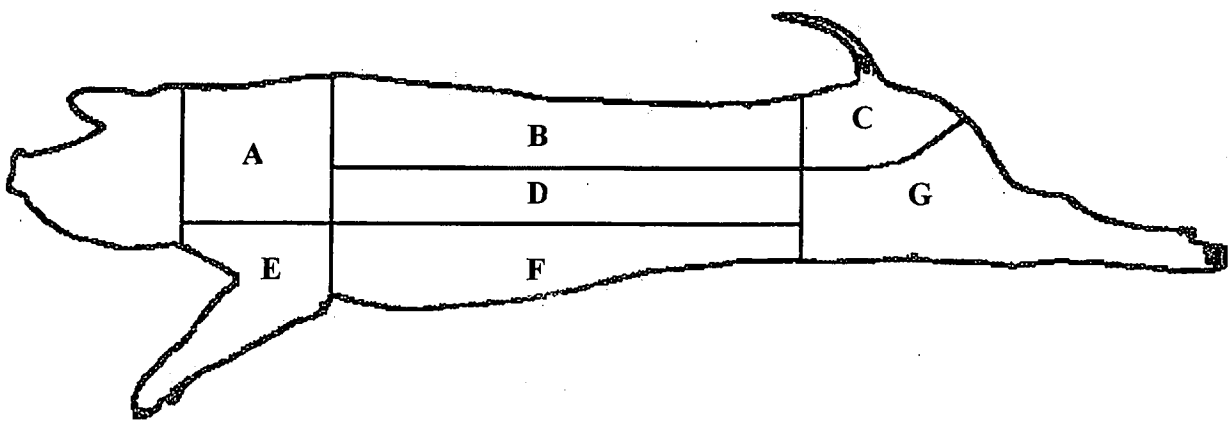

Figure 1: Sampling positions for subcutaneous fat (Barton-Gade, 1983).

Chemical fat quality measurements

Lipid extraction

Extraction of total lipid from subcutaneous fat (± 1 g) was performed quantitatively according to Folch, Lees and Sloane-Stanley (1957) using chloroform and methanol in a ratio of 2:1. Butylated hydroxytoluene (BHT) was added at a concentration of 0.001 % to the chloroform : methanol mixture as an antioxidant. The extracts were dried under vacuum in a rotary evaporator and further dried in a vacuum oven at 50 °C for three hours with phosphorus pentoxide as moisture adsorbent. Total extractable fat content was determined by weighing and expressed as % fat (w/w) per 100g tissue. The fat free dry matter content was determined by weighing the residue on a preweighed filter paper, used for Folch extraction, after drying. By determining the difference in weight, the fat free dry matter content could be expressed as % fat free dry matter (w/w) per 100 g tissue. The moisture content of the muscle and BF was determined by subtraction (100% - % lipid - % FFDM) and expressed as % moisture (w/w) per 100 g tissue. Of the total lipid extracted, ± 10 mg was weighed into a glass vial and stored under a blanket of nitrogen at – 20 °C until methylated.

Fatty acid analysis

Methylation and fatty acid analysis of subcutaneous fat was performed as described under feed analysis on p. 28 of this thesis. The only deviation was that nonadecanoic acid (C19:0) (SIGMA N-5377) was used as the internal standard to improve quantitative FAME estimation. Fatty acid data were used to calculate the following ratios of fatty acids: C16:0 + C18:0, (C16:1+C18:1c9)/(C16:0 + C18:0); C16:0/C18:2; C18:0/C18:2; total MUFA; total dienoic fatty acids; total trienoic fatty acids; total tetraenoic fatty acids; total pentaenoic fatty acids, total hexaenoic fatty acids; total pentaenoic + total hexaenoic fatty acids; total SFA; total PUFA; total UFA; MUFA/SFA; PUFA/SFA and the ratio of omega-6 to omega-3 (n-6/n-3) fatty acids. Double bond index (DBI) was calculated as: DBI = $\sum$ % 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 et al., 1998).

Other fat quality parameters

Iodine value of subcutaneous fat was determined with the Hanus method (AOAC, 2000). Refraction index of fat was determined with a Abbé refractometer at 50 °C, after which readings was converted to 40 °C (AOAC, 2000).

Accelerated oxidation test (Schaal oven test)

An accelerated oxidation test was carried out on fresh subcutaneous fat sampled for this purpose. Lipid from the fat of of each pig was extracted in duplicate , therefore there was a total of 28 samples. Forty ml of melted fat was kept at 63 ± 0.5 °C in a 250 ml low form glass beaker with free access to air (McGinley, 1991). Peroxide value (AOAC, 2000) was determined in duplicate on each of the 14 fat samples from each dietary group on a daily basis. The sample size used for peroxide value determination was 1 g. The keeping quality was determined as the number of days needed until the average peroxide value of each treatment was 100 milliequiv./kg fat (Hertzman et al., 1988).

Reagents

All the reagents that were used were obtained from Merck, Halfway House, South Africa. The reagents were of analytical grade.

Statistical analysis

Differences in parameters between treatments were determined by using an analysis of variance (ANOVA) procedure. When applicable, the Tukey-Kramer multiple comparison test (α=0.05) was used to identify differences between treatment means (NCSS, 2001). Pearson correlation analysis (NCSS, 2001) was used to determine which fat quality parameter was best correlated with the firmness of backfat as measured with the Fat Hardness Meter.

CHAPTER 4

RESULTS AND DISCUSSION

Survey on feed ingredients

Seventeen of the 23 companies that received questionnaires, responded. The results of this survey are summarized in Table 1. This table indicates that feedstuffs like wheaten bran and maize related products like maize grain, maize meal and hominy chop were the raw materials used most often in pig diets. They were also included at relatively high concentrations. Wheaten bran was typically included at 10.64 %, maize meal at 65 %, maize grain at 51.17 % and hominy chop at 8.36 %. Fullfat soya was also used by a number of companies at a typical inclusion level of 9 %. Feedstuffs like sunflower oilcake, soya oilcake and fishmeal were also used fairly often in pig diets. Sunflower oilcake and soya oilcake have a very low fat content because both are byproducts of the edible oil industry and most oil had usually been removed by pressing or solvent extraction. Products like sunflower oilcake, soya oilcake and fishmeal are mainly included to serve as a protein source.

Lipid composition of fat containing feed ingredients

Table 2 shows the mean as well as the minimum and maximum values for iodine value and fatty acid profiles of the feed samples collected from different companies. The feedstuffs most often used by the feed industry, like maize (± 3.5 % fat content) and its related products (maize flakes and maize germ meal) had high mean iodine values of between 102 and 105. Wheaten bran, the other popular ingredient, also had a relatively high mean iodine value of 98.47 and a fat content of ± 4 %. Full fat soya, another very popular ingredient, had a very high fat content of between 14 and 19%. This high fat content was accompanied by a very high iodine value of ± 105 and depending on the cultivar used, it varied between 102 and 108.

Linoleic acid was the PUFA present at the highest concentrations in these popular grain products. The C18:2 content of these feedstuffs is shown in Table 2. The mean C18:2 content of the various maize products varied from 48.94 % for the maize flakes to 49.93 % for the grain to 50.38 % for the maize germ meal. Wheaten bran had a very high mean C18:2 content of 57.86 %. Fullfat soya had a mean C18:2 content of 54.78 %. Although only the major fatty acids are indicated in Table 2, there

Table 1: Results of questionnaire on the frequency of use of different feedstuffs in pig diets.

FEEDSTUFF	Number of companies that use it often	Number of companies that use it sometimes	Number of companies that never use it	Typical inclusion range (%)	Average inclusion level (%)
Acid oil	3	3	11	0.50 - 1.50	0.75
Apple pomace	0	0	17	-	-
Acorn meal	0	0	17	-	-
Acorns	0	0	17	-	-
Algae	0	0	17	-	-
Bagasse	0	0	17	-	-
Barley	0	4	13	1.00 - 30.00	10.83
Blood meal	2	0	15	Not supplied	-
Bone meal	1	1	15	2.00 - 4.00	3.00
Brewers grain	0	1	16	Not supplied-	-
Barley brewersgrain	0	1	16	Not supplied	-
Canola fullfat	0	2	15	3.00 - 5.00	4.00
Canola oilcake (Imported)	0	0	17	-	-
Canola oilcake (Local)	0	2	15	3.00	3.00
Canola oilcake	0	1	16	3.00	3.00
Coconut fat	0	0	17	-	-
Carcass meal	0	2	15	5.00	5.00
Cassava meal	0	0	17	-	-
Citrus meal	0	0	17	-	-
Colostrum	0	0	17	-	-
Copra meal	0	0	17	-	-
Copra oilcake	0	0	17	-	-
Cotton oilcake (Local)	0	0	17	-	-
Cotton oilcake (imported)	0	0	17	-	-
Cotton seed (Imported)	0	0	17	-	-
Cotton seed (Local)	0	1	16	5.00	5.00
Cotton seed	0	1	16	5.00	5.00
Cotton seed oilcake	0	0	17	-	-
Chestnuts	0	0	17	-	-
Cowpeas	0	0	17	-	-
Defatted maize germ meal	2	0	15	5.00 - 10.00	7.50
Fat (cattle)	0	1	16	Not supplied	-
Fat (poultry)	1	2	14	0.50 - 2.00	1.00
Fat (pig)	0	0	17	-	-
Fat (plant oil)	2	0	15	1.00 - 2.00	1.50
Fat	0	1	16	Not supplied	-
Feather meal	1	2	14	2.00 - 4.00	3.00
Feed wheat	0	5	12	1.00 - 30.00	15.00
Fish meal (Imported)	5	2	10	1.00 - 15.00	6.10
Fish meal (Local)	12	0	5	1.00 - 15.00	5.31
Fish meal	7	1	9	1.00 - 15.00	5.50
Fullfat soya	7	2	8	1.00 - 20.00	9.00
Fullfat soybean meal	2	2	13	1.00 - 20.00	9.50
Fresh sunflower oil	0	2	15	1.00 - 20.00	1.50
Groundnut hay	0	0	17	-	-
Groundnut oilcake (Imported)	1	0	16	Not supplied-	-
Groundnut oilcake (Local)	1	1	15	2.00 - 3.00	2.50
Hominy chop	8	3	6	1.00 - 30.00	8.36
Linseed oil	0	0	17	-	-
Lucern hay	0	0	17	-	-

Table 1: Results of questionnaire on the frequency of use of different feedstuffs in pig diets (continued).

FEEDSTUFF	Number of companies that use it often	Number of companies that use it sometimes	Number of companies that never use it	Typical inclusion levels (%)	Average inclusion level (%)
Lucern meal	1	4	12	0.50 - 2.00	1.00
Lupine	0	1	16	1.00 - 10.00	5.00
Lupin meal	0	0	17	-	-
Maize (grain)	12	0	5	1.00 - 70.00	51.17
Maize germ meal	2	3	12	1.00 - 10.00	8.13
Maize germ oilcake	0	1	16	1.00 - 10.00	10.00
Maize gluten feed	2	4	11	1.00 - 10.00	5.83
Maize gluten meal (20%)	3	4	10	1.00 - 10.00	4.50
Maize gluten meal (60 %)	4	4	9	1.00 - 5.00	3.05
Maize meal	8	1	8	50.00 - 100.00	65.00
Maize screenings	1	1	15	4.00	4.00
Meat & bone meal	3	1	13	2.50 - 5.00	3.75
Naked oats	0	0	17	-	-
Oats	0	0	17	-	-
Palm Kernel oilcake (Local)	0	0	17	-	-
Poultry byproduct	2	3	12	1.00 - 5.00	3.56
Rapeseed	0	0	17	-	-
Rapeseed oil	0	0	17	-	-
Rice bran	0	0	17	-	-
Safflour	0	0	17	-	-
Skimmed milk powder	2	2	13	5.00	5.00
Silo fodder	0	0	17	-	-
Sorghum	1	5	11	1.00 - 70.00	25.00
Sorgum brewersgrain	0	1	16	Not supplied	-
Soya meal	4	0	13	1.00 - 25.00	13.33
Soya oilcake (Imported)	12	0	5	1.00 - 25.00	11.89
Soya oilcake (Local)	5	1	11	10.00 - 15.00	12.83
Soya oilcake	10	0	7	1.00 - 25.00	12.83
Sterilized poultry manure	0	0	17	-	-
Sunflower hulls	0	0	17	-	-
Sunflower oilcake (Imported)	5	3	9	1.00 - 15.00	6.30
Sunflower oilcake (Local)	10	2	5	1.00 - 20.00	8.28
Sunflower oilcake	7	2	8	1.00 - 15.00	8.14
Sunflower seed (with hulls)	0	0	17	-	-
Triticale	0	2	15	20.00	20.00
Used sunflower oil	0	0	17	-	-
Wheaten bran	17	0	0	1.00 - 30.00	10.64
Wheaten flour	0	0	17	-	-
Wheaten straw	0	0	17	-	-
White fish meal	2	1	14	1.00 - 10.00	4.17

were also other PUFA present that will play a definite role in decreasing the saturation of the fatty acid profiles of these feedstuffs. The total PUFA percentage of maize products was ± 50 % which was not exceptionally high compared to wheaten bran and fullfat soya which had mean PUFA contents of 62.43 % and 64.08 % respectively. As far as total UFA was concerned, wheaten bran

Table 2: Extractable fat content, iodine value, content of important fatty acids (%) and important fatty acid ratios of fat containing feed samples collected from the different animal feed companies.

	Fat content (%)	Iodine value	C16:0	C18:0	C18:1c9	C18:2	SFA	MUFA	PUFA	UFA
Acid oil	85.11 ± 14.68	78.23 ± 27.37	17.10 ± 7.44	12.19 ± 9.48	24.70 ± 5.41	28.24 ± 22.37	34.85 ± 16.95	30.42 ± 5.49	32.34 ± 20.95	62.76 ± 16.54
Min	48.52	34.31	5.05	2.97	7.81	1.56	11.74	22.64	2.91	38.45
Max	95	111.06	25.62	29.07	30.04	63.02	59.95	40.16	63.21	86.89
n	14	14	14	14	14	14	14	14	14	14
Barley	1.76 ± 0.06	97.72 ± 1.13	19.45 ± 1.28	1.43 ± 0.28	13.82 ± 1.87	55.13 ± 0.67	21.88 ± 1.22	15.45 ± 2.00	61.94 ± 1.52	77.39 ± 1.12
Min	1.68	96.60	17.45	1.09	11.09	54.5	20.73	12.26	58.96	75.46
Max	1.84	99.85	21.10	1.86	17.34	56.2	23.92	19.00	63.21	78.68
n	7	7	7	7	7	7	7	7	7	7
Bone meal	2.70 ± 0.02	56.04 ± 0.90	18.62 ± 0.11	15.90 ± 0.41	46.28 ± 0.86	2.56 ± 0.36	37.75 ± 0.64	51.84 ± 0.82	4.05 ± 0.46	55.89 ± 0.36
Min	2.69	55.40	18.54	15.61	45.68	2.31	37.30	51.26	3.73	55.63
Max	2.72	56.68	18.70	16.20	46.89	2.81	38.21	52.42	4.38	56.14
n	2	2	2	2	2	2	2	2	2	2
Brewers grain	8.34 ± 0.19	98.83 ± 0.62	21.51 ± 0.05	1.49 ± 0.01	11.03 ± 0.15	55.46 ± 0.11	24.28 ± 0.11	12.49 ± 0.18	62.08 ± 0.06	74.57 ± 0.12
Min	8.21	98.39	21.48	1.48	10.92	55.38	24.2	12.36	62.03	74.48
Max	8.47	99.27	21.55	1.50	11.14	55.54	24.35	12.61	62.12	74.65
n	2	2	2	2	2	2	2	2	2	2
Canola full fat	35.44 ± 0.18	103.20 ± 2.16	3.93 ± 0.07	1.96 ± 0.01	56.42 ± 0.24	21.39 ± 0.01	6.68 ± 0.48	59.86 ± 0.16	33.19 ± 0.08	93.04 ± 0.08
Min	35.31	101.67	3.88	1.95	56.25	21.39	6.34	59.74	33.13	92.99
Max	35.56	104.72	3.98	1.97	56.59	21.39	7.01	59.97	33.24	93.10
n	2	2	2	2	2	2	2	2	2	2
Canola oilcake	4.48 ± 0.07	100.00 ± 0.09	5.60 ± 0.07	2.11 ± 0.01	45.33 ± 0.02	24.52 ± 0.05	9.54 ± 0.02	56.7 ± 0.02	33.76 ± 0.04	90.46 ± 0.02
Min	4.43	99.93	5.55	2.11	45.31	24.48	9.52	56.70	33.73	90.45
Max	4.53	100.06	5.65	2.11	45.34	24.55	9.55	56.72	33.78	90.48
n	2	2	2	2	2	2	2	2	2	2
Copra meal	16.11 ± 0.17	10.25 ± 0.26	9.35 ± 0.04	3.15 ± 0.01	7.39 ± 0.06	2.12 ± 0.04	90.46 ± 0.15	7.39 ± 0.06	2.12 ± 0.04	9.50 ± 0.10
Min	15.99	10.07	9.32	3.14	7.34	2.09	90.35	7.34	2.09	9.43
Max	16.24	10.44	9.38	3.16	7.43	2.14	90.57	7.43	2.14	9.57
n	2	2	2	2	2	2	2	2	2	2
Feed wheat	1.95 ± 0.40	99.44 ± 1.47	15.58 ± 2.38	1.23 ± 0.34	17.29 ± 3.29	55.79 ± 8.78	17.61 ± 2.07	21.26 ± 9.10	61.06 ± 7.49	82.32 ± 2.05
Min	1.67	98.13	11.46	0.84	14.57	40.45	14.30	15.67	48.22	80.12
Max	2.64	101.34	17.14	1.68	22.79	61.80	19.81	37.39	66.98	85.61
n	5	5	5	5	5	5	5	5	5	5
Fish meal	10.42 ± 2.13	98.78 ± 5.48	17.62 ± 2.12	4.42 ± 1.35	12.88 ± 5.34	1.48 ± 0.39	28.48 ± 4.42	27.68 ± 7.80	31.11 ± 7.65	58.79 ± 5.23
Min	7.43	85.85	15.27	3.17	6.69	0.99	22.92	19.62	15.73	50.07
Max	13.17	102.92	20.76	7.37	19.7	2.23	37.01	38.17	39.85	65.73
n	8	8	8	8	8	8	8	8	8	8
Fullfat soya	16.81 ± 1.67	105.52 ± 2.53	9.41 ± 0.46	4.48 ± 0.34	20.08 ± 0.74	54.78 ± 0.82	15.05 ± 0.44	20.86 ± 0.77	64.08 ± 1.06	84.94 ± 0.44
Min	14.81	102.50	8.89	4.10	19.10	53.68	14.22	19.81	62.97	84.48
Max	19.82	108.53	10.26	5.09	21.12	56.05	15.52	21.87	65.98	85.78
n	7	7	7	7	7	7	7	7	7	7
Hominy chop	9.13 ± 1.72	103.24 ± 0.65	11.70 ± 0.11	2.50 ± 0.25	34.91 ± 3.12	48.40 ± 3.26	15.21 ± 0.30	35.30 ± 3.13	49.48 ± 3.35	84.77 ± 0.33
Min	8.00	102.69	11.55	2.34	32.70	43.69	14.87	32.99	44.64	84.34
Max	11.67	104.17	11.83	2.88	39.33	50.61	15.60	39.70	51.76	85.13
n	4	4	4	4	4	4	4	4	4	4

Table 2: Extractable fat content, iodine value, content of important fatty acids (%) and important fatty acid ratios of fat containing feed samples collected from the different animal feed companies (continued).

	Fat content (%)	Iodine value	C16:0	C18:0	C18:1c9	C18:2	SFA	MUFA	PUFA	UFA
Lucern meal	1.67	Not Determined	18.14	3.88	0.46	20.34	31.44	2.53	50.83	53.36
Min	-	-	-	-	-	-	-	-	-	-
Max	-	-	-	-	-	-	-	-	-	-
n	1	1	1	1	1	1	1	1	1	1
Lupine	6.63 ± 0.30	94.55 ± 3.72	7.65 ± 0.21	1.66 ± 0.10	46.29 ± 5.40	18.71 ± 4.00	15.75 ± 0.58	54.25 ± 5.52	30.00 ± 4.93	84.25 ± 0.58
Min	6.42	91.92	7.50	1.59	42.47	15.88	15.34	50.35	26.51	83.83
Max	6.84	97.18	7.80	1.73	50.10	21.53	16.17	58.15	33.49	84.66
n	2	2	2	2	2	2	2	2	2	2
Maize flakes	3.62 ± 0.24	102.01 ± 2.05	10.48 ± 0.49	2.42 ± 0.03	35.56 ± 0.93	48.94 ± 0.16	13.88 ± 0.61	35.94 ± 0.85	50.02 ± 0.22	85.97 ± 0.63
Min	3.45	100.56	10.13	2.39	34.90	48.82	13.45	35.34	49.87	85.52
Max	3.79	103.46	10.83	2.44	36.22	49.05	14.31	36.54	50.18	86.41
n	2	2	2	2	2	2	2	2	2	2
Maize germ meal	10.38 ± 0.03	104.97 ± 1.56	11.40 ± 0.16	2.60 ± 0.02	33.00± 0.10	50.38 ± 0.03	14.97 ± 0.15	33.39 ± 0.14	51.60 ± 0.05	84.99 ± 0.10
Min	10.36	103.87	11.28	2.59	32.93	50.36	14.87	33.29	51.56	84.92
Max	10.40	106.08	11.52	2.62	33.08	50.40	15.08	33.50	51.63	85.06
n	2	2	2	2	2	2	2	2	2	2
Maize (grain)	3.61 ± 0.20	102.27 ± 1.41	10.54 ± 0.49	2.42 ± 0.11	34.68 ± 1.06	49.93 ± 1.12	13.97 ± 0.52	34.96 ± 1.07	51.04 ± 1.06	85.99 ± 0.50
Min	3.40	101.02	9.99	2.26	33.54	48.61	13.43	33.86	49.87	85.29
Max	3.86	104.47	11.10	2.54	35.82	51.34	14.71	36.16	52.32	86.57
n	5	5	5	5	5	5	5	5	5	5
Maize gluten feed	1.34 ± 0.64	98.9 ± 1.78	11.28 ± 0.06	2.38 ± 0.09	29.7 ± 1.92	51.76 ± 0.80	15.16 ± 0.12	30.18 ± 1.80	54.61 ± 1.74	84.79 ± 0.05
Min	0.89	97.64	11.24	2.32	28.35	51.20	15.08	28.91	53.38	84.76
Max	1.79	100.16	11.31	2.45	31.06	52.33	15.24	31.45	55.85	84.83
n	2	2	2	2	2	2	2	2	2	2
Maize gluten meal (20%)	1.78 ± 0.52	96.56 ± 2.17	14.95 ± 5.19	2.33 ± 0.05	24.49 ± 5.36	52.56 ± 1.23	18.73 ± 5.13	25.18 ± 5.13	55.92 ± 1.61	81.09 ± 5.30
Min	1.33	94.26	11.56	2.28	18.69	51.56	15.37	19.66	54.68	74.98
Max	2.35	98.58	20.92	2.39	29.28	53.93	24.64	29.79	57.74	84.47
n	3	3	3	3	3	3	3	3	3	3
Maize gluten meal (60%)	0.90 ± 0.18	97.78 ± 1.42	11.48 ± 0.56	2.47 ± 0.03	31.19 ± 1.55	50.57 ± 1.46	15.69 ± 0.69	31.70 ± 1.51	52.53 ± 1.60	84.23 ± 0.73
Min	0.70	96.52	10.95	2.43	29.48	49.09	15.00	29.99	51.14	83.30
Max	1.12	99.81	12.02	2.50	33.12	52.00	16.52	33.53	54.02	84.92
n	4	4	4	4	4	4	4	4	4	4
Meat & bone meal	8.79 ± 4.43	57.05 ± 16.85	17.22 ± 6.65	16.71 ± 7.98	41.82 ± 9.86	6.26 ± 5.92	38.53 ± 15.98	49.50 ± 9.01	7.96 ± 6.86	57.46 ± 15.56
Min	4.83	42.35	11.05	9.55	33.22	1.13	23.99	41.68	2.02	43.70
Max	12.69	72.63	23.05	23.67	51.27	11.43	52.51	58.39	14.05	72.44
n	4	4	4	4	4	4	4	4	4	4
Oats	5.43 ± 0.26	92.01 ± 3.61	14.02 ± 2.59	1.56 ± 0.93	44.47 ± 1.95	36.72 ± 1.39	15.95 ± 3.65	45.63 ± 2.19	37.89 ± 1.42	83.52 ± 3.61
Min	5.25	89.46	12.19	0.90	43.09	35.73	13.36	44.09	36.89	80.98
Max	5.61	94.57	15.85	2.22	45.85	37.70	18.53	47.18	38.90	86.07
n	2	2	2	2	2	2	2	2	2	2
Poultry byproduct	24.08 ± 7.23	70.89 ± 9.54	23.69 ± 1.16	7.29 ± 0.55	38.89 ± 3.28	16.17± 5.97	33.31 ± 1.39	46.98 ± 4.90	18.19 ± 6.49	65.17 ± 2.09
Min	14.59	56.41	21.77	6.55	35.00	7.11	31.01	41.54	8.56	62.05
Max	34.72	78.80	25.32	8.05	43.36	22.28	35.27	53.82	24.89	67.58
n	8	8	8	8	8	8	8	8	8	8

Table 2: Extractable fat content, iodine value, content of important fatty acids (%) and important fatty acid ratios of fat containing feed samples collected from the different animal feed companies (continued).

	Fat content (%)	Iodine value	C16:0	C18:0	C18:1c9	C18:2	SFA	MUFA	PUFA	UFA
Sorghum	2.67 ± 0.23	100.02 ± 1.40	11.13 ± 0.41	1.15 ± 0.39	33.25 ± 2.97	50.43 ± 2.78	12.94 ± 0.66	34.09 ± 2.95	52.69 ± 2.77	86.78 ± 0.79
Min	2.11	97.32	10.68	0.20	27.67	45.58	11.70	28.74	47.99	84.31
Max	3.02	102.11	11.85	1.46	38.28	55.18	13.79	39.11	58.05	87.48
n	14	14	14	14	14	14	14	14	14	14
Soya oilcake	1.72 ± 0.52	89.04 ± 3.62	14.01 ± 0.70	4.50 ± 0.09	17.06 ± 1.50	54.04 ± 0.95	19.84 ± 0.79	18.35 ± 1.38	61.75 ± 1.05	80.11 ± 0.78
Min	0.88	85.7	12.17	4.34	14.64	52.13	17.70	16.33	59.65	79.42
Max	2.93	98.48	14.70	4.65	19.82	55.45	20.58	20.77	63.28	82.30
n	11	11	11	11	11	11	11	11	11	11
Sunflower oilcake	1.37 ± 0.59	101.84 ± 2.86	6.91 ± 0.37	5.31 ± 0.21	23.30 ± 1.71	61.44 ± 1.73	13.88 ± 0.62	23.78 ± 1.73	61.88 ± 1.71	85.66 ± 0.69
Min	0.77	99.39	6.33	5.00	20.94	58.69	13.26	21.43	59.11	84.30
Max	2.66	107.03	7.37	5.55	26.06	63.61	14.92	26.64	63.86	86.34
n	8	8	8	8	8	8	8	8	8	8
Triticale	1.82 ± 0.07	97.29 ± 1.08	14.22 ± 0.98	1.20 ± 0.28	18.25 ± 4.25	54.39 ± 6.51	16.67 ± 0.34	22.18 ± 6.33	60.33 ± 6.73	82.51 ± 0.57
Min	1.75	96.23	13.50	0.87	13.35	50.06	16.28	14.87	55.90	81.87
Max	1.88	98.39	15.34	1.37	20.95	61.88	16.92	25.97	68.07	82.94
n	3	3	3	3	3	3	3	3	3	3
Wheaten bran	3.98 ± 0.47	98.47 ± 1.47	15.64 ± 0.80	1.21 ± 0.09	18.22 ± 1.01	57.86 ± 1.37	17.60 ± 0.80	19.73 ± 1.12	62.43 ± 1.38	82.16 ± 0.78
Min	3.24	96.67	14.29	1.08	17.18	55.27	16.42	18.56	60.01	80.84
Max	4.49	100.67	16.46	1.32	19.47	59.14	18.67	21.18	63.76	82.99
n	6	6	6	6	6	6	6	6	6	6
White gluten	1.29	100.61	11.38	2.43	31.12	51.55	15.23	31.55	53.22	84.77
Min	-	-	-	-	-	-	-	-	-	-
Max	-	-	-	-	-	-	-	-	-	-
N	1	1	1	1	1	1	1	1	1	1

had a total UFA content of 82.16 %. Maize, maize flakes and maize germ meal had total UFA contents of 85.99 %, 85.97 % and 84.99% respectively. Fullfat soya had a total UFA content of 84.94 %. The SFA content of these popular feedstuffs were very low. Maize products had a SFA content of ± 15 % while wheaten bran had a SFA content of 17.60 % and full fat soya 15.05 %.

This survey clearly illustrated that the feedstuffs (maize, wheaten bran, and fullfat soya) most commonly used in pig diets in South Africa, had a high content of C18:2, PUFA and total UFA and very little SFA. This may be one of the major reasons for the poor backfat quality of South African pigs found in the survey of Hugo and Roodt (2002). It is known that the SFA and UFA from the diet pass directly through the digestive system in monogastric animals like pigs, and are deposited in the different depots without change (Nürnberg et al., 1994a, 1994b; Kracht et al., 1996).

Selection of feedstuffs with a fatty acid profile saturated enough to improve the subcutaneous fat quality of pigs

The six requirements for feedstuffs used to improve the subcutaneous fat quality of pigs were discussed under Materials and Methods on p. 28 - 29 of this thesis. Table 2 was studied intensively to identify feedstuffs with low iodine value, low content of C18:2, low PUFA content and high contents of C16:0, C18:0 and total SFA. The total fat content of the feedstuffs was also considered. In order to make an impact on the fatty acid profile of the diet as a whole, it must make a significant contribution to the total lipid content of the diet. If available, literature on the use and effects of a specific feedstuff in pig nutrition, was also consulted.

According to Madsen et al. (1992) the PUFA and especially C18:2 have a notable negative effect on the firmness of the fat. Pigs are not able to synthesize C18:2 (Madsen et al., 1992), which means that this fatty acid has to derive from the diet of the pig. That is why the content of this fatty acid in the feed is a very important factor to consider when formulating diets to improve subcutaneous fat quality. None of the companies that took part in the survey took fatty acid composition into consideration when formulating pig diets. They formulated their diets according to the amino acid profiles of the feedstuffs. The high C18:2 and PUFA content of the grain products (maize and wheaten bran), used by all manufacturers of pig feed, was discussed in the previous section. It was, therefore, decided that the control diet (which represent the situation in South Africa) would definitely contain maize and wheaten bran as major ingredients.

The following fatty acids have a large impact on firmness of subcutaneous fat: C16:0 (positively), C18:0 (positively) and C18:2 (negatively) (Davenel et al., 1999; Roberts & Enser, 1988). These fatty acids as well as total SFA, total PUFA and total UFA were therefore considered when selecting feedstuffs from Table 2 for inclusion in the experimental diet. As an additional aid in selecting feedstuffs for improvement of fat quality, the iodine value and fatty acid profiles of candidate feedstuffs were compared with that of wheaten bran and maize (major ingredients of the control diet).

The first ingredient considered was hominy chop. The mean C16:0 content of hominy chop was 11.7 % which was slightly higher than that of maize at 10.54 %, but lower than that of wheaten bran at 15.64 %. (Table 2). The C18:0 concentration of hominy chop was 2.50 % which was slightly higher than that of maize at 2.42 % and wheaten bran at 1.21 % (Table 2). The total SFA content of hominy chop was 15.21 % which is higher than that of maize at 13.97 % but lower than that of wheaten bran at 17.6 %. Hominy chop had a mean C18:2 content of 48.4 % which was ± 10 % lower than that of wheaten bran at 57.86%, and slightly lower than that of maize at 49.93 %. The PUFA content of hominy chop was 49.48 % which was lower than the 51.04 % of maize and the 62.43 % of wheaten bran. The total UFA content of hominy chop was 84.77 % which was more or less the same as that of maize at 85.99 % but slightly higher than that of wheaten bran at 82.16 %. The iodine value of hominy chop was 103.24 which was close to that of maize at 102.27 but slightly higher than that of wheaten bran at 98.47. The degree of saturation of the fatty acid profile of hominy chop was, therefore, not particularly low. It can thus be concluded that hominy chop had an exceptionally low content of C18:2 and PUFA and higher concentrations of C18:0 compared to maize and wheaten bran. It was therefore decided that this feedstuff might have the potential to improve the saturation of pig fat. Hominy chop was also regularly used in the pig feed industry (Table 1), meaning that the feed industry would not have great difficulty in accepting this feedstuff as an ingredient in their diets.

According to Siebrits et al. (1987) feed wheat had the ability to improve the fat quality of pigs by increasing the saturation of the subcutaneous fat. Table 2 indicates that the iodine value of feed wheat was 99.44 which was lower than that of maize at 102.27 and slightly higher than that of wheaten bran at 98.47. The C16:0 (15.58 %) and the SFA (17.61 %) content of feed wheat were higher than that of maize (10.54 % C16:0 and 13.97 % SFA) but the concentration of C18:0 (2.42 %) of maize was slightly higher than that of feed wheat (1.23 %). The concentrations of C18:1c9 (17.29 %), MUFA (21.26 %) as well as the total UFA (82.32 %) of feed wheat was lower than that

of maize (34.68 % C18:1c9, 34.96 % MUFA and 85.99 % UFA). Unfortunately, the maize had lower concentrations of C18:2 (49.93 %) and PUFA (51.04 %) compared to the feed wheat (55.79 % C18:2 and 61.06 % PUFA). It was concluded that the higher concentrations of C16:0 and SFA and lower concentrations of C18:1c9, MUFA and UFA of feed wheat compared to maize may indicate that this feedstuff may have some potential in increasing the saturation of the pig fat when it is used to replace maize in pig diets. As expected, very little differences were observed between the iodine value and fatty acid profile of feed wheat and wheaten bran. The only indication that feed wheat had a higher SFA content than that of wheaten bran, was that the feed wheat had a slightly lower concentration of C18:2 (55.79 %) and PUFA content (61.06 %) than that of wheaten bran (57.86 % C18:2 and 62.43 % PUFA).

According to van der Merwe and Smith (1991), barley is a feedstuff with the potential to improve the fat quality of pigs by increasing the saturation of the pig fat. Table 2 indicates that the iodine value of barley was 97.72 which is lower than that of maize (102.27) and wheaten bran (98.47). The C16:0 and the SFA content of barley was 19.45% and 21.88% respectively, which was substantially higher than that of maize (10.54 % C16:0 and 13.97 % SFA) and wheaten bran (15.64 % C16:0 and 17.60 % SFA). The C18:0 content of barley (1.43 %) was slightly higher than that of wheaten bran (1.21 %) but lower than that of maize (2.42 %). Table 2 indicates that the C18:2 and the PUFA concentrations of barley at 55.13% and 61.94% respectively, were lower than that of wheaten bran (57.86 % C18:2 and 62.43 % PUFA) but higher than that of maize (49.93 % C18:2 and 51.04 % PUFA). The C18:1c9 (13.82 %), MUFA (15.45 %) and the total UFA (77.39 %) content of barley were lower than that of maize (34.68 % C18:1c9, 34.96 % MUFA and 85.99 % UFA) and wheaten bran (18.22 % C18:1c9, 19.73 % MUFA and 82.16 % UFA). It was concluded that barley should have some potential to increase the saturation of pig fat if it replaces maize and wheaten bran in pig diets because of the higher concentration of SFA, especially C16:0, lower concentrations of C18:1c9, MUFA and UFA and the lower iodine value of barley compared to that of maize and wheaten bran.

Van der Merwe and Smith (1991) also recommended sorghum as a feedstuff with the potential to increase the deposition of SFA in the pig. Fourteen sorghum samples were analyzed (Table 2). The C16:0 content of sorghum, was 11.13 % which was only 0.59 % higher than that of maize and 4.51 % lower than that of wheaten bran. The content of C18:0 in sorghum was 1.15 % which was lower than the 2.42 % of maize and the 1.21 % of wheaten bran. Sorghum (12.94 %) had a lower content of SFA than wheaten bran (17.60 %), and maize (13.97 %). The C18:2 content of sorghum and

maize was ± 50 % in both cases, which was substantially lower than the 57.86 % for wheaten bran. Sorghum had a mean PUFA content of 52.69 % which was 9.74% lower than that of wheaten bran and 1.65 % higher than that of maize. The UFA content of sorghum was 86.78 % which was higher than that of maize (85.99 %) and wheaten bran (82.16 %). Sorghum also had an iodine value of 100.02 which was slightly lower than that of maize (102.27) and higher than that of wheaten bran (98.47). From these iodine values and fatty acid profiles the researcher could not find any real evidence that suggested that sorghum had a higher SFA content than that of a feedstuff like maize and therefore, would increase the saturation of pig fat if replaced by feedstuffs like maize or wheaten bran in pig diets.

It seems as if feed ingredients from grain origin did not have either a high enough fat content or high enough SFA content to make a big enough impact on the total SFA content of the pig diets if they were used to replace maize or wheaten bran. It was, therefore, decided to evaluate a byproduct from the poultry industry, with a very high fat content of 24.08 %, for its potential for improving the level of saturation of pig diets. Poultry byproduct has an iodine value of 70.89 which was considerably lower than any of the grain products analyzed (Table 2). The C16:0, C18:0 and total SFA content of poultry byproduct was 23.69 %, 7.29 % and 33.31 % respectively which was considerably higher than that of any grain derived feedstuff discussed thus far. The opposite trend was observed in the unsaturated fraction where the content of C18:2, total PUFA and total UFA were 16.17 %, 18.19 % and 65.17 % which were considerably lower than any other feedstuff considered thus far. Poultry byproduct definitely had the potential to improve the fat quality of the pigs by making it more saturated.

Another feedstuff in Table 2 with a very high SFA content was acid oil. Closer inspection of the data on acid oil in Table 2 revealed that there was considerable variation in the minimum and the maximum iodine value as well as the different fatty acid contents between the fourteen acid oil samples analyzed. The minimum iodine value was 34.31 compared to the maximum value of 111.06. The same large variation was observed in C16:0 (5.05 % vs 25.62 %), C18:0 (2.97 % vs 29.07 %), C18:1c9 (7.81 % vs 30.04 %) and C18:2 (1.56 % vs 63.02 %). It would be very difficult for the pig feed industry to produce a diet with a standardized level of saturation from an ingredient with so much variation. It was, therefore, decided not to consider acid oil as an ingredient for inclusion in our experimental diet.

Brewers grain also appears like a feedstuff with a fairly high SFA content (Table 2.). Unfortunately,

only one of the 17 companies that submitted a questionnaire indicated that they use brewers grain from time to time (Table 1). No literature could be found on the safety of the addition of brewers grain to pig diets and what effect it would have on the growth of the pig as well as on its fatty acid composition. Brewers grain was, therefore, also excluded as a potential canditate for inclusion in our experimental diet.

Oats also looked like a feedstuff with the potential to improve the fat quality of pigs (Table 2) but none of the companies contacted, used it (Table 1). There was also no literature available that could indicate that oats would improve the fat quality of the pigs or what the effect of this feedstuff would be on the growth performance of pigs. It was therefore also excluded.

Lucern meal had a high content of C16:0 (18.14 %) and low content of C18:2 (20.34 %) (Table 2). Unfortunately, it had a very low fat content (1.67 %) and according to Table 1, it was also included at very low levels (0.5 - 1 %). Both these factors would limit its contribution to the level of saturation of a total diet. The ether extract of this feedstuff was so contaminated with other ether soluble components that it was impossible to determine its iodine value. These ether soluble contaminants also made it difficult to determine its lipid content accurately. That is why it was decided not to use this feedstuff.

Copra meal is another feedstuff with a very low iodine value (10.25) as well as a high content of total SFA (90.46 %) (Table 2). Thorne, Wisman, Cole and Machin (1992) reported, however, that increasing levels of copra meal may result in a reduction in the growth rate of the pigs as a result of decreasing levels of feed intake. None of the companies contacted indicated that they use this feedstuff in their pig diets. Although not shown in Table 2, lipid from copra meal contained very high levels of C12:0 (46.77 %) and C14:0 (19.15 %). These fatty acid will be transferred to the subcutaneous fat and according to Bonanome and Grundy (1988), consumption of fat tissue containing these fatty acids will lead to an increase in blood cholesterol levels. After considering all the factors discussed above, it was decided not to use copra meal as a feed ingredient.

Products like meat and bone meal or carcass meal have a high content of SFA in their lipid composition as indicated in Table 2 and should make a positive contribution towards the amount of SFA present in pig diets thereby enhancing the fat quality of the pigs by making it more saturated. Due to the stigma surrounding these feedstuffs concerning bovine spongiform encephalopathy (BSE), it was decided not to use this product in our experimental diet.

Formulating the control and experimental diets

From the discussion above, it was clear that barley, feed wheat, hominy chop and poultry byproduct were the only feedstuffs available in South Africa that conform satisfactorily to the six requirements set for inclusion in an experimental diet with the aim of improving subcutaneos fat quality of pigs. Although the fatty acid profile of sorghum suggested otherwise, it was included in this preliminary work because Van der Merwe and Smith (1991) indicated that it had the potential to improve fat quality. All these ingredients are already being used by the pig feed industry. A recommendation to the pig feed industry to increase the inclusion level of one or more of these feedstuffs would, therefore, be relatively easy to be accepted by them.

The Excel program described under Materials and Methods on p. 29 of this thesis, was then used in the selection of possible combinations of feedstuffs. Barley, feed wheat, hominy chop and poultry byproduct was then substituted in various combinations while observing the changes in the fatty acid profile of the diets. It became clear that sorghum could make no significant contribution to increase the SFA content of diets. Sorghum was, therefore, not considered as a possible feed ingredient in the experimental diet. The results from the Excel calculations were then handed over to an animal nutritionist at NOLKO and she was asked to formulate a control diet as well as six preliminary experimental diets taking the fatty acid profiles into consideration. Based on the results from the survey and the lipid analyses, the nutritionist was asked to adhere to the following restrictions:

1. The proximate analysis of all seven these diets had to be as close as possible to a typical finishing diet for growing pigs: 16% protein, 3% fat, 13.5 MJ/kg energy and 4 % fibre.
2. Fishmeal, sunflower oilcake and soya oilcake had to be used as protein source in all seven diets and as closely as possible, at the same level.
3. The main ingredients of the control diet had to be maize and wheaten bran.
4. The six experimental diets had to contain various combinations of barley, hominy chop, feed wheat and poultry byproduct.

The formulation and nutrient composition of the preliminary control and six experimental diets formulated by NOLKO are shown in Tables 3 and 4. The main difference between test diet 1 and the control diet, is the addition of 3 % poultry byproduct. The main difference between test diet 2 and the control diet, is the addition of 21.6 % hominy chop, the addition of 22 % feed wheat, elimination

Table 3: Percentage composition of preliminary control and experimental diets on an air dry basis.

	Control	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6
Component	%	%	%	%	%	%	%
Yellow maize meal	65.30	66.30	35.00	-	-	-	24.20
Wheaten bran	12.30	8.30	-	-	-	-	-
Hominy chop	-	-	21.60	10.00	-	-	-
Barley	-	-	-	34.00	-	36.30	24.20
Feed wheat	-	-	22.00	34.00	72.60	36.30	24.20
Poultry byproduct	-	3.00	-	-	5.00	5.00	5.00
Soya oil cake	9.40	9.40	9.80	9.40	9.40	9.40	9.40
Fish meal	5.20	5.20	5.50	5.20	5.20	5.20	5.20
Sunflower oil cake	3.60	3.60	2.00	3.60	3.60	3.60	3.60
Synthetic lysine	0.08	0.04	0.06	0.08	0.08	0.08	0.08
Savanna lime	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Mono calcium phosphate	1.70	1.70	1.70	1.70	1.70	1.70	1.70
Fine salt	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Mineral and vitamin premix	0.20	0.20	0.20	0.20	0.20	0.20	0.20

Table 4: Nutrient composition of the preliminary control and experimental diet on an air dry basis.

Nutrient composition:	**Unit**	**Control**	**Diet 1**	**Diet 2**	**Diet 3**	**Diet 4**	**Diet 5**	**Diet 6**
Protein	%	16.01	17.01	16.44	18.44	21.79	20.77	19.27
Digestible energy	MJ/kg	13.51	13.81	13.47	11.96	13.23	12.15	12.85
Fibre	%	4.42	4.03	4.55	5.74	4.35	5.26	4.23
Fat	%	3.86	4.56	4.20	2.67	3.29	3.35	3.51
Lysine	%	0.90	0.9	0.90	0.90	1.02	0.98	0.91
Methionine	%	0.33	0.34	0.32	0.32	0.36	0.34	0.34
Tryptophane	%	0.18	0.18	0.18	0.21	0.23	0.22	0.21
Calcium	%	1.13	1.19	1.13	1.12	1.23	1.23	1.23
Phosphorous	%	0.94	0.90	0.89	0.93	0.90	0.91	0.89

of wheaten bran and a ± 30 % reduction in maize content. In test diet 3, maize and wheaten bran of the control diet were substituted with hominy chop, barley and feed wheat. No poultry byproduct was added to this diet. In test diet 4, the maize and wheaten bran were replaced with 72.6 %

feed wheat and 5 % poultry byproduct. In test diet 5, the maize and the wheaten bran of the control were replaced with 36.3% feed wheat, 36.3% barley and 5% poultry byproduct. In test diet 6, the wheaten bran was left out completely and the maize content was lowered from 65.3 % in the control to 24.2 %. Barley at 24.2%, feed wheat at 24.2 % and 5% poultry byproduct were also added to test diet 6.

The preliminary control and six experimental diets were mixed on a small scale (1 kg) in the laboratory and lipid was extracted from it for lipid analysis. The extractable fat content, iodine value, content of important fatty acids and important fatty acid ratios of these diets are shown in Table 5. As expected, the iodine value, C18:2 content, PUFA content and UFA content of the control diet were much higher and the C16:0, C18:0 and total SFA content much lower than that of most of the experimental diets. If one takes into consideration that the control diet was formulated to be as representative as possible of a typical finishing diet in South Africa, it becomes easier to understand the reason for the poor fat quality of South African pigs observed by Hugo and Roodt (2002). Although slightly better than the control diet, the level of saturation of experimental diets 1, 2 and 3 were much lower than that of experimental diets 4, 5 and 6 (Table 5). The iodine value of the control diet and experimental diets 1- 3 were ± 100 while the iodine value of experimental diets 4 - 6 were ± 92. Experimental diets 1 - 3 were, therefore, not further considered as candidates for the experimental diet.

The experimental diets with the best iodine values, fatty acid profiles and fatty acid ratios from a fat quality point of view, was diet 5, followed by diet 4, followed by diet 6. The main difference between these three diets was that diet 4 contained feed wheat (at 72.6 %) as the main grain source, diet 5 contained equal amounts (36.3 %) of barley and feed wheat as grain source while diet 6 contained equal amounts (24.2 %) of feed wheat, barley and maize as grain source (Table 3). The researcher was sceptical about using a single grain source like feed wheat as in diet 4 in the experimental diet. If one looks at Table 2, it was clear that there was also a lot of variation between different feed wheat cultivars in fatty acid composition. The C18:2 content, for example, varied between 40.45 % and 61.80 % for the five samples analyzed. The animal feed industry do not do fatty acid analyses on feed samples before mixing diets. It is, therefore, possible that a batch of feed wheat with high content of C18:2 and PUFA may be mixed into a pig diet intended to improve the fat quality of pigs, which might jeopardize the whole aim of the exercise. It was, therefore, decided not to use experimental diet 4. The risk of something like that happening would be drastically reduced if two or more grain

Table 5: Extractable fat content, iodine value, content of important fatty acids (%), and important fatty acid ratios of the control and six experimental diets mixed on laboratory scale.

	Control n = 3	Diet 1 n = 3	Diet 2 n = 3	Diet 3 n = 3	Diet 4 n = 3	Diet 5 n = 3	Diet 6 n = 3
Chemical properties:							
% Extractable fat.	3.59 ± 0.07 (3.60)	4.26 ± 0.12 (4.20)	4.29 ± 0.08 (4.43)	3.04 ± 0.02 (2.93)	3.20 ± 0.07 (3.37)	3.45 ± 0.01 (3.30)	3.83 ± 0.04 (3.73)
Iodine value	101.16 ± 0.58 (100.63)	99.98 ± 1.54 (95.61)	102.39 ± 0.86 (101.47)	100.65 ± 0.82 (99.61)	91.78 ± 1.59 (88.68)	92.39 ± 0.45 (88.12)	94.62 ± 0.86 (90.17)
Fatty acid composition (%):							
C16:0	12.70 ± 0.33 (12.40)	14.84 ± 0.12 (14.21)	13.36 ± 0.11 (12.57)	15.71 ± 0.09 (15.31)	19.57 ± 0.19 (18.60)	20.15 ± 0.26 (19.41)	18.04 ± 0.20 (17.57)
C18:0	2.61 ± 0.07 (2.69)	3.54 ± 0.09 (3.53)	2.78 ± 0.08 (2.70)	2.50 ± 0.06 (2.51)	4.42 ± 0.09 (4.12)	4.26 ± 0.10 (4.22)	4.15 ± 0.09 (4.15)
C18:1c9	28.82 ± 1.10 (28.21)	31.42 ± 0.13 (30.48)	30.81 ± 0.07 (29.54)	25.39 ± 0.12 (21.35)	25.31 ± 0.16 (24.37)	27.05 ± 0.36 (23.85)	29.54 ± 0.35 (27.37)
C18:2	44.56 ± 1.48 (44.06)	40.43 ± 0.62 (38.79)	44.47 ± 0.58 (43.78)	42.61 ± 0.55 (43.30)	33.86 ± 0.16 (32.92)	33.07 ± 0.29 (32.32)	34.77 ± 0.29 (33.66)
Fatty acid ratios:							
SFA (%)	18.83 ± 2.81 (16.91)	20.14 ± 0.21 (19.68)	17.67 ± 0.23 (16.97)	20.15 ± 0.16 (19.81)	26.30 ± 0.26 (25.01)	26.53 ± 0.25 (25.99)	24.21 ± 0.18 (23.94)
MUFA (%)	31.15 ± 1.36 (30.89)	34.42 ± 0.22 (34.12)	32.78 ± 0.13 (32.14)	28.74 ± 0.08 (25.52)	31.33 ± 0.08 (31.37)	32.31 ± 0.20 (30.46)	34.13 ± 0.31 (32.95)
PUFA (%)	49.45 ± 1.58 (50.22)	44.83 ± 0.64 (44.25)	48.85 ± 0.52 (49.21)	49.74 ± 0.34 (52.13)	40.76 ± 0.03 (40.99)	39.89 ± 0.40 (40.74)	40.44 ± 0.35 (40.66)
UFA (%)	80.60 ± 2.90 (81.11)	79.25 ± 0.68 (78.37)	81.62 ± 0.41 (81.35)	78.48 ± 0.27 (77.65)	72.09 ± 0.08 (72.36)	72.20 ± 0.22 (71.20)	74.56 ± 0.16 (73.61)

Values in brackets are theoretical estimations calculated from the Excel program linked with the database on feedstuffs.

sources could be included, as in experimental diet 5. The researcher was, however, careful about the high level (36.3 %) of barley in experimental diet 5. Brand (1999) reported that high levels of barley in pig diets might result in lower feed intake as well as lower growth rates. It was, therefore, decided to use diet 6 as the experimental diet for this study although it had a slightly higher iodine value, lower content of SFA and higher content of PUFA and UFA than diets 4 and 5, due to its 24.2 % maize content. There was no real cost difference between the control diet and the experimental diet optimized for fat quality. At the time the experiment was performed (February 2002) the experimental diet costed R 1630.85/ton compared to the R 1626.85/ton of the control diet.

After 1800 kg of each of the control and experimental diets were mixed by NOLKO, samples were taken from six randomly selected bags of each treatment and analyzed for iodine value and fatty acid content. The extractable fat content, iodine value, fatty acid content and fatty acid ratios of the control and experimental diets are shown in Table 6. Examination of Table 6 clearly indicate that the experimental diet (29.15 % SFA) had a substantially higher SFA content than that of the control diet (17.75 %). The major differences between the control and experimental diets are also summarized in Figure 2. The iodine value of the control diet (100.58) was much higher than that of the experimental diet (79.84). The experimental diet had substantially more C16:0 (21.38 % vs 13.23 %), C18:0 (4.59 % vs 2.62 %) and total SFA (29.15 % vs 17.75 %) as compared to the control diet. The opposite trend was observed in the unsaturated fraction where the experimental diet had much less C18:2 (29.48 % vs 43.77 %), total PUFA (33.13 % vs 48.72 %) and total UFA (70.37 % vs 82.12 %) than the control diet.

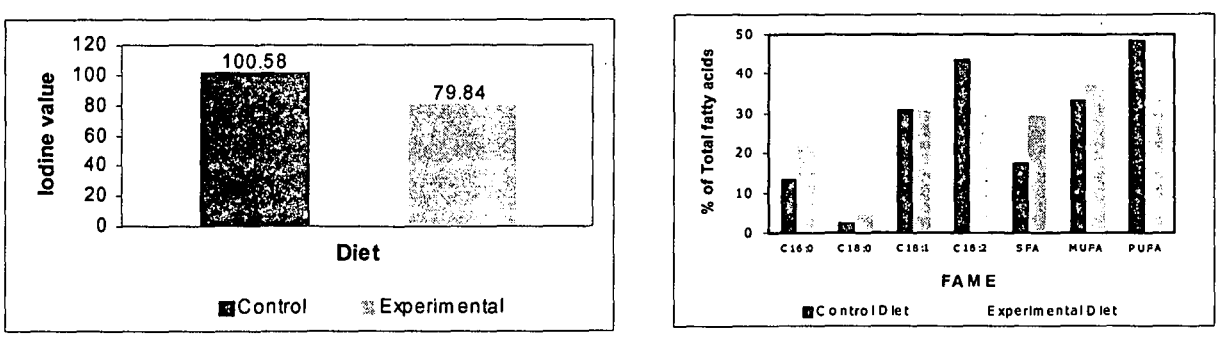

Figure 2: Iodine value and fatty acid profiles of the control versus the experimental diet.

Table 6: Extractable fat content, iodine value, fatty acid composition (%) and fatty acid ratios of the control and experimental diets used in this study.

	Control diet		Experimental diet	
	Determined content n = 6	**Calculated content**	**Determined content n = 6**	**Calculated content**
Chemical properties:				
% Extractable fat	3.96 ± 0.40	3.60	3.82 ± 0.23	3.73
Iodine value/ 100 gm fat	100.58 ± 1.13	100.63	79.84 ± 1.27	90.17
Fatty acid composition (%)				
C12:0	Not Detected	-	0.21 ± 0.02	-
C14:0	0.92 ± 0.04	-	1.73 ± 0.05	-
C15:0	0.01 ± 0.03	-	0.13 ± 0.04	-
C16:0	13.23 ± 0.21	12.40	21.38 ± 0.36	17.57
C16:1	1.15 ± 0.01	-	2.92 ± 0.06	-
C17:0	0.08 ± 0.04	-	0.19 ± 0.02	-
C17:1	0.13 ± 0.07	-	0.14 ± 0.05	-
C18:0	2.62 ± 0.14	2.69	4.59 ± 0.10	4.15
C18:1t9	0.04 ± 0.04	-	0.64 ± 0.15	-
C18:1c9	31.03 ± 0.15	28.21	30.73 ± 0.23	27.37
C18:1c7	0.44 ± 0.02	-	0.86 ± 0.03	-
C18:2	43.77 ± 0.43	44.06	29.48 ± 0.53	33.66
C18:3n-3	1.61 ± 0.05	-	1.41 ± 0.03	-
C19:0	0.10 ± 0.23	-	0.08 ± 0.06	-
C20:0	0.43 ± 0.02	-	0.45 ± 0.02	-
C20:1	0.38 ± 0.04	-	0.48 ± 0.01	-
C20:2	0.18 ± 0.06	-	0.23 ± 0.18	-
C20:4	0.08 ± 0.04	-	0.05 ± 0.05	-
C20:5	1.95 ± 0.09	-	1.24 ± 0.11	-
C21:0	Not Detected	-	0.02 ± 0.04	-
C22:0	0.17 ± 0.02	-	0.22 ± 0.01	-
C22:1	0.21 ± 0.03	-	0.20 ± 0.07	-
C22:2	0.01 ± 0.03	-	Not Detected	-
C22:5	0.16 ± 0.08	-	0.06 ± 0.07	-
C22:6	0.95 ± 0.11	-	0.67 ± 0.09	-
C23:0	Not Detected	-	0.01 ± 0.03	-
C24:0	0.19 ± 0.02	-	0.14 ± 0.07	-
C24:1	0.03 ± 0.03	-	1.27 ± 2.81	-
Fatty acid ratios:				
MUFA (%)	33.40 ± 0.20	30.89	37.24 ± 3.04	32.95
Dienoic (%)	43.96 ± 0.45	-	29.71 ± 0.56	-
Trienoic (%)	1.61 ± 0.05	-	1.41 ± 0.03	-
Tetraenoic (%)	0.08 ± 0.04	-	0.05 ± 0.05	-
Pentaenoic (%)	2.12 ± 0.09	-	1.30 ± 0.14	-
Hexaenoic (%)	0.95 ± 0.11	-	0.67 ± 0.09	-
Penta- + Hexaenoic (%)	3.07 ± 0.19	-	1.97 ± 0.17	-
C16:0 + C18:0	15.85 ± 0.29	-	25.97 ± 0.43	-
C16:1 + C18:1 / C16:0 + C18:0	2.03 ± 0.04	-	1.30 ± 0.01	-
C18:0 / C18:2	0.06 ± 0.01	-	0.16 ± 0.01	-
C16:0 / C18:2	0.30 ± 0.01	-	0.73 ± 0.02	-
SFA (%)	17.75 ± 0.50	16.91	29.15 ± 0.39	23.94
UFA (%)	82.12 ± 0.46	81.11	70.37 ± 3.05	73.61
MUFA / SFA	1.88 ± 0.06	-	1.28 ± 0.09	-
Double bond index	142.77 ± 1.18	-	111.57 ± 3.04	-
Peroxidizability index	68.65 ± 1.29	-	46.78 ± 1.51	-
PUFA	48.72 ± 0.44	50.22	33.13 ± 0.67	40.66
PUFA/SFA	2.75 ± 0.09	-	1.14 ± 0.03	-
n-6	44.03 ± 0.48	-	29.76 ± 0.55	-
n-3	4.68 ± 0.20	-	3.37 ± 0.20	-
n-6/n-3	9.41 ± 0.45	-	8.84 ± 0.48	-

The database on iodine value and fatty acid content of individual feedstuffs as well as the Excel program were used to predict the fat content, iodine value, content of important fatty acids and important fatty acid ratios of the preliminary control diet, preliminary experimental diets, final control diet and final experimental diet. The predicted values are shown in brackets in Tables 5 and 6. With closer investigation of the preliminary diets in Table 5, it was clear that the predicted values were generally very close to the chemically determined values. If one looks at the actual control and experimental diets (Table 6), the estimations was reasonably good, but not as good as in the case of the preliminary diets. The reason for the much better estimations of the preliminary diets, was that the preliminary diets were mixed from the pooled feedstuffs collected from the different pig feed manufacturers. As the database will be expanded (more replications of each feedstuff) the accuracy of estimations will definitely increase.

Growth and carcass characteristics

As indicated in Table 7, no significant differences ($P > 0.05$) were observed in growth performance and carcass characteristics between the control and experimental groups. Because no significant differences were observed, the P values were included in Table 7. Worth mentioning, is the very high average daily weight gain of both the control (0.97 kg/day) and the experimental (0.95 kg/day) groups. If one takes into consideration that this average growth rate was calculated over the whole growth period of 55 days, it was really exceptional. The high average daily feed intake and low feed conversion ratios were also an indication of excellent genetic material and well balanced highly nutritious diets. The fact that no significant differences were observed between the average daily feed intake, feed conversion ratio or average daily gain between the control and experimental groups, implied that the experimental diet optimized for fat quality was acceptable to the pigs, was as nutritious as the control diet and had no nutritional deficiencies.

The fact that no significant differences ($P > 0.05$) were observed in carcass characteristics between the control and experimental groups could also be considered as very positive because it means that the experimental diet optimized for fat quality did not result in excessive fat deposition or other carcass problems (Table 7). This was especially demonstrated by the lean meat content of the control (69.32 %) and the experimental (69.26 %) groups which can for all practical purposes be considered as identical. The very low average backfat thickness obtained by both the control (12.71 mm) and the experimental (12.86 mm) groups meant that one of the major aims of this study, namely the production of P and O (backfat thickness < 18 mm) pig carcasses, was achieved. There were 3 pigs

Table 7: Growth performance and carcass characteristics of gilts in the two dietary groups.

	Control group	Experimental group	Significance level
Number of pigs	7	7	-
Days of trial	55	55	-
GROWTH PERFORMANCE			
Initial weight (kg)	43.30 ± 3.07	43.33 ± 3.33	NS (0.9870)
Slaughter weight (kg)	96.79 ± 4.83	95.36 ± 4.57	NS (0.5805)
Weight increase (kg)	53.49 ± 3.25	52.03 ± 4.18	NS (0.4801)
Average daily gain (kg)	0.97 ± 0.06	0.95 ± 0.08	NS (0.4801)
Total feed intake (kg)	153.45 ± 11.19	156.68 ± 12.11	NS (0.6137)
Average daily feed intake (kg)	2.79 ± 0.20	2.85 ± 0.22	NS (0.6137)
Feed conversion ratio	2.87 ± 0.16	3.01 ± 0.13	NS (0.0890)
CARCASS CHARACTERISTICS			
Warm carcass weight (kg)	78.34 ± 5.18	77.80 ± 3.76	NS (0.8263)
Cold carcass weight (kg)	76.01 ± 5.04	75.47 ± 3.64	NS (0.8211)
Dressing percentage (warm weight)	80.89 ± 1.49	81.59 ± 1.24	NS (0.3581)
Dressing percentage (cold weight)	78.49 ± 1.45	79.15 ± 1.18	NS (0.3670)
Backfat thickness (mm)	12.71 ± 2.43	12.86 ± 3.34	NS (0.9286)
Conformation grade	4.29 ± 0.76	4.29 ± 0.49	-
Lean meat content (%)	69.32 ± 0.98	69.26 ± 1.34	NS (0.9286)

NS = Not significant ($P > 0.05$)

with P and 4 pigs with O classification in each of the control and experimental groups.

Subcutaneous fat quality

Physical quality measurements

The physical fat quality measurements, colour and fat hardness were only performed on backfat of pigs from both treatments, whereas all the other fat quality measurements (extractable fat content, refraction index, iodine value, fatty acid content and fatty acid ratios) were performed at all seven positions as indicated in Figure 1. The results of the colour and fat hardness measurements were, therefore, tabulated and discussed seperately (Table 8). Minolta colour measurements (L*, a*, and b* values) of the backfat did not differ significantly ($P > 0.05$) between the control and experimental group (Table 8). This finding was important because it indicated that the diet optimized for fat quality had no negative effect on the colour of backfat. As mentioned earlier, consumers and processors prefer fat to be white and firm (Barton-Gade, 1983; Enser, 1983). The fat hardness measurement of the experimental group (643.56) was significantly higher ($P < 0.01$) than that of the

Table 8: Physical properties of backfat of gilts in the two dietary groups.

	Control group	Experimental group	Significance level
	n = 14	n = 14	-
Minolta *L**	78.44 ± 1.81	78.65 ± 1.96	NS
Minolta *a**	2.03 ± 1.63	2.00 ± 1.94	NS
Minolta *b**	10.99 ± 1.40	10.39 ± 0.95	NS
Fat Hardness	501.96 ± 91.23	643.56 ± 126.41	**

NS = Not significant (P > 0.05); ** = P < 0.01

control group (501.96), indicating that backfat from the experimental group was firmer than that of the control group (Table 8). This was an indication that the experimental diet was successful in improving the firmness of backfat compared to that of pigs receiving the control diet. This is especially important because it means that one of the other most important aims of this project, namely the improvement of the firmness of subcutaneous fat, was achieved. These results clearly indicated that the experimental diet was successful in improving the firmness of backfat compared to that of pigs receiving the control diet.

Chemical quality measurements

Table 9 shows the significance levels of the main variables (diet, sampling position and side) on all the chemical parameters measured. It clearly illustrated that diet (control diet vs experimental diet) as well as sampling position, had a highly significant effect on most of the fat quality parameters measured. Side, in other words, whether samples were taken from the left or the right side of carcasses, had no significant effect on any of the parameters measured. It was, therefore, possible that measurements from fat samples taken from the left or right hand side of the carcass could serve as duplicates for each other. All interactions with side involved were, therefore, not significant. A few interactions between diet and position was significant. This implied that diet may have a bigger effect on fat quality at certain positions on the carcass. These interactions will be discussed later.

Tables 10 - 12 give the results for chemical analysis and fatty acid profiles for each position (A - G) within each dietary group (control group vs experimental group). Researchers are mainly only interested in backfat. Values for backfat (position B) were, therefore, highlighted in Tables 10 to 12 to ease comparisons with international guidelines.

Table 9: Significance levels of main variables and their interactions.

	A	B	C	A x B	A x C	B x C	A x B x C
Chemical properties:							
Extractable fat (%)	**	***	NS	**	NS	NS	NS
Fat Free Dry Matter (%)	NS	***	NS	NS	NS	NS	NS
Moisture(%)	**	***	NS	*	NS	NS	NS
Iodine value	***	***	NS	NS	NS	NS	NS
Refraction index	***	NS	NS	NS	NS	NS	NS
Fatty acid composition (%):							
C10:0	NS	**	NS	NS	NS	NS	NS
C12:0	NS	NS	NS	NS	NS	NS	NS
C14:0	***	***	NS	NS	NS	NS	NS
C15:0	***	***	NS	NS	NS	NS	NS
C16:0	***	**	NS	NS	NS	NS	NS
C16:1	***	***	NS	NS	NS	NS	NS
C17:0	***	***	NS	NS	NS	NS	NS
C17:1	***	NS	NS	NS	NS	NS	NS
C18:0	***	***	NS	NS	NS	NS	NS
C18:1c9	**	***	NS	NS	NS	NS	NS
C18:1c7	**	***	NS	NS	NS	NS	NS
C18:2n-6	***	***	NS	**	NS	NS	NS
C18:3n-3	***	***	NS	*	NS	NS	NS
C20:0	**	***	NS	NS	NS	NS	NS
C20:1	***	***	NS	NS	NS	NS	NS
C20:2n-6	***	***	NS	NS	NS	NS	NS
C20:3n-6	NS	**	NS	NS	NS	NS	NS
C20:3n-3	***	NS	NS	NS	NS	NS	NS
C20:4n-6	***	NS	NS	NS	NS	NS	NS
C20:5n-3	***	***	NS	**	NS	NS	NS
C21:0	**	NS	NS	NS	NS	NS	NS
C22:2n-6	***	*	NS	NS	NS	NS	NS
C22:5n-3	***	***	NS	NS	NS	NS	NS
C22:6(n-3)	***	***	NS	NS	NS	NS	NS
Fatty acid ratios:							
MUFA (%)	***	***	NS	NS	NS	NS	NS
Dienoic (%)	***	***	NS	**	NS	NS	NS
Trienoic (%)	***	***	NS	NS	NS	NS	NS
Tetraenoic (%)	***	NS	NS	NS	NS	NS	NS
Pentaenoic (%)	***	***	NS	*	NS	NS	NS
Hexanoic (%)	***	***	NS	NS	NS	NS	NS
Penta- + Hexaenoic (%)	***	***	NS	*	NS	NS	NS
SFA (%)	***	***	NS	NS	NS	NS	NS
UFA (%)	***	***	NS	NS	NS	NS	NS
PUFA	***	***	NS	**	NS	NS	NS
MUFA/SFA	***	***	NS	NS	NS	NS	NS
PUFA/SFA	***	***	NS	*	NS	NS	NS
C16:0 + C18:0 (%)	***	**	NS	NS	NS	NS	NS
C16:1 + C18:1/ C16:0 + C18:0	***	***	NS	NS	NS	NS	NS
C18:0/C18:2	***	***	NS	NS	NS	NS	NS
C16:0/C18:2	***	***	NS	NS	NS	NS	NS
Double bond index	***	***	NS	NS	NS	NS	NS
Peroxidizability index	***	***	NS	***	NS	NS	NS
n-6 (%)	***	***	NS	**	NS	NS	NS
n-3 (%)	***	***	NS	**	NS	NS	NS
n-6/n-3	*	NS	NS	NS	NS	NS	NS

A = Diet; B = Position; C = Side; NS = Not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Table 10: Chemical properties of subcutaneous fat of control and experimental groups at different sampling positions.

		CONTROL GROUP Sampling positions							EXPERIMENTAL GROUP Sampling positions							
Parameter	**IG**	**A** n = 14	**B** n = 14	**C** n = 14	**D** n = 14	**E** n = 14	**F** n = 14	**G** n = 14	**A** n = 14	**B** n = 14	**C** n = 14	**D** n = 14	**E** n = 14	**F** n = 14	**G** n = 14	**Sign. level**
Extractable fat (%)	> 84 %	79.59^{df} (1.36)	76.08^{bd} (2.76)	81.61^{ef} (2.49)	77.52^{cde} (2.33)	73.47^{bc} (5.76)	66.29^{a} (4.13)	77.04^{cd} (3.12)	80.52^{df} (1.05)	74.76^{bc} (2.84)	82.62^{f} (3.01)	76.91^{cd} (6.34)	76.94^{cd} (2.18)	71.67^{b} (3.94)	79.66^{df} (2.84)	***
Fat Free Dry Matter (%)	-	7.52^{ac} (1.30)	9.16^{c} (1.98)	6.51^{ab} (2.19)	7.42^{ac} (1.73)	8.33^{ac} (2.33)	8.60^{bc} (2.98)	6.36^{ab} (1.79)	7.61^{ac} (1.46)	8.13^{ac} (1.93)	6.10^{a} (1.42)	8.05^{ac} (1.62)	8.15^{ac} (1.85)	7.43^{ac} (1.86)	6.81^{ac} (1.20)	***
Moisture(%)	-	12.89^{ac} (1.47)	14.76^{ad} (3.72)	11.88^{ab} (2.95)	15.07^{ad} (2.10)	18.20^{dg} (4.80)	25.12^{h} (4.92)	16.60^{bcde} (3.61)	11.87^{a} (1.74)	17.11^{cdf} (3.22)	11.28^{a} (3.12)	15.04^{ad} (6.70)	14.91^{ad} (3.01)	20.90^{efgh} (3.83)	13.53^{ad} (2.94)	***
Iodine value	< 70 or < 65	71.54^{e} (2.19)	70.83^{e} (3.73)	70.21^{de} (2.72)	70.13^{de} (3.45)	69.54^{de} (3.03)	66.77^{cd} (2.18)	69.05^{de} (3.26)	64.80^{bc} (3.12)	62.01^{ab} (2.18)	62.48^{ab} (1.90)	62.17^{ab} (2.35)	62.87^{ab} (2.27)	61.11^{a} (2.73)	63.10^{ab} (1.87)	***
Refraction index	< 1.4598	1.46083^{b} (0.00043)	1.46074^{b} (0.00041)	1.46065^{b} (0.00052)	1.46069^{b} (0.00050)	1.46069^{b} (0.00047)	1.46040^{b} (0.00037)	1.46053^{b} (0.00036)	1.45983^{a} (0.00030)	1.45976^{a} (0.00029)	1.45972^{a} (0.00018)	1.45960^{a} (0.00026)	1.45978^{a} (0.00032)	1.45970^{a} (0.00020)	1.45969^{a} (0.00022)	***

Means with different superscripts within the same row differ significantly

Value in brackets refer to standard deviation

IG = International guideline; *** = $P < 0.001$

Table 11: Fatty acid composition (%) of subcutaneous fat of the control and experimental groups at different sampling positions.

		CONTROL GROUP Sampling positions							EXPERIMENTAL GROUP Sampling positions							
	IG	A n = 14	B n = 14	C n = 14	D n = 14	E n = 14	F n = 14	G n = 14	A n = 14	B n = 14	C n = 14	D n = 14	E n = 14	F n = 14	G n = 14	Sign. level
C10:0	-	0.13^{ab} (0.07)	0.18^{ab} (0.01)	0.10^{a} (0.08)	0.14^{ab} (0.08)	0.14^{ab} (0.08)	0.17^{ab} (0.05)	0.15^{ab} (0.08)	0.14^{ab} (0.08)	0.19^{b} (0.06)	0.12^{ab} (0.08)	0.10^{a} (0.09)	0.13^{ab} (0.09)	0.17^{ab} (0.05)	0.16^{ab} (0.05)	*
C12:0	-	0.19 (0.08)	0.21 (0.06)	0.16 (0.10)	0.15 (0.12)	0.23 (0.34)	0.18 (0.10)	0.18 (0.10)	0.21 (0.10)	0.20 (0.09)	0.19 (0.08)	0.20 (0.09)	0.19 (0.11)	0.17 (0.11)	0.18 (0.10)	NS
C14:0	-	1.36^{ab} (0.09)	1.42^{ad} (0.13)	1.32^{a} (0.10)	1.38^{ac} (0.11)	1.40^{ad} (0.10)	1.47^{bcdf} (0.11)	1.36^{ab} (0.11)	1.50^{dh} (0.07)	1.57^{fgh} (0.08)	1.45^{bcde} (0.06)	1.50^{dh} (0.05)	1.54^{efgh} (0.04)	1.58^{fgh} (0.07)	1.48^{cdg} (0.06)	***
C15:0	-	0.10^{c} (0.05)	0.08^{bc} (0.06)	0.07^{ac} (0.06)	0.06^{ac} (0.06)	0.06^{ac} (0.06)	0.01^{a} (0.02)	0.03^{ab} (0.06)	0.05^{ac} (0.07)	0.04^{ac} (0.06)	0.04^{ac} (0.06)	0.05^{ac} (0.05)	0.02^{ab} (0.04)	0.01^{a} (0.04)	0.02^{ab} (0.05)	***
C16:0	-	22.13^{a} (1.06)	22.67^{ab} (1.20)	22.21^{a} (1.31)	22.37^{a} (1.35)	22.37^{a} (1.10)	23.38^{ac} (1.06)	22.15^{a} (1.26)	23.72^{bc} (0.99)	24.65^{c} (0.65)	24.19^{c} (0.63)	24.49^{c} (0.89)	24.20^{c} (0.79)	24.68^{c} (0.71)	23.76^{bc} (0.91)	***
C16:1	-	2.36^{ad} (0.25)	2.43^{bcd} (0.47)	1.94^{a} (0.23)	2.30^{ac} (0.30)	2.64^{cdf} (0.33)	3.11^{gh} (0.48)	2.48^{bcde} (0.40)	2.62^{bcde} (0.29)	2.78^{dg} (0.39)	2.20^{ab} (0.24)	2.54^{bcde} (0.24)	2.88^{efgh} (0.31)	3.22^{h} (0.32)	2.62^{bcde} (0.29)	***
C17:0	-	0.51^{efg} (0.15)	0.46^{cdf} (0.14)	0.46^{dg} (0.15)	0.45^{cdf} (0.10)	0.41^{aefg} (0.11)	0.33^{ac} (0.06)	0.37^{ad} (0.12)	0.43^{bcde} (0.10)	0.36^{ad} (0.07)	0.39^{aefg} (0.07)	0.36^{ad} (0.06)	0.33^{ac} (0.06)	0.30^{a} (0.06)	0.32^{ab} (0.05)	***
C17:1	-	0.36^{b} (0.11)	0.33^{ab} (0.09)	0.31^{ab} (0.11)	0.34^{ab} (0.09)	0.33^{ab} (0.09)	0.29^{ab} (0.08)	0.32^{ab} (0.12)	0.32^{ab} (0.08)	0.27^{ab} (0.05)	0.27^{ab} (0.06)	0.26^{a} (0.06)	0.27^{ab} (0.07)	0.26^{a} (0.08)	0.26^{a} (0.07)	*
C18:0	> 12 %	11.34^{ac} (0.73)	11.67^{ad} (1.39)	12.56^{bcde} (1.30)	11.76^{ad} (1.34)	10.84^{a} (0.92)	10.62^{a} (0.86)	11.09^{ab} (1.16)	13.20^{deg} (1.51)	13.60^{eh} (1.50)	14.78^{gh} (1.31)	14.17^{fgh} (1.38)	12.73^{cdef} (1.16)	12.15^{ac} (1.12)	12.80^{cdef} (1.41)	***
C18:1c9	-	37.87^{ab} (1.03)	37.28^{a} (1.35)	38.22^{ab} (1.12)	38.30^{ab} (0.96)	40.55^{cd} (0.94)	41.31^{d} (1.22)	41.92^{d} (1.16)	38.27^{ab} (1.29)	38.57^{ab} (1.21)	38.68^{ab} (1.37)	39.14^{bc} (0.82)	40.92^{d} (1.23)	41.19^{d} (0.75)	41.93^{d} (1.76)	***
C18:1c7	-	2.15^{ab} (0.12)	2.26^{ab} (0.53)	1.96^{a} (0.15)	2.16^{ab} (0.21)	2.57^{ab} (0.46)	3.54^{c} (0.97)	2.46^{ab} (0.36)	2.45^{ab} (0.53)	2.69^{b} (0.77)	2.13^{ab} (0.21)	2.36^{ab} (0.21)	2.79^{b} (0.57)	3.77^{c} (0.90)	2.68^{b} (0.57)	***
C18:2n-6	< 15 %	17.18^{h} (1.45)	16.63^{h} (2.14)	16.19^{h} (1.50)	16.11^{h} (1.95)	14.45^{fg} (1.51)	11.83^{ce} (1.06)	13.43^{eg} (1.26)	13.04^{def} (0.97)	11.31^{bc} (0.72)	11.74^{cd} (0.94)	11.02^{bc} (0.86)	10.27^{ac} (0.92)	9.05^{a} (0.77)	10.06^{ab} (1.10)	***
C18:3n-3	-	0.93^{f} (0.06)	0.92^{f} (0.09)	0.92^{f} (0.06)	0.90^{f} (0.09)	0.82^{e} (0.08)	0.69^{ac} (0.06)	0.79^{de} (0.06)	0.80^{de} (0.07)	0.76^{ce} (0.05)	0.75^{ce} (0.05)	0.72^{bcd} (0.04)	0.70^{ac} (0.06)	0.64^{a} (0.06)	0.66^{ab} (0.05)	***
C20:0	-	0.21^{a} (0.03)	0.23^{ac} (0.04)	0.25^{ade} (0.04)	0.25^{bcd} (0.04)	0.22^{ab} (0.03)	0.22^{ab} (0.03)	0.22^{ab} (0.03)	0.24^{ade} (0.03)	0.25^{bcd} (0.04)	0.27^{ce} (0.02)	0.28^{de} (0.03)	0.24^{ade} (0.03)	0.25^{ade} (0.03)	0.25^{ade} (0.03)	***

Means with different superscripts within the same row differ significantly

Value in brackets refer to standard deviation

IG = International guideline; NS = Not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Table 11: Fatty acid composition (%) of subcutaneous fat of the control and experimental groups at different sampling positions (continued).

		CONTROL GROUP Sampling positions							EXPERIMENTAL GROUP Sampling positions							
	IG	A n = 14	B n = 14	C n = 14	D n = 14	E n = 14	F n = 14	G n = 14	A n = 14	B n = 14	C n = 14	D n = 14	E n = 14	F n = 14	G n = 14	Sign. level
C20:1	-	0.58^{ab} (0.06)	0.54^{a} (0.06)	0.63^{bcd} (0.06)	0.63^{bcd} (0.08)	0.61^{ad} (0.06)	0.68^{cdf} (0.07)	0.69^{dg} (0.07)	0.62^{ad} (0.07)	0.59^{ac} (0.05)	0.67^{bcde} (0.09)	0.67^{bcde} (0.05)	0.67^{bcde} (0.07)	0.72^{efg} (0.06)	0.73^{efg} (0.09)	***
C20:2n-6	-	0.61^{ef} (0.08)	0.56^{df} (0.09)	0.61^{ef} (0.09)	0.60^{ef} (0.09)	0.54^{cde} (0.08)	0.47^{bc} (0.07)	0.56^{df} (0.09)	0.49^{bd} (0.04)	0.42^{ab} (0.03)	0.47^{bc} (0.04)	0.45^{b} (0.04)	0.42^{ab} (0.04)	0.37^{a} (0.03)	0.44^{ab} (0.05)	***
C20:3n-6	-	0.06^{ab} (0.04)	0.05^{ab} (0.04)	0.07^{b} (0.04)	0.06^{ab} (0.05)	0.05^{ab} (0.05)	0.02^{a} (0.03)	0.03^{ab} (0.04)	0.07^{b} (0.04)	0.03^{ab} (0.04)	0.04^{ab} (0.04)	0.05^{ab} (0.04)	0.05^{ab} (0.04)	0.02^{ab} (0.04)	0.04^{ab} (0.04)	**
C20:3n-3	-	0.09^{ab} (0.04)	0.09^{ab} (0.03)	0.10^{ab} (0.03)	0.11^{b} (0.01)	0.09^{ab} (0.05)	0.09^{ab} (0.03)	0.08^{ab} (0.04)	0.09^{ab} (0.03)	0.07^{ab} (0.04)	0.07^{ab} (0.04)	0.07^{ab} (0.04)	0.06^{a} (0.05)	0.06^{a} (0.04)	0.05^{a} (0.04)	**
C20:4n-6	-	0.20^{ab} (0.04)	0.20^{ab} (0.04)	0.20^{ab} (0.04)	0.20^{b} (0.04)	0.19^{ab} (0.04)	0.20^{ab} (0.04)	0.18^{ab} (0.03)	0.20^{ab} (0.04)	0.17^{ab} (0.03)	0.17^{ab} (0.04)	0.17^{ab} (0.03)	0.17^{a} (0.03)	0.18^{ab} (0.04)	0.17^{ab} (0.03)	**
C20:5n-3	-	0.23^{ef} (0.03)	0.26^{f} (0.03)	0.24^{ef} (0.03)	0.22^{df} (0.03)	0.20^{de} (0.03)	0.16^{bc} (0.02)	0.19^{cd} (0.04)	0.14^{b} (0.02)	0.15^{bc} (0.03)	0.12^{ab} (0.04)	0.14^{b} (0.02)	0.14^{b} (0.03)	0.09^{a} (0.05)	0.12^{ab} (0.03)	***
C21:0	-	0.01 (0.02)	0.01 (0.02)	0.01 (0.03)	0.02 (0.03)	0.01 (0.03)	0.01 (0.02)	0.00 (0.01)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)	0.03 (0.03)	NS
C22:2n-6	-	0.06^{bc} (0.05)	0.07^{bc} (0.04)	0.07^{c} (0.04)	0.07^{bc} (0.05)	0.05^{ac} (0.04)	0.03^{ac} (0.04)	0.03^{ac} (0.04)	0.02^{ab} (0.04)	0.02^{ab} (0.04)	0.03^{ac} (0.04)	0.02^{ab} (0.03)	0.02^{ab} (0.03)	0.01^{a} (0.02)	0.02^{ab} (0.04)	***
C22:5n-3	-	0.41^{d} (0.05)	0.42^{d} (0.04)	0.41^{d} (0.05)	0.41^{d} (0.04)	0.35^{cd} (0.06)	0.32^{bc} (0.04)	0.32^{bc} (0.10)	0.31^{ac} (0.03)	0.31^{ac} (0.03)	0.31^{ac} (0.03)	0.28^{ab} (0.03)	0.26^{ab} (0.08)	0.25^{a} (0.04)	0.27^{ab} (0.03)	***
C22:6n-3	-	0.45^{hi} (0.06)	0.44^{gi} (0.04)	0.44^{gi} (0.05)	0.42^{fgh} (0.05)	0.37^{def} (0.06)	0.33^{ce} (0.06)	0.38^{eg} (0.05)	0.32^{ce} (0.03)	0.30^{bcd} (0.03)	0.30^{bcd} (0.05)	0.25^{ab} (0.08)	0.24^{ab} (0.08)	0.22^{a} (0.08)	0.28^{ac} (0.05)	***

Means with different superscripts within the same row differ significantly

Value in brackets refer to standard deviation

IG = International guideline; NS = Not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Table 12: Fatty acid ratios of subcutaneous fat of the control and experimental groups at different sampling positions.

		CONTROL GROUP Sampling position							EXPERIMENTAL GROUP Sampling position							
	IG	**A** n = 14	**B** n = 14	**C** n = 14	**D** n = 14	**E** n = 14	**F** n = 14	**G** n = 14	**A** n = 14	**B** n = 14	**C** n = 14	**D** n = 14	**E** n = 14	**F** n = 14	**G** n = 14	**Sign. level**
MUFA (%)	< 57	43.32^{ab} (0.87)	42.83^{a} (1.93)	43.06^{ab} (1.29)	43.72^{ab} (1.15)	46.71^{cd} (0.95)	48.93^{e} (1.31)	47.87^{de} (1.58)	44.28^{ab} (1.80)	44.90^{ac} (2.18)	43.95^{ab} (1.77)	44.97^{bc} (1.19)	47.53^{de} (1.77)	49.16^{e} (1.67)	48.22^{de} (2.42)	***
Dienoic (%)	< 10	17.84^{h} (1.50)	17.26^{h} (2.23)	16.88^{h} (1.58)	16.78^{h} (2.04)	15.04^{fg} (1.56)	12.32^{ce} (1.13)	14.02^{eg} (1.34)	13.55^{def} (0.99)	11.75^{bc} (0.73)	12.24^{bcd} (0.96)	11.48^{bc} (0.91)	10.71^{ac} (0.96)	9.42^{a} (0.79)	10.52^{ab} (1.14)	***
Trienoic (%)	< 1	1.08^{e} (0.11)	1.06^{e} (0.14)	1.08^{e} (0.10)	1.07^{e} (0.12)	0.95^{de} (0.12)	0.80^{ac} (0.09)	0.90^{cd} (0.11)	0.96^{de} (0.10)	0.86^{bcd} (0.06)	0.86^{bcd} (0.08)	0.84^{ad} (0.10)	0.80^{ac} (0.10)	0.72^{a} (0.09)	0.75^{ab} (0.09)	***
Tetraenoic (%)	< 0.5	0.20^{ab} (0.04)	0.20^{ab} (0.04)	0.20^{ab} (0.04)	0.20^{b} (0.04)	0.19^{ab} (0.04)	0.20^{ab} (0.04)	0.18^{ab} (0.03)	0.20^{ab} (0.04)	0.17^{ab} (0.03)	0.17^{ab} (0.04)	0.17^{ab} (0.03)	0.17^{a} (0.03)	0.18^{ab} (0.04)	0.17^{ab} (0.03)	**
Pentaenoic (%)		0.64^{fg} 0.07	0.67^{g} (0.06)	0.65^{g} (0.06)	0.63^{fg} (0.07)	0.56^{ef} (0.08)	0.48^{ce} (0.05)	0.50^{de} (0.10)	0.45^{bcd} (0.04)	0.46^{bcd} (0.05)	0.43^{bcd} (0.06)	0.42^{ac} (0.03)	0.40^{ac} (0.09)	0.34^{a} (0.08)	0.39^{ab} (0.05)	***
Hexanoic (%)		0.45^{hi} (0.06)	0.44^{gi} (0.04)	0.44^{gi} (0.05)	0.42^{fgh} (0.05)	0.37^{def} (0.06)	0.33^{ce} (0.06)	0.38^{eg} (0.05)	0.32^{ce} (0.03)	0.30^{bcd} (0.03)	0.30^{bcd} (0.05)	0.25^{ab} (0.08)	0.24^{ab} (0.08)	0.22^{a} (0.08)	0.28^{ac} (0.05)	***
Penta- + Hexaenoic (%)	< 1	1.09^{g} (0.12)	1.12^{g} (0.09)	1.09^{g} (0.09)	1.05^{fg} (0.10)	0.92^{ef} (0.14)	0.81^{ce} (0.11)	0.88^{de} (0.13)	0.77^{bcd} (0.06)	0.76^{bcd} (0.07)	0.73^{bc} (0.10)	0.67^{ac} (0.11)	0.64^{ab} (0.15)	0.56^{a} (0.15)	0.67^{ac} (0.09)	***
SFA (%)	> 41	35.98^{a} (1.57)	36.92^{ac} (2.00)	37.14^{ad} (2.30)	36.58^{ab} (2.39)	35.68^{a} (1.59)	36.38^{a} (1.48)	35.56^{a} (2.07)	39.51^{dg} (2.35)	40.87^{efg} (2.00)	41.45^{efg} (1.84)	41.17^{efg} (2.13)	39.41^{cdf} (1.78)	39.33^{cdf} (1.65)	39.00^{bcde} (2.17)	***
UFA (%)	< 59	63.53^{c} (1.57)	62.47^{bc} (1.91)	62.32^{bc} (2.25)	62.84^{c} (2.29)	63.82^{c} (1.55)	63.05^{c} (1.52)	63.86^{c} (1.93)	59.76^{a} (2.27)	58.45^{a} (2.02)	57.95^{a} (1.78)	58.13^{a} (2.02)	59.84^{a} (1.76)	60.04^{ab} (1.61)	60.34^{ab} (2.11)	***
PUFA	< 15	20.22^{h} (1.64)	19.64^{h} (2.40)	19.25^{h} (1.69)	19.12^{h} (2.14)	17.11^{fg} (1.73)	14.13^{ce} (1.24)	15.99^{eg} (1.42)	15.49^{def} (1.08)	13.55^{bc} (0.78)	13.99^{bcd} (1.07)	13.16^{bc} (1.09)	12.32^{ac} (1.12)	10.88^{a} (0.87)	12.11^{ab} (1.26)	***
MUFA/SFA		1.21^{bcde} (0.06)	1.16^{ad} (0.09)	1.16^{ad} (0.09)	1.20^{bcde} (0.09)	1.31^{efg} (0.06)	1.35^{fg} (0.08)	1.35^{fg} (0.11)	1.13^{ac} (0.10)	1.10^{ab} (0.11)	1.06^{a} (0.08)	1.10^{ab} (0.08)	1.21^{bcde} (0.09)	1.25^{dg} (0.09)	1.24^{cdf} (0.12)	***
PUFA/SFA		0.56^{f} (0.07)	0.54^{ef} (0.09)	0.52^{df} (0.08)	0.53^{ef} (0.09)	0.48^{de} (0.07)	0.39^{bc} (0.05)	0.45^{cd} (0.06)	0.39^{bc} (0.05)	0.33^{ab} (0.03)	0.34^{ab} (0.03)	0.32^{ab} (0.04)	0.31^{a} (0.04)	0.28^{a} (0.03)	0.31^{a} (0.04)	***
C16:0 + C18:0 (%)		33.47^{a} (1.52)	34.34^{ac} (1.98)	34.77^{ad} (2.32)	34.13^{ab} (2.36)	33.21^{a} (1.63)	34.00^{a} (1.40)	33.24^{a} (2.05)	36.92^{dg} (2.37)	38.25^{efg} (2.07)	38.97^{efg} (1.84)	38.66^{efg} (2.20)	36.93^{dg} (1.85)	36.83^{cdf} (1.73)	36.56^{bcde} (2.24)	***
C16:1 + C18:1/ C16:0 + C18:0		1.20^{ce} 0.06	1.16^{ac} (0.08)	1.16^{ac} (0.10)	1.20^{bcd} (0.09)	1.30^{def} (0.06)	1.31^{eg} (0.07)	1.34^{fg} (0.11)	1.11^{ac} (0.10)	1.09^{ab} (0.10)	1.05^{a} (0.08)	1.08^{ab} (0.08)	1.19^{bcd} (0.09)	1.21^{ce} (0.08)	1.22^{ce} (0.12)	***

Means with different superscripts differ significantly

Value in brackets refer to standard deviation

IG = International guideline; NS = Not significant; *** = $P < 0.001$

Table 12: Fatty acid ratios of subcutaneous fat of the control and experimental groups at different sampling positions (continued).

		CONTROL GROUP Sampling position							EXPERIMENTAL GROUP Sampling position							
	IG	A n = 14	B n = 14	C n = 14	D n = 14	E n = 14	F n = 14	G n = 14	A n = 14	B n = 14	C n = 14	D n = 14	E n = 14	F n = 14	G n = 14	Sign. level
C18:0/C18:2	> 1.2	0.67^{a} (0.09)	0.71^{ab} (0.13)	0.79^{ab} (0.14)	0.74^{ab} (0.15)	0.76^{ab} (0.13)	0.90^{bc} (0.11)	0.83^{ac} (0.12)	1.02^{cd} (0.17)	1.21^{de} (0.14)	1.27^{e} (0.16)	1.30^{e} (0.22)	1.25^{e} (0.15)	1.35^{e} (0.17)	1.29^{e} (0.18)	***
C16:0/C18:2		1.30^{a} (0.15)	1.39^{ab} (0.20)	1.39^{ab} (0.19)	1.41^{ab} (0.22)	1.57^{ac} (0.21)	2.00^{de} (0.27)	1.67^{bc} (0.24)	1.83^{cd} (0.19)	2.19^{ef} (0.16)	2.07^{de} (0.20)	2.24^{ef} (0.25)	2.37^{f} (0.23)	2.75^{g} (0.27)	2.39^{f} (0.31)	***
Double bond index	< 80	88.95^{f} (3.36)	87.36^{ef} (4.12)	86.77^{ef} (3.94)	87.03^{ef} (4.36)	85.41^{ef} (3.55)	81.14^{cd} (2.66)	84.13^{de} (2.99)	79.26^{bc} (3.21)	75.80^{ab} (2.14)	75.62^{ab} (2.51)	74.72^{a} (3.44)	75.46^{ab} (2.69)	73.88^{a} (1.98)	75.83^{ab} (2.53)	***
Peoxidizability index		29.34^{h} (2.12)	28.84^{h} (2.69)	28.35^{h} (1.99)	28.02^{h} (2.14)	25.17^{g} (2.31)	21.45^{cde} (1.70)	23.78^{efg} (1.63)	22.67^{df} (1.34)	20.47^{bd} (0.96)	20.69^{bd} (1.45)	19.45^{bc} (1.82)	18.50^{ab} (1.92)	16.58^{a} (1.43)	18.48^{ab} (1.69)	***
n-6 (%)		18.04^{i} (1.55)	17.44^{i} (2.26)	17.08^{i} (1.62)	16.98^{hi} (2.09)	15.23^{fgh} (1.61)	12.51^{ce} (1.14)	14.20^{eg} (1.39)	13.80^{def} (1.02)	11.93^{bc} (0.74)	12.42^{bcd} (1.02)	11.68^{bc} (0.95)	10.90^{ac} (0.98)	9.62^{a} (0.79)	10.70^{ab} (1.16)	***
n-3 (%)		2.11^{i} (0.17)	2.13^{i} (0.16)	2.10^{i} (0.15)	2.07^{i} (0.10)	1.83^{gh} (0.19)	1.59^{cf} (0.16)	1.75^{fh} (0.13)	1.67^{efg} (0.08)	1.59^{def} (0.11)	1.55^{bce} (0.13)	1.47^{bcd} (0.16)	1.40^{ac} (0.18)	1.25^{a} (0.19)	1.39^{ab} (0.14)	***
n-6/n-3	< 6	8.56 (0.71)	8.18 (0.68)	8.14 (0.77)	8.20 (0.94)	8.37 (0.83)	7.92 (0.89)	8.14 (0.93)	8.27 (0.38)	7.50 (0.55)	8.04 (0.79)	8.03 (0.72)	7.88 (0.82)	7.87 (1.52)	7.75 (0.74)	NS

Means with different superscripts differ significantly

Value in brackets refer to standard deviation

IG = International guideline; NS = Not significant; *** = $P < 0.001$

According to Table 9, the significant differences in extractable fat content (Table 10) of subcutaneous fat were the result of the diet as well as the sampling position. Not the backfat (position B) nor any other position of both the control and experimental groups had extractable fat contents higher than the minimum value of 84 % proposed by Prabucki (1991) for good fat quality. For both the control (81.61 %) and the experimental (82.62 %) groups, position C had the highest extractable fat content. Except for position F, no significant differences were observed between corresponding positions of the control and experimental groups for extractable fat content. Position F had a significantly lower ($P < 0.001$) extractable fat content in the control group (66.29 %) compared to the experimental group (71.67 %). This was also the reason for the significant ($P < 0.01$) interaction between diet and position for extractable fat content (Table 9). It meant that pigs receiving the experimental diet deposited more lipid in position F than pigs receiving the control diet. This interaction was very difficult to explain. If one looked at the iodine value (Table 10) and C18:2 content (Table 11) it was clear that position F tended to be more saturated. It might be possible that there was not enough SFA in the control diet, and therefore less lipid was deposited at that position in the control group.

The significant ($P < 0.001$) difference in fat free dry matter content (Table 10) of subcutaneous fat was only the effect of sampling position differences (Table 9). No significant differences were observed between corresponding positions of the control and experimental groups for fat free dry matter content. In the control group, position B had a significantly higher fat free dry matter content than positions C and G. The only possible explanation for this may be that because the back area (position B) is more active than the hind leg area (Positions C and G), more connective tissue is deposited in the back area. According to Wood, Enser and Fisher (1983), 50 % of the fat free dry matter content of subcutaneous fat is collagen which is a connective tissue. Although not significant, the same trend was observed in the experimental group. This lack of significance may be due to the fact that there was enough SFA available in the experimental diet for deposition and, therefore, the connective tissue was diluted to some extent.

The significant difference ($P < 0.001$) observed in moisture content (Table 10) was the result of diet as well as sampling position (Table 9). No significant differences were observed between corresponding positions of the control and experimental groups for moisture content. Because moisture content was calculated by subtracting extractable fat content and fat free dry matter content from 100, it followed essentially the opposite trend than that of extractable fat content. The argument regarding the significant interaction between position and diet for extractable fat content

will therefore also be valid for the significant ($P < 0.05$) interaction between position and diet for moisture content. Another possible explanation for the lower fat content and higher moisture content observed in position F compared to the other positions in both the control and experimental groups, is that position F was the belly area. The belly area of gilts contain the mammary glands. It is possible that the presence of mammary glands in the fat tissue resulted in the higher moisture and lower lipid content of samples at this position.

The significant ($P < 0.001$) differences in iodine value observed in Table 10 was the result of dietary as well as positional differences (Table 9). Except for positions E, F and G, the backfat (position B) and all the other sampling positions of the control group had iodine values higher than the maximum value of 70 proposed by Barton-Gade (1983, 1987). All sampling positions from the experimental group had iodine values lower than 70 and even lower than the very strict maximum value of 65 proposed by Lea et al. (1970). To facilitate the explanation regarding differences in iodine value between treatments and sampling positions, the effect of iodine value is also visually presented in Figure 3. All sampling positions of the control group had significantly higher iodine values than the corresponding sampling position of the experimental group. In both the control and the experimental group, the lowest iodine value was observed in position F (belly fat) and the highest iodine value in position A. In the control group, the iodine value of position F was significantly lower than that of position A and B while in the experimental group, position F differed significantly only from position A. Barton-Gade, (1983) also reported that anatomical position did have a highly significant effect on iodine value of subcutaneous fat and that especially belly fat had lower iodine value (more saturated fat) than some other positions.

The highly significant ($P < 0.001$) difference observed in refraction index (Table 10) was the result of diet (Table 9). Sampling position had no effect (Table 9). The backfat (position B) as well as all other sampling positions of the control group had unacceptable refraction index values higher than the maximum of 1.4598 proposed by Hart (1956). All sampling positions of the control group had significantly higher refraction index values than the corresponding sampling position of the experimental group. Except for position A, all other sampling positions of the experimental group had acceptable refraction index values of less then the proposed maximum of 1.4598. This means that, from a refraction index point of view, the experimental group had good fat quality at most subcutaneous fat sampling positions and the control group poor fat quality at all positions. No significant differences in refraction index were observed between sampling positions within each of the control and experimental groups. Iodine value was able to discriminate between positions. This

means that the refraction index method is not sensitive enough to detect subtle difference in fat quality.

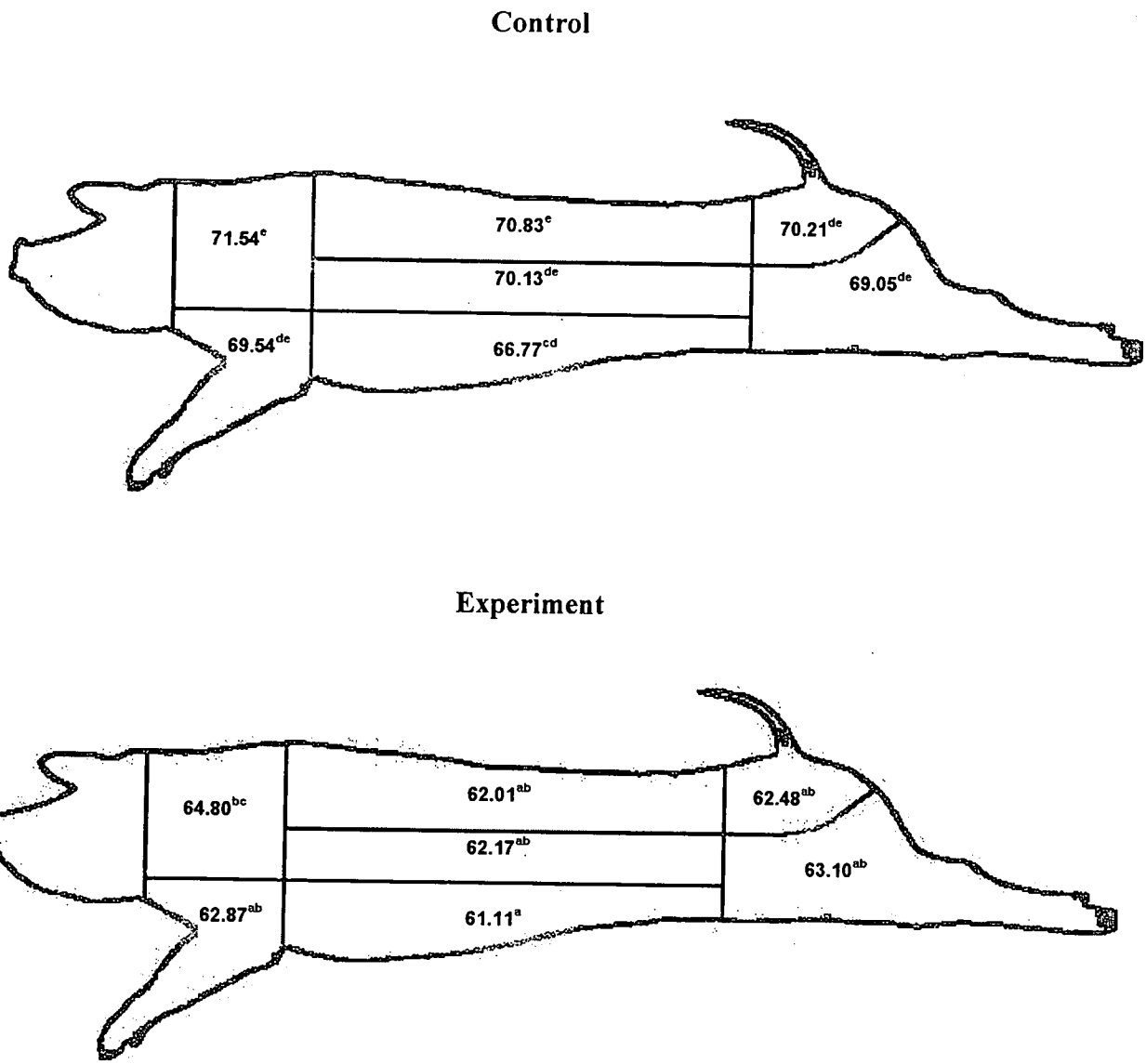

Figure 3: Variation in iodine value of subcutaneous fat at different positions on the carcass. Means with different superscripts differ significantly at $P < 0.001$.

Fatty acid content and fatty acid ratios

Except for C10:0, C12:0, C17:1, C20:3n-6, C20:3n-3, C20:4n-6, C21:0, % tetraenoic fatty acids and n-6/n-3, the significant differences in fatty acid content and fatty acid ratios observed in Tables 11 and 12 were the result of both diet and sampling position (Table 9). A very interesting observation was the presence of a few fatty acids (C10:0, C12:0, C20:3n-6 and C20:3n3) in the

subcutaneous fat that was not present in the feed. As far as C10:0 and C12:0 were concerned, it may be possible that these fatty acids were present in such low concentrations in the feed that the gas chromatograph could not detect it. It is possible that these fatty acids accumulate in the fat tissue during the 55 day feeding period to such an extent that it becomes detectable with the gas chromatograph. Christensen (1962; 1969) reported that medium chain length fatty acids can accumulate in pig fat tissue. The same argument can be valid for the presence of C20:3n-6 and C20:3n3 in the subcutaneous fat but not in the feed. There may, however, also be another explanation for the presence of these two fatty acids in the fat tissue. Christensen (1985) reported that fatty acids from the n-3 and n-6 family can be synthesized from C18:2 and C18:3n-3 fatty acids originating from the diet by desaturation and chain elongation reactions. It was, therefore, possible that the C20:3n-6 and C20:3n-3 fatty acids present in the fat tissue was synthesized in this way.

It is highly unlikely that individual fatty acids occurring at levels below 1 % would have a meaningful effect on the technological properties of the fat tissue. Only individual fatty acids occurring at more than 1 % were therefore discussed. Except for position F, all sampling positions of the control group had significantly lower ($P < 0.001$) C14:0, C16:0 and C18:0 contents than the corresponding sampling positions of the experimental group (Table 11). All sampling positions of the experimental group had a C18:0 content higher than the minimum value of 12 % proposed by Davenel et al. (1999) for good fat quality. Except for position C, all other positions of the control group had C18:0 values of less than 12 % (poor fat quality). No significant differences in C16:0 and C18:0 content were observed between sampling positions within each of the control and experimental group. In the case of C14:0, position C had a significantly lower content of C14:0 than position F for both the control and experimental groups. The significant differences in individual SFA were also reflected in total SFA (Table 12). All sampling positions of the control group had significantly lower total SFA contents than the corresponding sampling position of the experimental group. This means that the high SFA content of the experimental diet was successfully transferred to the subcutaneous fat of the experimental group. Being monogastric animals, it is to be expected that the fatty acid profile of the adipose tissue of pigs will be correlated to a large extent with the fatty acid profile of the diet of the pigs (Nürnberg et al., 1994a; 1994b; Kracht et al., 1996). No significant differences in total SFA contents were observed between sampling positions within each of the control and experimental groups. Positions C and D of the experimental group had total SFA contents of more than 41 % proposed by Häuser and Prabucki (1990) as the minimum for good fat quality. Positions A, E, F and G of the experimental group had total SFA contents of just below 41 % while all sampling positions of the control group had SFA contents (± 35 %) far below 41 %.

No significant differences were observed between corresponding positions of the control and experimental groups for C16:1, C18:1c9, C18:1c7 and total MUFA content (Tables 11 and 12). Although no international guidelines exist for individual MUFA, all the sampling positions of both the control and experimental groups had a total MUFA content of less than the maximum value of 57 % proposed by Häuser and Prabucki (1990) for good fat quality. As far as positional differences were concerned, position C had significantly lower C16:1 and C18:1c9 contents than positions F and G in both the control and experimental groups (Table 11). In the case of C18:1c7, position C had a significantly lower content of this fatty acid than position F in both the control and experimental groups (Table 11). In the case of total MUFA, positions A, B, C and D had significantly lower MUFA contents than positions E, F and G in both the control and the experimental groups (Table 12). If one look at the positions in Figure 1 it appears as if MUFA is preferentially deposited in the lower half of the carcass.

Linoleic acid was the only PUFA occurring at levels higher than 1 %. All sampling positions of the control group had a significantly higher ($P < 0.001$) C18:2 content than the corresponding sampling positions of the experimental group (Table 11). Subcutaneous fat from all sampling positions of the experimental group had a C18:2 content less than the maximum value of 15 % proposed by Whittington et al. (1986) as guideline. Backfat (position B) as well as positions A, C and D of the control group had C18:2 contents more than 15 % while positions E, F and G were below 15 %. As far as positional differences were concerned, positions A, B, C and D of the control group had a significantly higher C18:2 content than positions E, F and G. In the experimental group, position A had a significantly higher C18:2 contents than all the other sampling groups while positions F and G had a significantly lower C18:2 contents than positions A and C. Häuser and Prabucki (1990) proposed a very strict maximum of < 10 % total dienoic fatty acids (C18:2 + C20:2 + C22:2) for good fat quality. Although all sampling positions of the control group had significantly higher ($P < 0.001$) total dienoic fatty acid contents than the corresponding sampling positions of the experimental group (Table 12), only sampling position F of the experimental group had a total dienoic fatty acid content of less than 10 %.

According to Sink et al. (1964) and Jeremiah (1982), most of the major fatty acids like C16:0, C16:1, C18:0, C18:1c9 and C18:2 show a site preference deposition pattern. With the exception of C16:0 and C18:0, it was also observed in this study. Jeremiah (1982) found that the backfat samples had lower concentrations of C16:0 and C18:0 than the belly fat. In this study there was no significant

differences between backfat and belly fat for C16:0 and C18:0. In the case of C16:1 and C18:1c9, the backfat samples (position B) had significantly lower contents of these fatty acids than the belly fat samples (position F) in both the control and the experimental groups. This was also in contrast with the results of Jeremiah (1982) who indicated that the backfat had higher concentrations of C18:1c9 compared to belly fat. Jeremiah (1982) also found that the backfat samples contained higher concentrations of C18:2 than the belly. That finding was confirmed by this study which indicated that backfat samples had a significantly higher ($P < 0.001$) content of C18:2 than the belly fat in both the control and the experimental groups.

According to Table 9, all the significant interactions between diet and sampling position for fatty acids, was for PUFA (C18:2, C18:3n-3 and C20:5n-3). A significant interaction indicated that diet had a greater effect on some of the sampling positions than other with regard to a specific fatty acid's concentration. Careful examination of Table 11 indicated that the C18:2 content of position F in the control group was significantly lower than 5 other positions (A, B, C, D and E) in the same group. The difference in C18:2 content of position F and position B was 4.8 %. The C18:2 content of position F in the experimental group was significantly lower ($P < 0.001$) than that of 4 other positions (A, B, C and D) in this group. The difference in C18:2 content of position F and position B was 2.26 %. This indicated that although the control diet had enough C18:2 available, it was not deposited to the same extent in position F (belly fat) than in position B (backfat). This significant ($P < 0.01$) interaction was therefore the result of the site preference deposition pattern discussed in the previous paragraph. The significant interactions between diet and sampling position for C18:3n-3 ($P < 0.05$) and C20:5 ($P < 0.01$) followed exactly the same pattern as for C18:2. The significantly lower ($P < 0.001$) content of C18:3n-3 and C20:5 in the belly fat (position F) compared to the backfat (position B) indicated that these fatty acids followed exactly the same site preference deposition pattern that Jeremiah (1982) described for C18:2.

Total trienoic fatty acid content (C18:3n-3 + C20:3n-6 + C20:3n-3) of all positions of the experimental group was lower than the maximum value of 1 % proposed by Häuser and Prabucki (1990) (Table 12). In the control group positions A, B, C and D had a total trienoic acid content higher than 1 % while positions E, F and G had values lower than 1 %. The total tetraenoic acid (C20:4) content of all positions of both the control and the experimental groups were lower than the maximum value of 0.5 % that Häuser and Prabucki (1990) proposed for good fat quality. The total content of total pentaenoic + hexaenoic fatty acids (C20:5 + C22:5 + C22:6) of all positions of the experimental group were lower than the maximum value of 1 % that Häuser and Prabucki (1990)

proposed for good fat quality. In the control group, positions E, F and G were also within the 1 % maximum while positions A, B, C and D were above the maximum. According to Prabucki (1991), backfat of good quality should contain less than 59 % total UFA. Only positions B, C and D of the experimental group complied with this requirement while none of the positions of the control group could comply. Warnants et al. (1996) proposed that total PUFA should not exceed 15 % for good quality backfat while Wenk et al. (1990) proposed a maximum of 13 % and Prabucki (1980) a maximum of 12 %. Except for position A, all other sampling positions of the experimental group conformed to the 15 % maximum. Positions E, F and G conformed also to the 13 % maximum while positions F and G could even conformed to the 12 % maximum. In the control group, only position F did conform to the PUFA maximum of 15 %. All other sampling positions in the control group had PUFA contents higher than 15 %.

A very handy fat quality parameter, proposed by Prabucki (1991), was the double bond index. A maximum value of 80 is considered as the cut-off point for good fat quality. All sampling positions of the experimental group had double bond index values of less than 80 while all sampling positions of the control group had double bond index values of more than 80. Except for position A, all other sampling positions of the experimental group had C18:0/C18:2 ratios higher than the minimum value of 1.2 proposed by Honkavaara (1989) for good fat quality. No sampling position in the control group could reach this value. All sampling positions of the experimental group had significantly better ($P < 0.001$) fatty acid ratios (penta + hexaenoic fatty acids, total UFA, total PUFA, C18:0/C18:2, and double bond index) from a fat quality pont of view than the corresponding sampling positions of the control group (Table 12). The exceptions were total trienoic and total tetraenoic fatty acids. No international guidelines exist for the other fatty acid ratios (total pentaenoic fatty acids, total hexaenoic fatty acids, MUFA/SFA, PUFA/SFA, C16:0 + C18:0, C16:1 + C18:1c9 / C16:0 + C18:0 and C16:0/C18:2). All sampling positions of the experimental group had significantly better ($P < 0.001$) fatty acid ratios (total pentaenoic fatty acids, total hexaenoic fatty acids, PUFA/SFA and C16:0/C18:2) from a fat quality point of view than the corresponding sampling positions of the control group (Table 12). Although a few interactions between diet and sampling position for fatty acid ratios were also significant (Table 9), they were all directly related to significant interactions of C18:2, C18:3n-3 and C20:5 that were already discussed. The fatty acid ratio related interactions will, therefore, not be discussed further.

From an iodine value, fatty acid and fatty acid ratio point of view, this experiment was an enormous success. Most fat sampling positions of the control group (pigs receiving a typical South African

finishing diet) did not conform to most of the fat quality requirements. After pigs received the experimental diet (optimized for fat quality) for 55 days, most sampling positions complied with nearly are the requirements in terms of iodine value, content of specific fatty acids and fatty acid ratios for good fat quality. Although no international guideline exists for peroxidizability index, it was calculated for both treatments. All sampling positions of the control group had significantly higher ($P < 0.001$) peroxidizability index values than the corresponding sampling positions of the experimental group (Table 12). That means that subcutaneous fat from all the sampling positions of the control group will be more susceptible to oxidation than subcutaneous fat from the same sampling positions of the experimental group. That implies that the increased deposition of SFA in the experimental group will result in meat products with more resistance to oxidative spoilage. As far as positional differences were concerned, position F had a significantly lower peroxidizability index than positions A, B, C and D for both the control and experimental groups. (Table 12). That implies that belly fat will generally be more resistant to oxidation than, for example, backfat which means that belly fat may be more suitable for use in some meat products (salami and bacon) than backfat.

As mentioned in the introduction of this thesis, consumers are becoming more health conscious. If consumers become aware of the fact that pig diets are supplemented with SFA to improve the saturation of the fatty tissue, some buyer resistance may develop. It was, therefore, decided to look at the health related fatty acid ratios as well. Subcutaneous fat from all the positions of the control group had PUFA/SFA ratios of more than 0.45 proposed by Levnedmiddelstyrelsen (1986) and Honkavaara (1989) as the minimum acceptable value from a health point of view. The PUFA/SFA ratio of all positions of subcutaneous fat of the experimental group was below this value, in other words, unhealthy fat (Table 12). The ratio of PUFA/SFA is, however, an outdated evaluation parameter for fat. Nowadays, consumers, are advised to reduce the intake of omega 6 (n-6) fatty acids and to increase the intake of omega-3 (n-3) fatty acids, in other words, to reduce the ratio of n-6 to n-3 fatty acids in their food (Okuyama, 1997). If one looks at the health properties of the fat tissue of this experiment from this angle, the situation does not look so bleak anymore. All sampling positions of the control group had significantly higher ($P < 0.001$) n-6 contents than the corresponding sampling positions of the experimental group (Table 12). The same significant ($P < 0.001$) trend was observed for the n-3 fatty acids (Table 12). The reduction in n-6 content of the control group compared to the experimental group, was however, much larger, than the reduction of n-3 content of the control group compared to the experimental group. This resulted in the n-6/n-3 ratio not differing significantly between the control and experimental groups. From a n-6/n-3 ratio point of view, the health properties of the experimental group were, therefore, not inferior to that of

the control group. Unfortunately, the n-6/n-3 ratio of both the control and the experimental groups were slightly higher than the minimum value of 6 : 1 proposed by Verbeke et al. (1999). Addition of higher levels of a feedstuff like fish meal, rich in n-3 fatty acids, to the finishing diets, may improve the situation. Because fishmeal is also rich in SFA (C16:0) (Table 2) it will increase the levels of n-3 fatty acids without having a detrimental effect on fat quality.

Correlation between backfat firmness and fat quality parameters

The experimental group had significantly firmer backfat compared to the control group as measured by the Fat Hardness Meter (Table 8). The chemical properties, fatty acid content and fatty acid ratios from a fat quality point of view of subcutaneous fat, were for most parameters significantly better in the experimental group compared to the control group (Tables 10 - 12). It was, however, not possible to determine exactly which fat quality parameter was responsible for the higher firmness of the backfat. Pearson correlation analysis was, therefore, performed between the backfat firmness values and other backfat quality parameters. The results of the Pearson correlation analysis are shown in Table 13. Although many of the backfat quality parameters were significantly correlated with fat hardness, the ones best correlated were MUFA / SFA (r = -0.840460), C16:1+ C18:1c9 / C16:0 + C18:0 (r = -0.830872)) and C18:0 (r = 0.815568). Both MUFA / SFA and C16:1+ C18:1c9 / C16:0 + C18:0 was proposed by Lea et al. (1970) as fat quality parameters.. Unfortunately, no guidelines exist for these fatty acid ratios from a fat quality point of view. It may be a topic for further research to determine the appropriate cut-off points for these fatty acid ratios from a fat quality point of view. The highly positive correlation between C18:0 and fat hardness were expected. It is known that SFA and especially C18:0 are positively correlated with firmness of backfat (Wood & Enser, 1989; Madsen et al. 1992). The lack of a significant correlation between C18:2 content and firmness of backfat is surprising. Roberts and Enser (1988) reported that firmness of backfat was better correlated with C18:2 content than with the concentration of C18:0. The average C18:2 content of the backfat samples used for correlation analyses was 13.97 % because data from the control and experimental groups was pooled for the correlation analysis. This may help to explain the unexpectedly low and not significant interaction between C18:2 content and backfat firmness. According to Cameron et al. (1990), C18:0 is well correlated with fat firmness at a backfat C18:2 content of less than 15 %, but at a backfat C18:2 content of more than 15 %, C16:0 and C18: 2 are better correlated with firmness of backfat.

Table 13: Correlation between fat hardness and other fat quality parameters.

	Correlation coefficient	Sign. level
CARCASS CHARACTERISTICS		
Carcass weight (kg)	0.18	NS
Backfat thickness (mm)	0.27	NS
Lean meat content (%)	-0.27	NS
Physical and chemical properties:		
Extractable fat (%)	0.32	NS
Fat Free Dry Matter (%)	0.05	NS
Moisture(%)	-0.27	NS
Iodine value	-0.54	**
Refraction index	-0.43	*
Minolta *L**	0.63	***
Minolta *a**	-0.74	***
Minolta *b**	-0.67	***
Fatty acid composition (%):		
C10:0	-0.16	NS
C12:0	-0.27	NS
C14:0	-0.06	NS
C15:0	-0.15	NS
C16:0	0.52	**
C16:1	-0.39	*
C17:0	-0.02	NS
C17:1	-0.27	NS
C18:0	0.82	***
C18:1c9	-0.28	NS
C18:1c7	-0.55	**
C18:2n-6	-0.32	NS
C18:3n-3	-0.24	NS
C20:0	0.61	***
C20:1	0.27	NS
C20:2n-6	-0.26	NS
C20:3n-6	0.02	NS
C20:3n-3	0.02	NS
C20:4n-6	-0.61	***
C20:5n-3	-0.34	NS
C21:0	0.03	NS
C22:2n-6	-0.06	NS
C22:5n-3	-0.24	NS
C22:6n-3	-0.28	NS
Fatty acid ratios:		
MUFA (%)	-0.42	*
Dienoic (%)	-0.32	NS
Trienoic (%)	-0.17	NS
Tetraenoic (%)	-0.61	***
Pentaenoic (%)	-0.30	NS
Hexanoic (%)	-0.28	NS
Penta- + Hexaenoic (%)	-0.30	NS
SFA (%)	0.75	***
UFA (%)	-0.75	***
PUFA	-0.32	NS
MUFA/SFA	-0.84	***
PUFA/SFA	-0.43	*
C16:0 + C18:0 (%)	0.75	***
C16:1 + C18:1/ C16:0 + C18:0	-0.83	***
C18:0/C18:2	0.60	***
C16:0/C18:2	0.38	*
Double bond index	-0.52	**
Peroxidizability index	-0.34	NS
n-6 (%)	-0.32	NS
n-3 (%)	-0.28	NS

NS = Not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Accelerated oxidation test (Schaal oven test)

The Schaal oven test was performed to compare subcutaneous fat from the control group with that of the experimental group for susceptibility to oxidation. This test was basically done to imitate and accelerate the oxidation process that would take place in a meat product on the shelf. The results from the accelerated oxidation test are depicted in Figure 4 and Table 14 and clearly illustrated that subcutaneous fat from the experimental group was significantly more ($P < 0.001$) resistant to oxidation than that from the control group. It took fat from the experimental group 12.86 days to reach a peroxide value of 100 compared to 10.71 days for fat from the control group. The higher concentration of UFA in the subcutaneous fat of the control group is responsible for its increased susceptibility to oxidation. Holman (1954) and Grosch (1970) indicated that the more double bonds a fatty acid contains, the faster its oxidation rate will be. The results of this study was also in agreement with the calculated peroxidizability index (Table 12) which predicted a higher susceptibility to oxidation for the control group compared to the experimental group

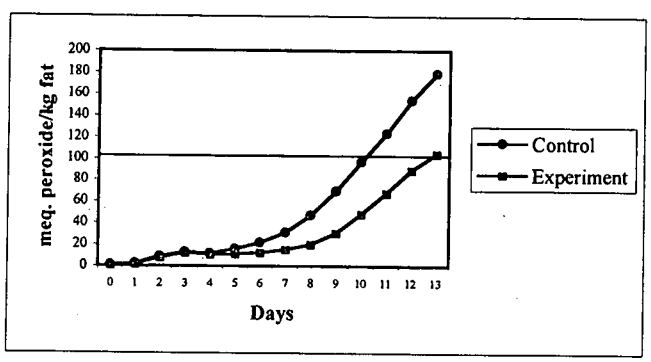

Figure 4 : Pattern and general trend of changes that took place in the peroxide value of backfat of different treatments during 13 days storage of extracted backfat at 63 ± 0.5 °C.

Table 14: Results of accelerated oxidation test (Schaal oven test)

	Control	Experiment	Sign. level
	n = 14	n = 14	
Days to reach peroxide value of 100	10.71 ± 1.20	12.86 ± 0.77	***

*** = P < 0.001

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

GENERAL DISCUSSION

The modern consumer requires pork to be healthy, lean, juicy, fresh, tender and tasty (Bredahl & Andersson, 1998). At present, consumers are more aware of diet, health and nutritional concerns than ever in the past (Verbeke et al., 1999). Pork meat was often controversial in the past because consumers considered it to contain an excess of fat, SFA and cholesterol (Hernández et al., 1998). Consumers were advised to maintain a ratio of PUFA to SFA of at least 0.5 in their diet (Enser et al., 1996). Currently, consumers are advised to reduce the ratio of omega-6 to omega-3 (n-6/n-3) fatty acids in their food (Okuyama, 1997)

The global meat industry responded to this consumer demand by utilizing modern breeding, feeding as well as altered management techniques to produce leaner pigs (Cannon et al., 1995). The percentage of pigs in the P classification group (pigs with a backfat thickness of less than 12 mm) increased drastically over the last 6 years, from 17.5 % in 1993 to 34.3 % of all pigs merchandized at South African auction markets during 2001 (SAMIC, 2002). During 2001, 74.7 % of all pigs merchandized at South African auction markets were classified as P and O (less than 18 mm backfat thickness) carcasses (SAMIC, 2002).

The response of the meat industry to the consumer demand for healthier pork has certain implications. As pigs become leaner, their fat tends to become softer and more unsaturated (Sather et al., 1995). This is good news for the health conscious consumer but may cause serious problems for the meat processor (Affentranger et al., 1996). Increased levels of PUFA in the thin backfat of lean pigs can have detrimental effects on the sensory and technological quality and acceptability of meat products (Warnants et al., 1998).

According to Bruwer (1992) the South African meat industry is unaware or unconcerned about fat quality and the contribution of fat quality to meat quality in both fresh and processed meats. In an attempt to obtain an overview of the situation regarding fat quality of pigs in South Africa, a survey on the backfat quality of South African pigs was conducted by Hugo and Roodt (2002) during which backfat samples from 2107 pig carcasses were collected and analyzed. Hugo and Roodt (2002)

concluded that South African pigs in general but especially those in the P and O classification groups have poor backfat quality. This is of special importance because 74.7 % of all pigs merchandized at South African auction markets during 2001 were classified as P and O carcasses (SAMIC, 2002).

In a literature survey it was determined that fat content or condition may have an effect on all the important meat quality properties namely, sensory properties, nutritional value, technological properties as well as the hygienic and toxicological status of meat and meat products. It was concluded that fat quality is as important as any other meat quality parameter. Any meat quality parameter must be measurable, and for this reason, the different ways of monitoring fat quality were discussed. From the the literature survey it became clear that the requirements for fat quality with regard to processing into meat products vary and are also dependent upon the type of product to be manufactured. The following factors were identified as factors that will influence fat quality of the pig: gender backfat thickness, slaughter weight, age, genetics, PSE condition, DFD condition, growth stimulants, diet and environment. Diet is a factor that can be manipulated very easily.

In monogastric animals like pigs, the SFA and UFA from the diet pass directly through the digestive system and are deposited in the different depots without change. Lipids in various tissues strongly reflect the major dietary fatty acids (Rhee et al., 1990). This means that it is possible to modify the fatty acid composition of pigs by the strategic use of specific dietary fat sources (Morgan, et al., 1992). This implies that dietary manipulation may be used to solve the problem of soft and low quality backfat of pigs, and that is the approach that was followed in this study in an attempt to improve the fat quality of South African pigs.

To identify feed ingredients with the potential to improve fat quality of pigs, a questionnaire was sent to the major companies involved in the formulation, mixing, and supply of pig feeds in South Africa to identify individual feed ingredients available as well as typical inclusion levels of such ingredients. All the available lipid containing feed ingredients were then analyzed for iodine value and fatty acid composition. From this data, barley, feed wheat, hominy chop and poultry byproduct was identified as the ingredients with the most potential to improve the fat quality of pigs. Diets were then formulated with the aim of improving fat quality of South African pigs with the aid of an Excel program that helped with the selection of possible combinations of feedstuffs. A control diet (which represents the situation in South Africa) was formulated with maize and wheaten bran as major ingredients. An experimental diet (with the aim of improving subcutaneous fat quality) was also formulated with feed wheat, barley and poultry byproduct as the major ingredients.

To illustrate experimentally that it is possible to produce baconer pigs in the P and O classification group with good fat quality, a feeding trial was performed by utilizing the diet optimized for fat quality against the control diet. At ± 95 kg live mass the pigs was slaughtered. Subcutaneous fat quality characteristics (iodine value, refraction index, extractable fat content and fatty acid profiles) of the subcutaneous fat of the two treatments were compared. To compare the chemical stability of subcutaneous fat between the two treatments, an accelerated oxidation test was also carried out on fresh subcutaneous fat samples.

The first objective of this experiment, namely the formulation of an experimental diet with the potential to improve the backfat quality of pigs, was successfully achieved. The palmitic (C16:0), stearic (C18:0) and total SFA content of the experimental diet was much higher than that of the control diet. Linoleic (C18:2) and total PUFA occurred at much lower levels in the experimental diet compared to the control diet. This was confirmed by the much lower iodine value of the experimental diet (79.84) compared to the control diet (100.58). The price difference between the two diets was very small. At the time the experiment was performed the experimental diet cost R 1630.85/ton compared to the R 1626.85/ton of the control diet.

No significant differences were observed in growth performance and carcass characteristics between the control and experimental groups which indicated that the diet optimized for fat quality had no negative effect on the growth of the animals or carcass characteristics. Three carcasses from each group received a P classification while four carcasses from each group received an O classification. Minolta colour measurements (L*, a*, and b* values) of the backfat did not differ significantly ($P > 0.05$) between the control and experimental group. The fat hardness measurement of the experimental group was significantly higher than that of the control group, indicating that backfat from the experimental group was firmer than that of the control group. The same significant trend was observed in refraction index value with refraction index of backfat from the experimental group lower than the international guideline of a maximum of 1.4598 while the control group had a value higher than 1.4598. A significant difference was also observed in backfat iodine value with the experimental group having an iodine value lower than the internationally proposed maximum of 70 and the control group having a value higher than this maximum. A site preference deposition pattern was observed for fatty acids and it was found that subcutaneous fat in the neck, shoulder and back areas had higher iodine values (more unsaturated) than subcutaneous fat in the belly area (more saturated). This implies that fatty tissue from certain parts of the carcass may be more suitable for specific meat products than other.

As far as the fatty acid composition were concerned, the experimental group had a significantly higher content of SFA (C16:0) and (C18:0) than the control group. The stearic acid (C18:0) content of the experimental group was higher than the internationally proposed minimum of 12 % while the control group had a lower value. Backfat from the experimental group also had a significantly lower linoleic acid (C18:2) content than that from the control group. Linoleic acid content of backfat from the experimental group was lower than the internationally proposed maximum of 15 % while C18:2 content of the control group was higher than this maximum.

These fatty acid differences were also reflected in the fatty acid ratios and resulted in the experimental group conforming to most international guidelines for fat quality. The experimental group conformed to the following international guidelines for fatty acid ratios while the control group did not: total trienoic fatty acids, total penta- + hexaenoic fatty acids, total UFA, total PUFA, C18:0/C18:2 ratio and double bond index. It was found that fat quality parameters best correlated with fat firmness were MUFA/SFA, C16:1+C18:1/C16:0+C18:0 and C18:0. An interesting observation was the n-6/n-3 ratio which did not differ significantly between the two groups. This means that although subcutaneous fat from the experimental group was much more saturated than that from the control group, it was not inferior from a health point of view.

The results from the accelerated oxidation test illustrated that subcutaneous fat from the experimental group was significantly more resistant to oxidation than that from the control group. It took fat from the experimental group 12.86 days to reach a peroxide value of 100 compared to 10.71 days for fat from the control group.

FINAL REMARKS

The research clearly illustrated that it is possible to formulate diets with the potential of improving fat quality, with feed ingredients available in South Africa, in a cost effective manner. It was illustrated experimentally that by utilizing such a diet it is possible to produce baconer pigs in the P and O classification groups with subcutaneous fat quality conforming to most international guidelines.

An aspect that must be kept in mind is that care will have to be exercised when reformulating pig diets to ensure that the fatty acid profile of adipose tissue is still acceptable from a health point of view. A compromise may be the answer and, therefore, it may even be necessary to differentiate

more strongly between pigs intended for the fresh meat market and those for the processing industry. The idea of modification of the fatty acid profile of animal tissues in an attempt to produce new "designer" or "functional" meats are not so far-fetched anymore. It seems perfectly possible to utilize dietary manipulation to design pigs with a higher SFA content for the processing industry or pigs with a high content of omega-3 fatty acids for the fresh meat market. As South Africa is reentering the international meat trade arena, meat quality is going to become more important and measurement of meat quality parameters like fat quality will become a necessity.

FUTURE RESEARCH

Although the database and Excel program that was developed to predict fat content, iodine value, fatty acid content and fatty acid ratios was not 100 % accurate, it showed a lot of potential. A challenge would be to expand the database and to refine the program that did the predictions. With a larger database (more replications of each feedstuff) the accuracy of estimations will definitely increase. By including additional feedstuffs to the database it may even be possibly to identify feedstuffs from plant origin with high enough SFA content to act as an alternative for poultry byproduct. The inclusion of fatty acid profiles in diet formulation can then become a standard practice. Currently only protein, fat, fibre, minerals and amino acids are taken into consideration when formulating pig diets. The database and prediction program can even be used to formulate diets rich in omega-3 fatty acids and conjugated linoleic acid (CLA) for the fresh meat market and health conscious consumer.

CHAPTER 6

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CHAPTER 7

APPENDIXES

APPENDIX 1

COVERING LETTER

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08 October / Oktober 2001

Dear AFMA member / *Geagte AFMA Lid*

Help with research project / *Hulp met navorsingsprojek*

Francois van Schalkwyk is a M.Sc. Agric student in Food Science at the University of the Free State. He must obtain information on feed ingredients used in South African pig rations as part of his research. Your help with his research project will be greatly appreciated. After completion of the project a report on the results will be communicated to you. For further inquiries, contact me at the above address. / *Francois van Schalkwyk is 'n M.Sc. Agric student in Voedselwetenskap aan die Vrystaatse Universiteit. As deel van sy studie moet hy inligting versamel oor voerbestandele wat in Suid-Afrikaanse varkrantsoene gebruik word. U hulp met sy navorsingsprojek sal opreg waardeer word. Na voltooiing van die projek sal daar ook aan u terugvoer verskaf word oor die resultate. Indien u enige navrae het, kontak my gerus by bostaande adres.*

If you are prepared to complete the attached questionnaire, please mail it to: / *Indien u bereid is om die aangehegte vraelys te voltooi kan u dit pos aan:*

Arno Hugo
Department of Food Science (72) / *Departement Voedselwetenskap (72)*
University of the Free State / *Universiteit van die Vrystaat*
Bloemfontein
9300

Kind regards / *Vriendelike groete*

Arno Hugo
Department of Food Science UFS / *Departement Voedselwetenskap UV*

APPENDIX 2

QUESTIONNAIRE FOR RESEARCH PROJECT / *VRAELYS VIR NAVORSINGSPROJEK:*

IMPROVEMENT OF FAT QUALITY OF SOUTH AFRICAN PORK / *VERBETERING VAN VETKWALITEIT VAN SUID - AFRIKAANSE VARKVLEIS*

It is well known that the modern consumer prefers meat with the minimum fat. This caused pig producers to strive towards the production of pigs with the minimum fat cover. This trend towards lean pigs resulted in the production of pigs with lower fat quality. Lower fat quality implies that the backfat of leaner pigs are richer in poly-unsaturated fatty acids with a soft and floppy consistency which cause the fat layer to separate from the muscle very easily. Poor fat quality causes problems in the manufacturing of products like bacon and salami. The high poly-unsaturated fat content is also responsible for a reduction in shelf life of pork because poly-unsaturated fatty acids are more susceptible to oxidation and may cause a rancid taste in the meat . A survey which was recently performed by the Department Food Science at the University of the Free State have shown that out of the 2107 pigs which have been sampled, only 36 % of the pigs had a iodine value of less than 70 in their backfat. If the iodine value of the backfat is higher than 70, the fat is considered to be unacceptable for use in especially processed meat products. Because a pig is a monogastric animal it deposits the fat which it consumes unchanged into its fat reserves. That is why it is possible to manipulate the composition of the fat by changing the diet of the pig to contain more saturated fatty acids. This will result in fat that is of a harder consistency and with a longer shelf life. It may, therefore, be possible to produce pigs with better backfat quality without increasing the backfat thickness or the fat percentage of the carcass. / *Dit is wel bekend dat die moderne verbruiker vleis verkies wat die minimum vet bevat. Dit het tot gevolg dat varkprodusente daarna streef om varke te produseer met so min as moontlik vetbedekking. Die tendens het egter veroorsaak dat die vetkwaliteit van die varke agteruit gegaan het. Met laer vetkwaliteit word bedoel dat die rugvet van maerder varke ryk is aan polie-onversadigde vetsure en dus 'n pap voorkoms het wat veroorsaak dat die vetlaag byvoorbeeld maklik skei van die spierlaag en probleme veroorsaak tydens die vervaardiging van produkte soos spek en salamie. Die polie-onversadigde vette veroorsaak ook dat die rakleeftyd van die vleis aansienlik verkort aangesien polie-onversadigde vette meer vatbaar is vir oksidasie en dus 'n galsterige smaak in die vleis veroorsaak. 'n Opname wat onlangs uitgevoer is deur die Departement Voedselwetenskap aan die Vrystaatse Universiteit het getoon dat rugvet van slegs 36% van die 2107 varke wat bemonster is, jodiumwaardes van minder as 70 gehad het. Indien die jodiumwaarde van rugvet die waarde van 70 oorskry, word die vet as onaanvaarbaar vir gebruik in veral geprosesseerde vleisprodukte beskou. Aangesien 'n vark 'n monogastriese dier is en dus die vetsure wat in die voer voorkom net so in die vetreserwes deponeer, is dit moontlik om die samestelling van die rugvet te manipuleer deur die voersamestelling van die vark so saam te stel dat die voer 'n groter hoeveelheid versadigde vetsure bevat. Die varkvet sal dus meer versadigde vette bevat wat sal veroorsaak dat die varkvet fermer is en ook 'n langer rakleeftyd het. Dus behoort varke geproduseer te kan word met 'n beter kwaliteit rugvet sonder om die rugvetdikte en die persentasie vet in die karkas te verhoog.*

The aim of this research project is to identify feeds with the potential to improve the fat quality of pigs. This information will then be used to reformulate growth rations economically. A feeding experiment will then be executed to determine whether it is possible to produce more pigs in the P, O and R classification groups with acceptable fat quality. / *Die doel van hierdie navorsingsprojek is om voerbestanddele identifiseer wat die potensiaal het om die vetkwaliteit van varke te verbeter. Hierdie inligting sal dan gebruik word om groeirantsoene ekonomies te herformuleer. 'n Voedingsproef sal dan gedoen word waarin vasgestel sal word of dit moontlik is om meer varke in die P,O en R klassifikasiegroepe te produseer met aanvaarbare vetkwaliteit.*

This project cannot be completed successfully without your cooperation. That is why we are kindly requesting you to complete the following questionnaire, so that we can determine which fat containing ingredients are used in South African pig rations. The column which is marked "typical use levels" is optional, if you feel that such information is too sensitive, you may ignore it. All the information that you supply will be considered as confidential. When writing up and summarizing the results, feed suppliers will only be identified by a code. We will also appreciate it if you could give us small samples of ± 250 g each of the fat containing feedstuffs as well as already mixed growing rations so that we can determine their iodine values. Your cooperation and help is appreciated. Thank you very much. / *Hierdie navorsingsprojek sal nie suksesvol deurgevoer kan word sonder u samewerking nie. Ons wil u daarom vriendelik versoek om onderstaande vraelys te voltooi ten einde ons in staat te stel om vas te stel watter vetbevattende bestanddele in varkrantsoene in Suid - Afrika gebruik word. Die kolom oor insluitingsvlakke is opsioneel, as u voel dat inligting oor insluitingsvlakke te sensitief is om bekend te maak kan u dit ignoreer. Alle inligting sal egter vertroulik hanteer word. Met die opskryf van die resultate sal daar net 'n kode aan elke voerverskaffer toegeken word. Ook sal dit waardeer word indien u aan ons klein monsters (± 250 g) van vetbevattende voerbestanddele wat u gemerk het op die vraelys en in u fabriek beskikbaar het asook klaargemengde groeirantsoene, beskikbaar sal stel vir jodiumwaardebepalings. U samewerking en hulp word opreg waardeer. Baie dankie.*

QUESTIONNAIRE ON THE USE OF DIFFERENT FAT CONTAINING FEEDSTUFFS IN PIG RATIONS / *VRAELYS OOR GEBRUIK VAN VERSKILLENDE VETBEVATTENDE VOERBESTANDDELE IN VARKRANTSOENE*

	HOW OFTEN DO YOU USE ? / *HOE GEREELD GEBRUIK U ?*			
FEEDSTUFF / *VOERBESTANDDEEL*	OFTEN / *GEREELD*	SOMETIMES / *SOMS*	NEVER / *GLAD NIE*	TYPICAL USE LEVEL (%) / *TIPIESE GEBRUIKSVLAKKE (%)*
Acid oil / *Suurolie*				
Apple pomace / *Appelmoes*				
Acorn meal / *Akkermeel*				
Acorns / *Akkers*				
Algae / *Alge*				
Bagasse				
Barley / *Gars*				
Blood meal / *Bloedmeel*				
Bone meal / *Beenmeel*				
Brewers grain / *Brouersgraan*				
Barley brewerersgrain / *Gars brouersgraan*				
Sorgum brewersgrain / *Sorgum brouersgraan*				
Canola fullfat / *Canola volvet*				
Canola oilcake (Imported) / *Canola oliekoek (Ingevoer)*				
Canola oilcake (Local) / *Canola oliekoek (Plaaslik)*				
Canola oilcake / *Canola oliekoek*				
Coconut fat / *Kokosneut olie*				
Carcass meal / *Karkasmeel*				
Cassava meal / *Kasawameel*				
Citrus meal / *Sitrusmeel*				
Copra meal / *Koprameel*				
Copra oilcake / *Kopra-oliekoek*				
Cotton oilcake (Local) / *Katoensaad oliekoek (Plaaslik)*				
Cotton oilcake (imported) / *Katoensaadoliekoek (Ingevoer)*				

	HOW OFTEN DO YOU USE ? / *HOE GEREELD GEBRUIK U ?*			
FEEDSTUFF / *VOERBESTANDDEEL*	OFTEN / *GEREELD*	SOMETIMES / *SOMS*	NEVER / *GLAD NIE*	TYPICAL USE LEVEL (%) / *TIPIESE GEBRUIKSVLAKKE (%)*
Cotton seed (Imported) / *Katoensaad (Ingevoer)*				
Cotton seed (Local) / *Katoensaad (Plaaslik)*				
Cotton seed / *Katoensaad*				
Cotton seed oilcake / *Katoensaadoliekoek*				
Chestnuts / *Kastaiings*				
Cowpeas / *Akkerboon*				
Defatted maize Germ meal / *Ontvette mieliekiemmeel*				
Fat (cattle) / *Beesvet*				
Fat (poultry) / *Vet (pluimvee)*				
Fat (pig) / *Varkvet*				
Fat (plant oil) / *Plantolie*				
Fat / *Vet*				
Feather meal / *Veremeel*				
Feed wheat / Voerkoring				
Fish meal (Local) / *Vismeel (Plaaslik)*				
Fish meal / *Vismeel*				
Fullfat soya / *Volvetsoja*				
Fullfat soybean meal / *Volvetsojaboonmeel*				
Fresh sunflower oil / *Vars sonneblomolie*				
Groundnut hay / *Grondboonhooi*				
Groundnut oilcake (Imported) / *Grondboon oliekoek (Ingevoer)*				
Groundnut oilcake (Local) / *Grondboon oliekoek (Plaaslik)*				
Hominy chop				
Colostrum / *Kolostrum*				
Linseed oil / *Lynsaadolie*				
Lucern hay / *Lusernhooi*				
Lucern meal / *Lusernmeel*				
Lupine / *Lupiene*				
Lupin meal / *Lupiene meel*				
Maize (grain) / *Mielies (graan)*				
Maize Germ meal/ *Mieliekiemmeel*				
Maize germ oilcake / *Mieliekiem-oliekoek*				
Maize gluten feed / *Mielie glutenvoer*				
Maize gluten meal / *Mielie glutenmeel (20%)*				
Maize gluten meal / *Mielie glutenmeel (60%)*				
Maize meal / *Mieliemeel*				
Maize Screenings / *Mieliesifsels*				
Meat & Bone meal / *Vleis-en-beenmeel*				
Naked oats / *Kaalhawer*				
Oats / *Hawer*				
Palm Kernel Oilcake (Local) / *Palm oliekoek (Plaaslik)*				
Poultry by-product / *Pluimveebyproduk*				
Rapeseed / *Raapsaad*				
Rapeseed oil / *Raapsaad olie*				

	HOW OFTEN DO YOU USE ? / *HOE GEREELD GEBRUIK U ?*			
FEEDSTUFF / *VOERBESTANDDEEL*	OFTEN / *GEREELD*	SOMETIMES / *SOMS*	NEVER / *GLAD NIE*	TYPICAL USE LEVEL (%) / *TIPIESE GEBRUIKSVLAKKE (%)*
Rice Bran / *Ryssemels*				
Sorghum				
Soya meal / *Soja meel*				
Soya oilcake (Imported) / *Soja-oliekoek (Ingevoer)*				
Soya oilcake (Local) / *Soja-oliekoek (Plaaslik)*				
Soya oilcake / *Soja-oliekoek*				
Sterilized poultry manure / *Gesteriliseerde hoendermis*				
Sunflower hulls/*Sonneblomdoppe*				
Sunflower oilcake (Imported) / *Sonneblomoliekoek (Ingevoer)*				
Sunflower oilcake (Local) / *Sonneblomoliekoek (Plaaslik)*				
Sunflower oilcake / *Sonneblomoliekoek*				
Sunflower Seed (with hulls) / *Sonneblompitte (met doppe)*				
Skimmed milk powder / *Afgeroomde-melkpoeier*				
Silo fodder / *Kuilvoer*				
Triticale / *Korog*				
Used sunflower oil / *Gebruikte sonneblomolie*				
Wheaten bran / *Koringsemels*				
Wheaten Flour / *Koringmeel*				
Wheaten Straw / *Koringstrooi*				
White fish meal / *Witvismeel*				
OTHER / *ANDER*				
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CHAPTER 8

SUMMARY

The objectives of this study were to identify feed ingredients with the potential to improve fat quality of pigs and to illustrate experimentally that it is possible to produce baconer pigs in the P and O classification groups with good fat quality.

A questionnaire was sent to animal feed companies in South Africa to identify individual feed ingredients available as well as typical inclusion levels of such ingredients. All available lipid containing feed ingredients were then analyzed for iodine value and fatty acid composition. From this data, individual feedstuffs with the potential of improving fat quality was identified. A diet was formulated with the aim of improving fat quality of pigs cost effectively. A feeding trial was performed, comparing a control diet with the one optimized for fat quality. Fourteen Large White x Duroc gilts weighing on average ± 43 kg were randomly divided into two groups of seven pigs each and assigned to either the control or experimental diet. Pigs were provided with *ad libitum* access to feed and water. Feed intake was measured daily and weight was recorded every week. At ± 95 kg live weight the pigs were slaughtered. Firmness of the subcutaneous fat was measured and colour of the backfat was determined. Lipid quality characteristics were determined on control and experimental pigs and compared with international guidelines for good fat quality. Differences in parameters between treatments were statistically compared.

The first objective of this experiment, namely the formulation of an experimental diet with the potential to improve the backfat quality of pigs, was successfully achieved. The experimental diet had a more saturated fatty acid profile than the control diet as indicated by iodine value and fatty acid analysis. No significant differences ($P > 0.05$) were observed in growth performance and carcass characteristics between the control and experimental groups. All pig carcasses were classified as either P or O carcasses. Minolta colour measurements (L*, a*, and b* values) of the backfat did not differ significantly ($P > 0.05$) between the control and experimental group. The fat hardness measurement of the experimental group was significantly higher ($P < 0.01$) than that of the control group, indicating that backfat from the experimental group was firmer than that of the control group. The same significant ($P < 0.001$) trend was observed in refraction index value with refraction index of backfat from the experimental group lower than the internationally proposed maximum of 1.4598 while the control group had a value higher than 1.4598. A significant difference ($P < 0.001$) was also

observed in backfat iodine value with the experimental group having an iodine value lower than the internationally proposed maximum of 70 and the control group having a value higher than this maximum. Anatomical differences was found in subcutaneous fat saturation. Backfat had higher iodine values (more unsaturated) than subcutaneous fat in the belly area (more saturated). As far as the fatty acid composition were concerned, the experimental group had a significantly higher ($P < 0.001$) content of saturated fatty acids (C16:0 and C18:0) than the control group. Linoleic acid content of subcutaneous fat from the experimental group was lower than the internationally proposed maximum of 15 % while C18:2 content of the control group was higher than this maximum. These fatty acid differences were also reflected in the fatty acid ratios and resulted in the experimental group conforming to most international guidelines for fat quality. The experimental group conformed to the following international guidelines for fatty acid ratios while the control group did not: total trienoic fatty acids, total penta- + hexaenoic fatty acids, total UFA, total PUFA, C18:0/C18:2 ratio and double bond index.

Key words: pig feedstuffs, diet, subcutaneous fat, iodine value, fatty acids

CHAPTER 9

OPSOMMING

Die doelwitte van hierdie studie was om voerbestandele te identifiseer wat die potensiaal het om vetkwaliteit van varke te verbeter en om eksperimenteel aan te toon dat dit moontlik is om spekvarke in die P en O klassifikasiegroepe te produseer wat beskik oor goeie vetkwaliteit.

'n Vraelys is gestuur aan veevoermaatskappye in Suid Afrika ten einde vas te stel watter voerbestanddele beskikbaar is vir varkvoeding en teen watter vlakke dit gebruik word. Alle vetbevattende voerbestanddele is toe ontleed vir jodiumwaarde en vetsuursamestelling. Uit hierdie data is individuele voerbestanddele wat die potensiaal het om vetkwaliteit te verbeter, geïdentifiseer. Daarna is 'n dieet wat ten doel gehad het om vetkwaliteit te verbeter, kostedoeltreffend geformuleer. 'n Voedingsproef is toe uitgevoer waarin 'n kontrole dieet vergelyk is met die eksperimentele dieet wat geoptimiseer is vir vetkwaliteit. Veertien Groot Wit x Duroc sôe wat gemiddeld ± 43 kg geweeg het is ewekansig verdeel in twee groepe van sewe varke elk. Een groep is toegewys aan die kontrole dieet en die ander aan die eksperimentele dieet. Varke het *ad libitum* toegang gehad tot voer en water. Voerinname is daagliks gemonitor en varke is weekliks geweeg. By 'n lewende gewig van ± 95 kg is die varke geslag. Fermheid en kleur van rugvet is gemeet. Vetkwaliteitseienskappe van kontrole en eksperimentele varke is bepaal en vergelyk met internasionale riglyne vir goeie vetkwaliteit. Verskille tussen behandelings is statisties vergelyk.

Die eerste doelwit van hierdie studie, naamlik die formulering van 'n eksperimentele dieet met die vermoë om vetkwaliteit van onderhuidse vet van varke te verbeter, is suksesvol afgehandel. Die eksperimentele dieet het 'n meer versadigde vetsuurprofiel as die kontrole dieet gehad, soos aangetoon deur jodiumwaardes en vetsuursamestelling. Geen betekenisvolle verskille ($P > 0.05$) is waargeneem in groeiprestasie en karkaseienskappe tussen die kontrole en eksperimentele groepe nie. Alle karkasse is geklassifiseer as P of O karkasse. Minolta kleurmetings (L*, a*, en b* waardes) van die rugvet het nie betekenisvol ($P > 0.05$) verskil tussen die kontrole en eksperimentele groepe nie. Die vethardheidsmetings van die eksperimentele groep was betekenisvol ($P < 0.01$) hoër as die van die kontrolegroep, wat aandui dat rugvet van die eksperimentele groep fermer was as die van die kontrolegroep. Dieselfde betekenisvolle ($P < 0.001$) neiging is ook waargeneem in refraksie-indekswaarde met refraksie-indeks van die onderhuidse vet van die eksperimentele groep laer as die internasionaal voorgestelde maksimum van 1.4598 terwyl die kontrolegroep 'n waarde gehad het van

meer as 1.4598. 'n Betekenisvolle ($P < 0.001$) verskil is ook waargeneem in jodiumwaarde van onderhuidse vet met die eksperimentele groep wat 'n jodiumwaarde laer as die internasionaal voorgestelde maksimum van 70 gehad het terwyl die kontrolegroep 'n waarde hoër as hierdie maksimum gehad het. Anatomiese verskille is ook gevind in onderhuidse vet versadigdheid. Rugvet het hoër jodiumwaardes (meer onversadig) gehad as onderhuidse vet in die buik area (meer versadig). Wat betref vetsuursamestelling het die eksperimentele groep 'n betekenisvol ($P< 0.001$) hoër inhoud van versadigde vetsure (C16:0 en C18:0) as die kontrolegroep gehad. Linoleïensuur van die onderhuidse vet van die eksperimentele groep was laer as die imternasionaal voorgestelde maksimum van 15 % terwyl C18:2 inhoud van die kontrolegroep hoër was as hierdie maksimum. Hierdie vetsuurverskille is ook gereflekteer in die vetsuurverhoudings en het daartoe gelei dat die eksperimentele groep voldoen het aan meeste internasionale riglyne vir vetkwaliteit. Die eksperimentele groep het voldoen aan die volgende internasionale riglyne vir vetkwaliteit en die kontrolegroep nie: totale trienoïese vetsure, total penta- + hexaenoïese vetsure, totale onversadigde vetsure, totale polie-onversadigde vetsure, C18:0/C18:2 verhouding en dubbelbindingsindeks.

Sleutelwoorde: vark, voerbestanddele, rantsoen, onderhuidse vet, jodiumwaarde, vetsure