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BACKFAT QUALITY OF SOUTH AFRICAN PIGS: A MEAT PROCESSING PERSPECTIVE

by

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Submitted in fulfilment of the requirements for the degree of

MAGISTER SCIENTIAE

in the

Department of Microbial, Biochemical and Food Biotechnology
Faculty of Natural and Agricultural Sciences
University of the Free State

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May 2003

Universiteit van die
Oranje-Vrystaat
BLOEMFONTEIN
13 FEB 2004
UOVS SASOL BIBLIOTEEK

To

ARNO, PIETER, MY MOTHER AND LATE FATHER

Thanks for teaching me the meaning of dedication
and perseverance and for believing in me.
You are all an inspiration in my life!

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ACKNOWLEDGEMENTS

I wish to thank the following:

Almighty God, for using me on earth and giving me the opportunity, strength and will to make a contribution to His Creation;

Dr. Gustav Klingbiel, from the Red Meat Research and Development Trust for much needed financial support. It is highly appreciated;

Messrs. Charl Bloem, Carraig Patterson, Louis Booysen and the staff of the Deboning Section at Enterprise Pork Packers for their good grace and allowing us to use their abattoir and always making us feel at home. The donation of the backfat and carcass grading information (especially Erika van Heerden for her friendly, capable assistance in providing us with the grading information) is acknowledged with gratitude;

Dr. Arno Hugo, Department of Food Science, University of the Free State, for having faith in me and inspiring me through his example of dedication and integrity. His more than able assistance and guidance in general were inestimable, especially with the statistical analyses as well as the operation of the Gas Chromatograph and during the sampling period of the study. His encouragement throughout my study is highly appreciated. Without him this study would not have been possible;

Pieter Botha, for his love, patience, understanding, constant encouragement and advice. His willing and more than able assistance with computer problems was priceless. I also wish to thank him for the use of his computer and printer. You are my light in the darkness;

My mother, Thora Roodt, for her love, tolerance, constant encouragement, interest, support, understanding and for proof-reading this thesis. Thanks for always "being there", you're the best mom anyone could ask for!;

My late father, Hennie Roodt, for his love and for always believing in me. I hope he would have been proud of me. He taught me the meaning of integrity and service to mankind;

Ms Rosalie Hunt, Department of Food Science, University of the Free State, for her interest and encouragement and for keeping the laboratory running by ordering and purchasing reagents and for arranging for the speedy repair of defect equipment so that the study could progress without any unnecessary loss of time;

Dr. Celia Hugo, Department of Food Science, University of the Free State, for her friendship, love, support and encouragement throughout my study as well as for assistance in revision of the thesis. Especially for the imposition on her husband's time, which she sacrificed so graciously. Thank you for being such a special person;

Ms. Liana van Wyk, my greatest supporter, and truly BEST friend, for her love, support, encouragement and unshakable faith in me. I can always count on you!;

Mss. Maryna de Wit, Carina Bothma and Elaine Sansom, Department of Food Science, University of the Free State, for their friendship, continuous interest, support and encouragement during my study and the use of the Sensory laboratory freezer;

Danie and Magriet Botha, their children and grandchildren for their love and interest and encouragement during the study;

Mr. Franz-Rouen Allers, from Irene Guesthouse, for being my home away from home during the sampling periods;

The local radiostation, OFM, for keeping me company during my long working hours;

The staff of the Department of Food Science, University of the Free State, who took an interest in my study;

Anyone, not mentioned here, who contributed to this study in any way.

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
BF	Backfat
BFT	Backfat thickness
CHD	Coronary heart disease
CLA	Conjugated linoleic acid
COMA	Committee on the Medical Aspects of Food Policy
COP	Cholesterol oxidation products
DB	Double bond(s)
DBI	Double bond index
DFD	Dark, firm and dry meat
EFC	Extractable fat content
FA	Fatty acid(s)
FAME	Fatty acid methyl esters

Individual FAME:

Abbreviation	*Common name*	*Complete Formula*	*Systematic (IUPAC) name*
C12:0	Lauric	C12:0	Dodecanoic
C14:0	Myristic	C14:0	Tetradecanoic
C15:0	Pentadecylic	C15:0	Pentadecanoic
C16:0	Palmitic	C16:0	Hexadecanoic
C16:1	Palmitoleic	C16:1c9	cis-9-Hexadecenoic
C17:0	Margaric	C17:0	Heptadecanoic
C17:1	Heptadecenoic	C17:1c10	cis-10-Heptadecenoic
C18:0	Stearic	C18:0	Octadecanoic
C18:1c7	Vaccenic	C18:1c7	cis-7-Octadecenoic
C18:1t7	Octadecenoic	C18:1t7	trans-7-Octadecenoic
C18:1c9	Oleic	C18:1c9	cis-9-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
C18:3n-6	λ-Linolenic	C18:3c6,9,12(n-6)	cis-6,9,12-Octadecatrienoic
C19:0	Nonadecanoic	C19:0	Nonadecanoic
C20:0	Arachidic	C20:0	Eicosanoic
C20:1	Eicosenoic	C20:1c11	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

Individual FAME:

Abbreviation	*Common name*	*Complete Formula*	*Systematic (IUPAC) name*
C22:0	Behenic	C22:0	Docosanoic
C22:1	Erucic	C22:1c13	cis-13-Docosenoic
C22:2	Docosadienoic	C22:2c13,16(n-6)	cis-13,16-Docosadienoic
C22:5	Docosapentaenoic	C22:5c7,10,13,16,19(n-3)	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
C24:0	Lignoceric	C24:0	Tetracosanoic
C24:1	Nervonic	C24:1c15	cis-15-Tetracosenoic

ABBREVIATION	**DESCRIPTION**
FFA	Free fatty acids
FFDM	Fat-free dry matter
FT	Fat thickness
GC	Gas chromatography
HDL	High-density lipoprotein
HGP	Hennesey Grading Probe
IV	Iodine value
IMF	Intramuscular fat
LDL	Low-density lipoprotein
LMC	Lean meat content
MAP	Modified atmosphere packaging
MUFA	Mono-unsaturated fatty acid(s)
n-3	Omega-3
n-6	Omega-6
NIR	Near infrared
NMR	Nuclear magnetic resonance
PI	Peroxidizabilty index
P/S	Polyunsaturated fatty acid/Saturated fatty acid ratio
PSE	Pale, soft and exudating meat
PUFA	Polyunsaturated fatty acid(s)
RI	Refraction index
SFA	Saturated fatty acid(s)
SFC	Solid fat content
TAG	Triacylglycerol(s) / Triglyceride(s)
TBA	Thiobarbituric acid
UFA	Unsaturated fatty acid(s)
UK	United Kingdom
USA	United States of America
WHC	Water holding capacity
WOF	Warmed-over flavour

CHAPTER 1

INTRODUCTION

Pork is by far the most important meat product globally. In 2000, the total world pig population were estimated to be about 1 billion. In 2020 estimates suggest this will increase to about 1.4 billion pigs. Current global annual per capita consumption is about 16 kg (Wenk, 2000). South Africa is 93 % self sufficient in pork supply with a commercial sow herd of 100 000 and an annual slaughtering of approximately 2 million pigs (Anon, 2002). The South African pig industry is aware of international developments and trends and is a dynamic, consumer driven industry, using only the best genetic material, modern feeding techniques and management practices to produce lean pork of excellent quality (Hugo, 2000). The smaller decrease in the per capita consumption of pork in South Africa in relation to other red meat species could be attributed to pork being cheaper than beef and mutton and the pig industry launching campaigns to increase consumption of pork (Bruwer, 1992).

Until recently, pig breeding programmes world-wide were essentially devoted to the improvement of growth rate, feed conversion efficiency and carcass quality, such as carcass lean content (Wood, Warriss & Enser, 1992; Bidanel, Ducos, Guéblez & Labroue, 1994). With the exception of problems related to the halothane susceptibility gene, meat quality was not taken into account. Meat quality is becoming increasingly important to meat processors and consumers (Bidanel et al., 1994) and is likely to be a factor in profitability as consumer and supermarket demands for product quality increase (Wood et al., 1992). Consumers have started to require high standards of quality assurance regarding diversity, eating quality and safety of products (Andersen, 2000). He stated that ethical, environmental and welfare aspects are also included in consumer demands regarding quality. Moss (1992) indicated that leanness, appearance/colour, flavour and texture/tenderness determine quality of pork. Consumers employ quite a large number of intrinsic cues to assess the quality of pork, with fat as the primary product characteristic (Bredahl & Andersson, 1998). Consumers in South Africa indicated that they do not want more than 6 mm fat on a pork chop (Bruwer, 1992). Consumers have become more aware of a healthy lifestyle and are presently more aware of diet, health and nutritional concerns than ever in the past (Rhee, Ziprin, Ordonez & Bohac, 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 increase the of polyunsaturated to saturated fatty acid (P/S) ratios in their diets for the maintenance of a healthy lifestyle (Enser, 2000; Honkavaara, 1989; Levnedmiddelstyrelsen, according to Madsen, Jakobsen & Mortensen, 1992; Phelps, 1991). For the prevention of diseases in the 21st century, consumers are also advised to decrease the omega-6 to omega-3 (n-6/n-3) fatty acid ratio of their foods (Okuyama, 1997; Kinsella, 1988; Verbeke et al., 1999; Enser, 2000; Gerster, according to Högberg, Pickova, Dutta, Babol & Bylund, 2001).

According to Andersen (2000) the meat industry responded to these consumer demands by producing leaner pigs, with a more than 50 % reduction in backfat thickness (BFT) and a simultaneous increase in lean meat content (LMC) over the last 20 years in certain European countries. Producers in the United Kingdom (UK) and other countries have received a higher price per kg for carcasses with thinner backfat (BF). Taking production and processing costs into account, these carcasses produce the lean cuts demanded by the consumers more economically than preparing defatted cuts. As a result of price incentives for leaner carcasses, producers have made production changes in the following main areas: genetics (using superior breeding animals selected on the basis of growth and carcass criteria); nutrition (use of high protein-high energy diets to maximize the potential of leaner stock) and the balance between the sexes (entire males grow faster and are leaner than castrates) (Wood et al., 1992). South Africa is faced with the same dilemma as the rest of the world. Here, as in Britain, production of lean pigs can be advantageous because producers are paid for predicted lean yield (Fischer, Mellett & Hoffman, 2000). They indicated that producers may even go so far as to deliberately include the halothane gene in pigs. This will cause a higher lean percentage, but the halothane gene leads to stress susceptibility in pigs, resulting in poorer meat quality (Verbeke et al., 1999).

The Meat and Livestock Commission in the UK, according to Sharlach (1998), indicated that the average P2 BFT of pigs in the UK showed a dramatic decrease from 17.4 mm (1977) to 11.1 mm (1996). The same trend regarding leanness is currently observed in South Africa. Figure 1 indicates the pigs in the P classification group (BFT less than 12 mm) expressed as a percentage of the total annual slaughter for the past 10 years in South Africa. An increase from 17.5% (1993) to 51.2% (2002) was observed (SAMIC, 2003). A factor contributing to the low BFT of South African pigs may be the low slaughter weight (SLW) of pigs. During 2002, 54.8 % of the pigs marketed in South Africa had carcass weights less than 55 kg while 92.4 % had carcass weights less than 71 kg (SAMIC, 2003). This is in agreement with the findings of Kühne (1983) which indicated that by reducing the carcass fat content, the SLW of German pigs also declined.

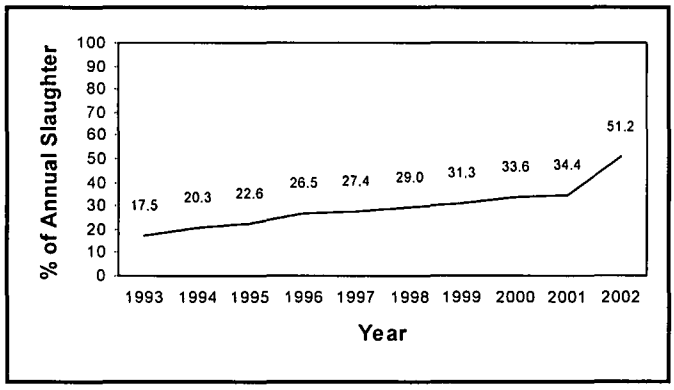


Figure 1: Pigs from the P classification group (BFT less than 12 mm) expressed as a percentage of the total annual slaughtering for the period 1993–2002 (SAMIC, 2003).

The response of the meat industry to the consumer demand for healthier pork has certain implications. Prabucki (1991) indicated that if fat content in a carcass decreases, it will lead to "empty fat tissues" which can influence the technological, marketing, hygiene and consumer quality of the fat. As the total fat content

of the carcass has declined with time, the fatty acid (FA) composition of the fat in various parts of the carcass has also changed towards a more unsaturated profile (Wood et al., 1992). Selection for lower BFT resulted in significantly higher concentrations of unsaturated fatty acids (UFA), especially linoleic acid (C18:2) and lower concentrations of SFA in the BF (Lea, Swoboda & Gatherum, 1970; Villegas, Hedrick, Veum, McFate & Bailey, 1973; Wood, 1973; Kühne, 1983), leading to soft BF. Fat quality defects are more frequently observed in pigs from very lean strains, commonly slaughtered at rather low SLW (Santoro, 1983). Very lean pigs may present problems regarding lack of firmness in the fat tissue. Soft fat lacks succulence and flavour and causes toughness in cooked meat. It also results in lower curing yields in bacon (Bruwer, 1992). It was found that fat from very lean pigs with thin BF was softer (less firm) and separated more easily from the other tissues due to the high level of unsaturation (Kempster, Dilworth, Evans & Fisher, 1986; Wood, Jones, Francombe & Whelehan, 1986b). Fat separation results in handling difficulties and higher rejection rates during bacon slicing (Kempster et al., 1986; Bruwer, Heinze, Zondagh & Naudé, 1991).

The potential for dietary manipulation of the FA composition of monogastric animals (like pigs) is much greater than for ruminants. In pigs, SFA and UFA from the diet pass through the digestive system without changing and are deposited in the different depots (Nürnberg, Wegner & Ender, 1998). This means that nutritional value and health aspects can be improved through adapting the pig diet composition (Verbeke et al., 1999). Researchers illustrated that by feeding the relevant oilseeds, both P/S ratios (Warnants, Van Oeckel & Boucqué, 1998) and n-6/n-3 ratios (Wood, Sheard, Enser, Nute, Richardson & Gill, 1999) of adipose tissue could be altered to fall within the dietary guidelines. Elevation of polyunsaturated fatty acid (PUFA) levels in fat tissue is good news for the health conscious consumer but may cause serious problems for the meat processor. Feed ingredients rich in PUFA have the potential to produce soft BF with poor technological properties and decreased storage stability, which are of concern to the meat processing industry (Madsen et al., 1992; Verbeke et al., 1999). Meat products containing these adipose tissue, often called soft fat, 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). The more expensive processed meat products like bacon and fermented sausages (salami) are especially affected by poor fat quality (Fischer, 1989a,b; Prabucki, 1991; Häuser and Prabucki, 1990). As a rule, fats with higher SFA contents have a softer consistency, lower melting point and greater susceptibility to oxidative spoilage (Fischer, 1989a). Other factors such as genotype, sex condition, slaughter mass, high fat diets and restricted feeding levels could produce unacceptably soft fat tissue (Bruwer, 1992).

Fat quality problems were reported in various European countries. The decrease in BFT of British pigs (Sharlach, 1998) resulted in meat handling problems and decreased quality of meat cuts (Kempster et al., 1986). Barton-Gade (1983) observed that lean pigs in Denmark caused quality problems in meat during processing. In Germany, Kühne (1983) also observed a reduction in the amount of fat in pork, leading to a decline in meat and fat quality. From a study in Switzerland by Häuser & Rhymer (1991) it was concluded that a high level of PUFA in fatty tissue led to decreased oxidative stability in pork. Fat quality is currently constantly monitored in Swiss abattoirs and also incorporated into their payment system (Häuser & Rhymer, 1991). Iodine value (IV) of fat is used to judge subcutaneous pig fat quality. Bad IV lead to a reduction in producers' gross profit margins (Affentranger, Gerwig, Seewer, Schwörer & Künzi 1996). The Swiss are also considering the inclusion of the double bond index (DBI) and pH-value in their payment system.

Conventional methods for fat quality measurement, such as FA profiles, IV determination, melting point and slip point require expensive equipment, are expensive to perform or are time consuming (Andersen, Borggaard, Nishida, Rasmussen, 1999). A rapid physical measurement, showing more potential for lipid quality measurement, is refraction index (RI) determination. Unfortunately a time consuming lipid extraction is still involved. Many rapid instrumental methods have been developed to differentiate between soft and hard fat. Rapid instrumental methods include the puncture test (Dransfield and Jones, 1984), The Bristol Fat Hardness meter (Sather, Jones & Joyal, 1991; Sather, Jones, Robertson & Zawadski, 1995). H^1-Nuclear Magnetic Resonance Spectroscopy (NMR) (Davenel, Riaublanc, Marchal & Gandemer, 1999) and a hand held near infrared (NIR) spectrometer (Andersen et al., 1999). Since pig carcasses in the South African system are usually not split, ribbed or dehided, these instrumental methods can unfortunately not be utilized in this system. An accurate on-line/at-line method that can measure demanded fat quality attributes at the abattoir needs to be developed (Andersen, 2000).

In France, the need for a simple method for selecting adipose tissues led to the development of an indirect method based on LMC (< 57%) and BFT (> 15 mm) (Davenel et al., 1999). This method is based on observations that adipose tissue with the lowest thickness lack consistency because they have the highest proportion of PUFA and the lowest proportion of SFA (Lea et al., 1970; Villegas et al., 1973; Wood, 1973). Carcass LMC is calculated from two BFT measurements and one muscle thickness measurement. Lean meat content for male animals is calculated according to the following formula: LMC = 58.15 – 0.198*G1* – 0.570*G2* + 0.255*M2* while the formula for females are: LMC = 61.68 – 0.142*G1* – 0.449*G2* + 0.154*M2*. The *G1* BFT measurement is made at the ¾ lumbar vertebra level, 8 cm from the middle of the carcass, perpendicular to the BF. The *G2* BFT and *M2* muscle thickness measurements are taken 6 cm from the middle of the carcass, parallel to the axis of the middle carcass cut (Lebret, according to Hugo, 2000). Although this method limits the risk of selecting pig carcasses with soft fat (Rampon et al, according to Davenel et al., 1999), it does not guarantee quality because soft adipose tissues may escape detection.

The system used by the French for predicting fat quality might be applicable to South African conditions, although certain modifications would have to be made because a different formula is used to calculate LMC and in the South African system no distinction is made between genders. According to Bruwer (1991) the current classification system was implemented in South Africa in 1991. It entails the calculation of LMC by means of a single measurement of BF and muscle thickness taken by either the Hennesey Grading Probe (HGP) or the Intrascope. In the case of the HGP, BF and muscle thickness measurements are used to calculate %LMC, while the Intrascope uses only BFT measurements. This measurement is made between the 2nd and 3rd last rib, 45 mm from the carcass midline (Bruwer et al., 1991). When the HGP is used, %LMC = 72.5114 – 0.4618*V* + 0.0547*S* where *V* = BFT in mm and *S* = muscle thickness in mm (Bruwer et al., 1991). Pigs are then classified into one of six groups, **PORCUS**, according to their %LMC (**P** = ≥ 70% LMC; **O** = 68–69% LMC; **R** = 66–67% LMC; **C** = 64–65% LMC; **U** = 62–63% LMC; **S** = ≤ 61% LMC) (SAMIC, 2002). In cases where the Intrascope is used, the formula changes to: % LMC = 74.4367 – 0.4023*V* where *V* = BFT in mm. The **PORCUS** system classify pigs in the following BFT groups (as measured by the Intrascope): **P** = ≤ 12 mm; **O** = 13–17 mm; **R** = 18–22 mm; **C** = 23–27 mm; **U** = 28–32 mm and **S** = < 32 mm (SAMIC, 2002). The values proposed by the French for good quality (LMC < 57% and BFT > 15 mm) will therefore have to be recalculated for the South African classification system.

Leaner and faster growing modern genotypes, combined with the use of entire males, have resulted in extremely low carcass fat levels and subsequent concerns over the quality of carcasses, meat and fat from such animals (Wood et al., 1986b). Producers in South Africa are also interested in implementing a non-castration policy (Heinze, Potgieter, Anderson, Snyman, Zondagh, Illsley, Visser & Britz, 1996). Due to the detrimental effects of very lean low SLW pigs on meat quality there is also an interest in increasing the SLW of pigs in South Africa (Osterhoff, 1988; Anon, 1995; Welgemoed, 1995; Vervoort, 1997). Both these production changes may have an impact on fat quality. Another factor that must be kept in mind is that fish meal, maize, soyabean oilcake, sunflower oilcake and wheaten bran are feed ingredients commonly used in pig diets in South Africa (Viljoen & Ras, 1991). All these feed ingredients are rich in PUFA and have the potential to produce soft BF with poor technological properties and decreased storage stability (Madsen et al., 1992).

A national survey was conducted in the UK into the firmness of pig BF to establish variation within British pigs and the extent of unacceptably soft fat (Wood, 1983). No such survey has ever been performed in South Africa. Bruwer (1992) undertook a survey to determine the carcass characteristics of South African pigs as part of the development and implementation of a new South African pig classification system in 1991. No fat quality measurements were performed but results of a questionnaire indicated that the South African meat industry was unaware or unconcerned about fat quality and the contribution thereof to meat quality both in fresh and processed meats (Bruwer, 1992).

Several factors, including the absence of an in depth study on the BF quality of pigs and the indifference of the South African meat processing industry regarding fat quality, indicated that it was timely and relevant to do a survey on the BF quality of South African pigs. The other factors are: the very thin BF layers and low SLW of these pigs as well as the possible aggravating effect of locally available feedstuffs. The interest in the utilization of young boars and employment of increased SLW also necessitated an investigation of the fat quality of South African pigs.

OBJECTIVES

The purpose of this research project was to:

1) Determine whether fat quality of pig carcasses differed between the respective classification groups (PORCUS) in the South African pig classification system and to obtain an overview of the situation regarding the fat quality of South African pig carcasses.
2) Ascertain whether seasonal variation affected the fat quality of South African pig carcasses.
3) Determine if there was variation in fat quality within a specific classification group of pig carcasses originating from different producers.
4) Ascertain the probability of selecting pig carcasses with good fat quality from the different classification groups to determine whether BFT and LMC may be used to predict fat quality of these carcasses.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Quality is a philosophical made-up word introduced by Cicero – derived from the Latin word "qualis" which means "how" or of "which character" (Andersen, 2000). Quality can be understood as the relationship between the real and the desired properties of a product or as a measure of the satisfaction of the consumer. It can also be understood as a measure of the agreement between the properties of the product and the quality standard or the contract conditions (Ingr, 1989). Prabucki (1991) divided meat quality into five categories namely nutritional, consumer, hygiene, technological and marketing quality. According to Andersen (2000) the concept "pork quality" includes, besides composition and size of pigs, eating, nutritional, technological, health, hygienic and ethical quality. Quality has different meanings to different people (Andersen, 2000). Depending on the point of view, expectations of quality differ (Prabucki, 1991).

For pig producers, pork quality equals those properties which raise the most favourable price when selling the pig to the slaughterhouse (Andersen, 2000). He stated that pig producers only raise pigs with optimum performance (high percentage lean), which by implication means low percentage fat. However, too much emphasis on maximising single performance criteria (e.g. growth rate or BF reduction) can lead to a deterioration in other desirable characteristics such as meat quality (Castell, Cliplef, Poste-Flynn & Butler, 1994) as explained in Chapter 1.

Butcheries and the meat industry are not concerned with performance of the pig but, according to Andersen (2000), pork quality will be judged by absence of pathogens, water-holding capacity (WHC), composition of the meat, microbial load, presence/absence of residues of contaminants, together with specific physical/chemical properties of value in further sale. Meat processors do not want to buy fat if they cannot sell it at a good profit margin (Phelps, 1991). Prabucki (1991) indicated that producers had to accommodate the processors by producing pigs with optimal and not minimal fat content. In turn the processor must adhere to good manufacturing practices to produce a product that is safe and satisfactory for the consumer. He mentioned that this is only possible if the raw material has optimal processing quality. Carcass quality is also of concern to the wholesaler who should supply the types of carcasses in greatest demand by the meat trade (Kempster et al., according to Bruwer, 1992). The retailer has to meet the customer's requirements in terms of size, attractiveness and composition of cuts or products offered for sale and have to estimate the saleable yield from each carcass (Kempster et al., according to Bruwer, 1992).

Bredahl & Andersson (1998) stated that consumers find it difficult to judge pork quality. They have expectations, which are either realised or disillusioned only upon consumption and they use quality cues such as visible or intrinsic features (fat content) or indirect factors (packaging) to judge quality. Moss (1992)

stated that leanness, appearance/colour, texture/tenderness and flavour determine quality of pork from a consumer point of view. Wood et al. (1992) indicated that fatness influences the eating quality of pork. Marbling fat is the aspect of fatness best correlated with eating quality characteristics (Bejerholm & Barton-Gade, 1986).

The main quality arguments for products of muscle and adipose tissues according to Wenk (2000) are:

- High content of essential nutrients
- Low incidence of **p**ale, **s**oft and **e**xudative (PSE) and **d**ark, **f**irm and **d**ry (DFD) meat
- High content of intramuscular **fat** (marbling)
- Good distribution of muscle fibre and connective tissues
- Low amount of total body **fat**, but high **fat** content in the adipose tissues (no "empty **fat** tissues")
- High oxidative stability
- Good consistency of the **adipose** tissues

Most of these are directly or indirectly related to the fat content and it can therefore be concluded that fat quality has a major impact on pork quality.

This being said, the focus can now be shifted towards fat quality. Fat tissue is known to be an important aspect of carcass quality, both in terms of meat processing and consumer acceptability (Whittington, Prescott, Wood, & Enser, 1986). Fat confers the characteristic species flavour on meat through complex interaction between components of fat and lean and also because it prevents drying out during cooking (Wood, 1984).

Fat is one of the major components of animals (Jeremiah, 1982), the others being lean and by-products (Gu, Schinkel & Martin, 1992). According to Fischer (1989a) fatty tissue consists of fat cells (lipocytes or adipocytes), in the diameter range of 50 to 100 µm, in which reticular connective tissue unites them into fat droves or fatty tissue lobes. He stated that fatty tissue contains water and protein, the scleroprotein consisting mainly of collagen and elastin. Lipids comprising animal fats are commonly classified as depot fat or adipose tissue, intramuscular or tissue lipids (Pearson, Love & Shorland, 1977; Fischer, 1989a) and fatty tissues from the carcass cavities (Fischer, 1989a). Depot fats are generally localized in subcutaneous deposits, although significant amounts may be located in the thoracic and abdominal cavities and as intermuscular fats (Gray & Crackel, 1992). This literature survey will mainly focus on the adipose or subcutaneous tissue, as it constitutes the BF of the pig. According to Gandemer (2002) BF contains approximately 75–80% lipids, 5–15% water and a small proportion of proteins as collagen.

Kinsella (1988) and Gandemer (2002) indicated that lipids contribute to organoleptical or sensory food (meat) quality, in terms of texture, colour, mouthfeel and mainly flavour. Lipids also perform important nutritional and biological functions (Kinsella, 1988). Suess (1993) indicated that lipids/fats also supply the essential FA and fat-soluble vitamins (A, D, E and K) and assist in the absorption of thereof (Kinsella, 1988). Fat has a high satiety value because it depresses appetite and delays gastric acid secretion and gastric emptying (Suess, 1993). Mathews & van Holde (1990) stated that fats serve as energy stores, organ protectors and thermal insulators. Campion (1987) indicated that fats are integral parts of membranes and

serve as a storage form of second messenger molecules and that each of these functions are critical to muscle growth.

In this literature survey, the basic composition of fat in pigs and metabolism thereof will be discussed. Backfat quality, its criteria and measurement and the factors influencing as well as technological aspects will also be investigated. This chapter will be concluded with health and nutritional concerns about fat.

BASIC COMPOSITION OF FATS

Heimann (1980) and Girard et al., according to Gandemer (2002), stated that lipids in animal fats are mainly esters of the trivalent alcohol glycerol and three FA molecules – triacylglycerols or triglycerides (TAG). Triacylglycerol degradation products namely the monoacyl- (one OH-group of glycerol esterified), diacylglycerols (two OH-groups esterified) and free fatty acids (FFA) and a small amount of cholesterol are also found. The term fat, or neutral fat, refers to TAG. A mammal may contain 5–25%, or more of its body weight as lipid, with as much as 90% in the form of TAG (Mathews & van Holde, 1990). They indicated that fats are derived from the diet as well as from the mobilization of fat stored in adipocytes. Gandemer (2002) stated that recently, more attention has been focused on TAG composition of BF because their properties are strongly correlated with their constituent FA, which determines the melting point and solid fat content (SFC) of adipose tissues, correlating with their consistency.

Eichhorn et al., according to Gray & Crackel (1992) indicated that depot fats consist mainly of TAG, which may vary according to species, diet, gender, age, environment and depot location within the animal. Muscle lipids are comprised of TAG and phospholipids and vary much less in proportion and FA composition (Gray & Crackel, 1992; Tejeda, Gandemer, Antequera, Viau & García, 2002). Gandemer (1998) stated that phospholipid content varies from 0.5% to 1% of wet weight, whatever the total lipid content of muscles and that the phospholipid fraction is mainly composed of phosphatidyl choline and phosphatidyl ethanolamine. Henderson & Tocher, according to Högberg et al. (2001), stated that polar or muscle lipids are important constituents of membranes and function as precursors in eicosanoid metabolism, whereas neutral lipids serve mainly as depot for lipids used as energy source. Wood (1984) indicated that intramuscular fat (IMF) contains a higher proportion of phospholipid (± 250 mg/g lipid) than fat depots (< 50 mg/g lipid). Coutron-Gambotti & Gandemer, according to Timón, Ventanas, Carrapiso, Jurado & García (2001) indicated that lipolytic changes occur specifically in unsaturated TAG.

The major compositional characteristic of the fat is its FA composition (Rossell, 1992). Alais & Linden (1991) stated that all FA have the –COOH (carboxyl) grouping at the end of a hydrocarbon chain, which varies in length. They have a polar structure with both a hydrophobic nature, which increases in relation to number of carbon atoms, and a hydrophilic nature (exhibited by the carboxyl group). Consequently, a hydrophobic "tail" with a hydrophilic "head" is found on a FA.

SATURATION AND UNSATURATION

According to Fischer (1989a) FA are referred to as SFA if hydrogen atoms occupy all carbon atoms in the hydrocarbon chain and if one or more carbon atom double bonds (DB) exist, such FA are defined as UFA.

Heimann (1980) indicated that UFA are characterized by having one or more DB. FA with one DB are known as mono-unsaturated (MUFA), two DB as dienoic, three DB as trienoic and four or more DB as polyenoic FA. The collective term used for FA with two or more DB is PUFA. He stated that some branched chain FA are found, although nearly all FA found in nature are straight chained.

THE DOUBLE BOND

The position of the DB has two notations namely the chemist's notation, which is in relation to the carboxyl group: C18:2$\Delta^{9,12}$ or in relation to the methyl (CH_3) group: C18:2$\omega^{6,9}$ which is the physiologist's notation (Alais & Linden, 1991).

E.g. linoleic acid (C18:2) is written as follows:

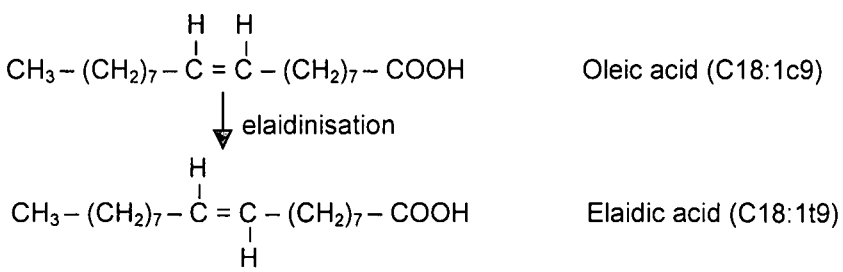
$$\mathbf{CH_3} - (CH_2)_4 - CH = CH - CH_2 - CH = CH - (CH_2)_7 - \mathbf{COOH}$$

From this side (the ω-notation) From this side (the Δ-notation).

Two families are distinguished within the PUFA according to the position of the DB, namely the n-6 FA, which are abundant in a lot of oilseeds and the n-3 FA, which are characteristic for marine species and some plants (linseed) (Verbeke et al., 1999). They continued by stating that the main representatives of the n-6 and n-3 series in animal fat are linoleic (C18:2) and linolenic acid (C18:3), respectively.

TRANS FATTY ACIDS

Heimann (1980) indicated that oleic acid (C18:1c9) actually undergoes elaidinisation during hardening of fat by hydrogenation or in the course of oxidation or during thermal polymerisation and forms the geometrical isomer – the trans or t form – elaidic acid (C18:1t9). These descriptions refer to the spatial orientation around the number 9 and 10 atoms from the –COOH group. The cis or c configuration refers to the fact that the hydrogen atoms on both carbon atoms are on the same side, introducing a bend in the FA molecule, according to Khosla & Hayes (1996). It is important to realize that this bend is still in a straight chain and it is not the same as a branched chain FA, referred to earlier. The trans configuration refers to hydrogen atoms on opposite sides on carbon 9 and 10, which produces a straight chain FA as Khosla & Hayes (1996) stated. As a consequence of these changes, the 18-carbon oleic acid (with 1 cis bond) has a melting point of 13°C whereas the 18-carbon elaidic acid (with 1 trans bond) has a melting point of 44°C (Khosla & Hayes, 1996).



FATTY ACID COMPOSITION OF PORCINE FAT

Typical FA compositions of subcutaneous porcine fat can be found in various scripts (Jeremiah, 1982; Kühne, Freudenreich, Ristic & Scheper, 1985; Fischer, 1989a; Alais & Linden, 1991; Rossell, 1992; Enser, Hallett, Hewitt, Fursey & Wood, 1996). According to the aforementioned authors, the long chained FA, in order of abundance in porcine fatty tissue, are C18:1c9, palmitic (C16:0), stearic (C18:0) and C18:2 acids.

The first three FA are synthesized in the tissue itself, as observed by Christensen, according to Madsen et al. (1992). She indicated that the medium-chained FA, lauric (C12:0) and myristic acid (C14:0) are deposited in the depot fat to a limited extent, if they are present in the feed. Hilditch, according to Sink, Watkins, Ziegler & Miller (1964), found that the principal SFA and UFA was C16:0 and C18:1c9, respectively. According to Enser (1983) C18:1c9 is the major component of pig fat, usually exceeding 40% of the total fat content. He also stated that there is an important relationship between dietary C18:2 and deposition of C18:0 – if deposited FA come from diet rather than *de novo* synthesis, C18:2 will increase at the expense of C18:0. Linoleic acid and C18:3 are synthesized in plants but not in the animal body (Okuyama & Ikemoto, 1999), if fed to pigs, C18:2 and C18:3 are also found in the depots (Madsen et al., 1992).

Fatty acid composition of fat differs significantly among the anatomical position on the carcass. Wood, Enser, MacFie, Smith, Chadwick, Ellis & Laird (1978) found a difference in the FA composition of BF TAG between the inner and outer layer. Ingr, according to Fischer (1989a), indicated that the outer layer has more UFA with a higher IV and lower melting point than the inner layer. Koch, Parr & Merkel (1968a) and Malmfors, Lundström & Hansson (1978a) stated that the inner layer had more C18:0 and C16:0 and less palmitoleic (C16:1), C18:1c9, C18:2 and C18:3 than the outer layer. According to Fischer (1989a) the firmness of the cutaneous (inner) layer is greater because the water and connective tissue content is lower. Santoro (1983) and Sikic, according to Fischer (1989a) indicated that the connective tissue framework in inner layer is arranged in a uniform narrow-meshed way, while the subcutaneous (outer) layer has irregular structuring. Timón et al. (2001) suggested that intense lipolysis occurs in the outer layer of the subcutaneous fat and that this layer has a small amount of PUFA.

Backfat samples had lower percentages of C16:0 and C18:0, long (≥ C18) and short (≤ C16) chain SFA and total SFA and higher percentages of C18:1c9 and C18:2, PUFA and total UFA than belly fat samples (Jeremiah,1982). In general there is a progressive increase in saturation from the peripheral (subcutaneous) through intermuscular and intramuscular to deep body sites (Christie, Jenkinson & Moore, 1972; Sink et al., 1964). The dorsal subcutaneous sites had rather similar values intermediate between perirenal fat (with high lipid and low water content) and intermuscular and belly fat (with low lipid and high water content) (Wood, Buxton, Whittington & Enser, 1986a). The ranking of the sites according to water and lipid content is not the same as that according to relative growth rate which suggests that the rate of fat deposition alone does not control chemical composition (Wood et al., 1986a). They indicated that given the high lipid content, perirenal fat should be close to maturity, but it has the highest growth rate, which means it is the most immature fat. Wood (1984) stated that the reason for these differences can partly be ascribed to the amount or rate of fat deposition in the different sites and partly to difference in temperature.

METABOLISM OF FAT IN PIGS

The metabolism of fat in pigs is a balance between two processes – lipogenesis (fat synthesis) and lipolysis (fat mobilization) (Farnworth & Kramer, 1987). Fat deposition is the difference between fat synthesis and fat mobilization and depends upon the energy intake of essential nutrients (Madsen et al., 1992). Both processes are substantially influenced by hormones (adrenalin, glucagon, insulin and thyroid hormones) (Müller, 1983). He also stated that hormones controlling lipolysis in adipose tissue have glycogenolytic

effects in muscle. Fat deposition can be characterized chemically by the continual accretion of lipids, primarily in the form of TAG and morphologically by adipocyte differentiation and hypertrophy (Nürnberg et al., 1998). Nutrients in excess of requirements for function of life and protein production will be deposited as fat in the body (Kühne, 1983).

The Pathway of Fat in the Pig

Intestinal absorption of FA occurs in such a manner that the long-chained FA are partitioned from those of lesser length. The short and medium-chained FA are not assembled into lipoproteins but released in free form for portal transfer to the liver where they are largely combusted. The appearance of FA with less than 14 carbons in body deposits are negligible unless exceptionally high dietary levels are employed. Mammals form chylomicrons, which are large and must employ lymphatic ducting to enter the vascular system before access to peripheral tissues. In blood, lipids are contained and distributed to other cells in the form of FFA and lipoproteins. Free fatty acids are generally combusted for energy after uptake by most cells. Lipoproteins are the means by which bulk quantities of FA are transferred between tissues. Adipocytes accept FA released from circulating lipoproteins. Hepatocytes co-ordinate the movement of FA to tissue(s) in most "need" (Moran, 1996). According to Gandemer (2002) lipases and phospholipases, with subsequent formation of FFA, control lipolysis. Both endogenous enzymes of fat cells and muscle fibres and enzymes of bacteria are involved in lipolysis (Gandemer, 2002).

The Essential Nature of Fatty Acids

Okuyama & Ikemoto (1999) indicated that SFA (C16:0; C18:0) and MUFA (C16:1; C18:1) are synthesized *de novo* in the animal body from carbohydrates and proteins and excess energy is converted to these FA. Madsen et al. (1992) and Gandemer (2002) found that when *de novo* synthesis, resulting in SFA and MUFA, is predominant, BF will be firm, while deposition of dietary PUFA will result in soft BF. Moran (1996) indicated that dietary PUFA can act as substitutes for *de novo* synthesized SFA and MUFA. Okuyama & Ikemoto (1999) indicated that C18:2(n-6) and C18:3(n-3) must be supplied in the diet of the pig as it cannot synthesize these FA itself. Linoleic acid(n-6) only reacts when it is the precursor of other FA in the n-6 series, such as arachidonic C20:4(n-6) and dihomogammalinolenic acid or C20:3(n-6). The latter two are the departure points for the prostaglandins (Alais & Linden, 1991). Alpha-linolenic acid is converted to form eicosapentaenoic or C20:5(n-3) and docosahexaenoic acid or C22:6(n-3) (Okuyama & Ikemoto, 1999).

Dietary FA, in addition to those of endogenous origin, may undergo successive desaturation and elongation within the organism. The same enzymes from Δ6 desaturase are capable of reacting with ingested C18:2 and C18:3, yielding the n-6 and n-3 types. The enzyme, Δ6 desaturase, shows high affinity for the most unsaturated substrate such as C18:3(n-3). Too much of this acid in the diet may inhibit the transformation of C18:2(n-6) into C20:4(n-6). The desaturases and the elongating enzymes, as indicated in Table 1, have high specificity only when the DB exists as ω^6 in the molecule. Where there is a deficiency of C18:2(n-6), the C18:1c9 may be transformed and C20:3$\omega^{9,12,15}$ accumulates without formation of prostaglandins. External symptoms (dermatitis) appear when the proportion of the latter to C20:4(n-6) exceeds 0.4 (Alais & Linden, 1991).

Table 1: Principal biosynthesis pathways of the n-6 and n-3 fatty acids.[a]

n-3	C18:3 Δ9,12,15	→	C18:4 Δ6,9,12,15	⇒	C20:4 Δ8,11,14,17	→	C20:5 Δ5,8,11,14,17	⇒	C22:5 Δ7,10,13,16,19	→	C22:6 Δ4,7,10,13,16,19
n-6	C18:2 Δ9,12	→	C18:3 Δ6,9,12	⇒	C20:3 Δ8,11,14	→	C20:4 Δ5,8,11,14	⇒	C22:4 Δ7,10,13,16	→	C22:5 Δ4,7,10,13,16

a: adapted from Alais & Linden (1991)
→ Desaturase
⇒ Elongation enzyme

THE PIGLET

The ability of pig skeletal muscle to metabolize FA develops fetally (Campion, 1987). At birth, according to Metz (1985) and Farnworth & Kramer (1987), the piglet's body has less than 2% fat that can be mobilized. Fat content increases rapidly thereafter, because fat from high-fat sow's milk is stored in the piglet's adipose tissue. Farnworth & Kramer (1987) indicated that the lypolytic (fat mobilizing) enzyme activity increases after birth and that weaning causes a pronounced but temporary decrease in total body lipid, despite an increase in fat synthesis. They concluded that this was because the change from a liquid high-fat diet to a grain-based high-carbohydrate diet causes a shock that affects the piglet's growth, body composition and metabolism. The increase in fat content of the adipose tissue relative to the increase in adipose tissue mass is highest in young pigs (Metz, 1985).

THE GROWING PIG

Metz (1985) indicated that about $^{2}/_{3}$ of total adipose tissue mass of pigs are located subcutaneously, approximately 30% intermuscularly (between muscles) and very little inside muscles (intramuscularly). According to Camara, Mourot & Février (1996) the dorsal subcutaneous adipose tissue or BF is the main component of subcutaneous adipose tissues in pigs. They indicated that BF and neck subcutaneous adipose tissue consist of two layers, separated by connective tissue, while Fortin (1986) observed a third layer and Steele, according to Metz (1985) observed a third and fourth BF layer during growth. Anderson & Kauffman (1973) and Fortin (1986) indicated that the outer layer is predominant early in life. With age, the middle layer thickens and finally the inner layer begins to develop. Kühne (1983) stated that the inner layer had approximately 2–4% more fat than the outer layer. Camara et al. (1996) observed that the inner layer was more sensitive to dietary source fat than the outer layer and suggested that BF should be considered as two separate tissues rather than a single entity. Hood & Allen, according to Camara et al. (1996), stated that during growth, the subcutaneous adipose tissue appears first, followed by mesenteric and perirenal fat, which is followed by the appearance of the intermuscular fat and finally, the IMF.

Farnworth & Kramer (1987) indicated that during the growing period, even though lipogenesis and lypolysis declines with age, body fat continues to build up, but factors such as diet, gender and breed influence the rate of lipogenesis. They also concluded that diet has a larger influence on lipogenesis than on lipolysis. Environment also has a major influence on the growth of an animal and hence on its tissue deposition and the physical characteristics of fat, including the melting point and degree of unsaturation (Close, 1983). Wood (1984) indicated that young fat tissue contains a high proportion of water and connective tissue and a low proportion of fat in small cells. As the animal ages, these cells increase in size and are packed more

closely together, thus more lipid and less water and connective tissue are found in them. As animals become fatter, chemical composition of the adipose tissue also changes (Aberle, Etherton & Allen, 1977).

In the growing pig, synthesis dominates mobilization. The rate of these processes depends upon the availability of substrates (e.g. glucose for fat synthesis, dietary fatty acids for direct incorporation into body fat) and the activities of the enzymes catalysing the metabolic reactions (Metz, 1985). In the pig, as in many other monogastric animals, the FA pattern found in the adipose tissue generally reflects the FA pattern of the ingested fat (Friend & Cunningham, 1967; Koch, Pearson, Magee, Hoefer, Schweigert, 1968b; Bowland, 1972; Castell & Falk, 1980). Wood (1984) observed that dietary FA are incorporated unchanged into the body fat because they are absorbed intact from the small intestine and directly deposited in the fat tissue. In the weight range 20–90 kg the dietary fat intake for Danish pigs is approximately 4 kg, but the carcass may contain more than 15 kg fat. Hence at least 11 kg fat has been synthesized *de novo* from dietary carbohydrates and protein (Madsen et al., 1992). Dietary fat supplementation influences the carcass fat composition by decreasing the endogenous fat synthesis and by increasing the deposition of dietary (animal or vegetable) fat into the fatty tissues of the pig (De Wilde, 1983). Wood (1983) stated that C18:2 in feed directly affects the melting point of fat, especially above 15%, but its proportion is reduced as fat thickness (FT) increases.

The IMF represents the "invisible" fat present in lean meat trimmed from all external fat (Warnants, van Oeckel &. Boucqué, 1996). The IMF is preferably found inside the muscle and it prevents pork from being dry (Osterhoff, 1988). To obtain satisfactory eating quality, the optimal IMF level in lean pork should range between 2.0 and 2.5% (Osterhoff, 1988; Warnants et al., 1996; Bejerholm & Barton-Gade, 1986). Intramuscular fat content may affect the juiciness (Wood et al., 1986b), flavour (Cameron, Warriss, Porter & Enser, 1990), aroma (Mottram & Edwards, 1983) and tenderness of pork (DeVol, McKeith, Bechtel, Novakofski, Shanks & Carr, 1988). Lean meat with a high IMF content has better sensory properties and palatability than meat with a low fat content (Madsen et al., 1992). Intra- and intermuscular fat have a closer association with meat and a more probable consumption than subcutaneous depots (Moran, 1996). Muscle depots generally grow to the largest extent during the finishing period prior to marketing (Moran, 1996). In contrast to BF quality, IMF quality is strongly influenced by genetics (Madsen et al., 1992). Christensen, according to Madsen et al. (1992), suggested that IMF may be synthesized in skeletal muscle independently of the overall FA synthesis and agreed that this could be regulated by physiological and genetic factors.

BACKFAT QUALITY OF PIGS

DEFINITION OF GOOD AND POOR FAT QUALITY

Wood (1984) defined good quality fat as firm and white and poor quality fat as soft, oily, wet, grey and floppy. Fat quality was therefore defined in terms of the firmness and cohesiveness of the subcutaneous fat (Wood, Jones, Bayntun & Dransfield, 1985). Wood (1984) indicated that flavour was also important when defining good and poor fat quality. From the above definition it is clear that colour and consistency play the most important roles in fat quality.

PROBLEMS ASSOCIATED WITH POOR QUALITY FAT

These problems were briefly mentioned in the first chapter. The processing industry needs a minimum quantity of good quality fat and extreme leanness results in a lack of cohesion between BF and the underlying muscle (Wood, 1984). Ellis & Isbell (1926) stated that the main problem is that BF is too soft because of a high C18:2 content and Whittington et al. (1986) indicated that genetically lean pigs, produced by restricted feeding (Wood & Enser, 1982) are more prone to this. The quality of fat tissue, in terms of firmness and appearance, depends, to some extent, on the quantity of the fat. As overall fatness is reduced, fat quality will decline (Wood, 1984). Changes in the composition of pig adipose fats may cause problems in meat technology, mainly concerning the consistency of meat products and their stability towards oxidation (Houben & Krol, 1983).

Common complaints from the meat industry regarding very lean meat was soft and floppy BF, carcasses not "setting" after chilling and that BF, muscle and meat was dry and tasteless after cooking (Wood, 1983; Kempster et al., 1986; Wood, et al., 1986b). Lack of consistency of adipose tissue is one of the main problems the manufacturers of meat products have to face (Bailey et al., 1973; Santoro, 1983). As a rule, fats with higher UFA contents have softer consistencies, lower melting points and greater susceptibility to oxidative spoilage (Lea et al., 1970; Villegas et al., 1973; Wood, 1973; Fischer, 1989a; Gandemer, 2002). Fat of poor quality will have a greater tendency to oxidize and transmit the rancidity flavour and odour to the meat (Barton-Gade, 1983; Santoro, 1983). Perrin et al., according to Davenel et al. (1999) indicated that consistency of adipose tissue is related to the physical state of the lipids, which depends on FA and TAG composition. Meat products containing soft fat, show quality defects, such as insufficient drying, oily appearance, rancidity development and lack of cohesiveness between muscle and adipose tissue on cutting (Bailey et al., 1973; Gandemer, 2002; Maw, Fowler, Hamilton & Petchey, 2003). Gandemer (2002) and Maw et al. (2003) indicated that meat products are difficult to cut if they contain soft fat, because the muscle and adipose tissue separates. Santoro (1983) observed that, with increasing temperature, soft fat exudes an intense oily substance. Gandemer (2002) indicated that this oily liquid covers the meat and prevents it from drying. Enser, Dransfield, Jolley, Jones & Leedham (1984) indicated that soft fat in vacuum-packed bacon rashers leads to a "squashy mass" appearance and the individual rasher appearance is lost.

Santoro (1983) reported that poor fat quality was exhibited by firm fat not sufficiently mature resulting in structural defects in the connective tissue. He indicated that products made from these fats will exhibit a granular surface on cutting, not the desired smooth surface associated with processed meat. Fischer (1989a) stated that water, pure fat and connective tissue contents may influence fat quality significantly. Wood & Enser (1982) and Whittington et al. (1986) indicated that water does not have significant effects on consistency in bacon weight pigs where water content is usually less than 20%. Enser et al. (1984) concluded that even though soft fat has a higher water content than hard fat, curing reversed this situation in that hard fat retained more brine. They proposed that the proportion of the fat-free dry matter (which is the connective tissue, mainly consisting of collagen) is approximately 5%. The contribution of fat-free dry matter (FFDM) to consistency of the fat, is the most important factor, since the degree or type of collagen cross-links that form the structural network in adipose tissue differs. According to Santoro (1983), the distinction between soft and firm fat probably depends on these differences in the protein structures of the adipose tissue.

From the definition of fat quality, it is evident that colour plays a very important role, as it is a visible feature by which a consumer judges quality. Young fat tissue feels soft and wet. It also separates more easily from the muscle and has a grey colour as opposed to white colour of mature fat (Wood, 1984). MacDougall & Disney, according to Wood (1984), observed that the grey colour of the young fat was partly due to the higher concentration of connective tissue, which lowers the whiteness value. Fatty acids themselves are colourless (Maw et al., 2003), fat tissue in which lipid has not fully solidified appears relatively grey or yellow because capillaries containing blood, connective tissue, and carotenoid pigments are visible (Wood, 1984). Carotenoids cause the yellow colour and are especially associated with C18:2 and C18:3 (Maw et al., 2003). In general, adipose tissue of low consistency has a yellow colour and a translucent appearance while firm adipose tissue appears white or slightly pink (Davenel et al., 1999). Increased translucency and fat softness were associated with increased percentages of C18:2 and C18:3 (Maw et al., 2003). Warnants et al. (1996) observed a yellow discolouration of the fat, known as "yellow fat disease" as a result of inclusion of too much PUFA. Santoro (1983) reported a pink colour from immature BF (thin layers BF not completely developed) due to the perfusion of the blood vessels. The colour of fresh pork fat exposed to oxygen is therefore pinkish due to the presence of oxypigments, changing to white with a yellow tinge on vacuum packaging (Barton-Gade, 1983). Hard adipose tissue appears whiter because the coloured haem components of the fat tissues are hidden by the opacity of the hard lipid (Enser, 1983). Santoro (1983) observed that with advancing oxidation the colour of the oxidized fat turned from normal light yellow to an intense brownish orange.

CRITERIA FOR GOOD QUALITY FAT

Firmness, melting point, and stability or resistance to fat spoilage, colour and taste are the most important criteria of fat quality (Fischer, 1989a). The firmness and the quality of the adipose tissue depend on the proportion of fat, but to a greater extent on the degree of unsaturation of the fat (Metz, 1983). Barton-Gade (1983) indicated that colour, consistency, keeping quality and percentage extractable fat (EFC) are important fat quality criteria in Denmark. She also stated that consumers prefer pork fat to be white, and visible discolouration, especially towards the yellow shades will be rejected. Prabucki (1991) indicated that oxidative stability must be high in order to have fat of good quality. The physical characteristics of the fat are temperature-dependent, although the effect of temperature on depot fat is not simple (Close, 1983). Various criteria for good quality fat have been proposed.

BACKFAT THICKNESS AND LEAN MEAT CONTENT

Commercial grading and classification systems for hog carcasses throughout the world are based on BF measurement(s) alone or in combination with carcass weight and/or muscle depth (Kempster, according to Fortin, 1986). The potential of applying the French system (with the necessary modifications) to South African conditions was discussed in detail in the first chapter. This system entails the use of an indirect method based on BFT (> 15 mm) and LMC (< 57%) (Davenel et al., 1999). Backfat thickness should be more than 18 mm in the middle of the back (Prabucki, 1991) according to Swiss standards. Cannon, Morgan, McKeith, Smith, Sonka, Heavner & Meeker (1996) proposed that the optimum range of BFT was between 17.5 mm and 20.0 mm to obtain good quality fat. Cohesiveness was less closely related to FT (Wood et al., 1985). Previous work has shown that a thinner BF layer corresponds to a lower %EFC, a higher protein and

water content, a higher IV and more UFA (Barton-Gade, 1983). As FT increases, the proportion of C18:2 decreases (Whittington et al., 1986).

Extractable Fat Content

The %EFC in pork fat is of economic importance for the production of lard (Barton-Gade, 1983). No "empty" fat tissues must be present (fat tissue should contain 84–90% fat) and depot fat should be more than 15% of the total fat content (Prabucki, 1991).

Fatty Acids

The quality of the fat is especially determined by the composition of the FA and their physical characteristics (Kühne, 1983). Individual FA, as well as combinations and ratios thereof, are used to predict fat quality (Ellis & Isbell, 1926; Elliot & Bowland, 1969; Lea et al., 1970; Wood et al., 1978; Enser, 1983; Houben and Krol, 1983; Wood, 1983; Enser, 1984; Enser et al., 1984; Whittington et al., 1986; Honkavaara, 1989; Cameron et al., 1990; Prabucki, 1991; Madsen et al., 1992; Warnants et al., 1996).

Individual Fatty Acids

Malmfors, Lundström & Hansson (1978b) indicated that **C14:0** and **C16:0** were negatively correlated with good flavour.

Stearic acid is the most significant FA in the regulation of the consistency of the lipid from pig BF (Lea et al., 1970; Wood et al., 1978; Enser, 1983; Enser et al., 1984; Whittington et al., 1986). Wood et al. (1985) indicated that C18:0 content was the single best predictor of firmness. Stearic acid was positively correlated with consistency of the BF (Enser, 1983; Cameron, 1990; Piedrafita, Christian, Lonergan, 2001). Good quality fat should contain more than 12% C18:0 (Houben & Krol, 1983; Girard et al., according to Lizardo, Van Milgen, Mourot, Noblet & Bonneau, 2002). Wood (1983) stated that the SFA and MUFA of C16 and C18 would best define the firmness of the BF.

Oleic acid is the major component of pig adipose tissue (constituting more than 40% of total fat content) and has a low melting point, but according to Enser (1983) and Davenel et al. (1999) its concentration is poorly related to consistency of fatty tissue. Palmitic acid and C18:0 are present at only 50 and 25% of the concentration of C18:1c9, respectively (Close, 1983). Oleic acid concentration is affected by the C18:2 concentration, the former decreases as the latter increases (Whittington et al., 1986).

High **Linoleic acid** content in the diet of the animal has been implicated as critical in determining carcass fat quality (Wood, 1984). This FA directly affects lipid melting point and its proportion is reduced as fatness is increased (Wood, 1983). Although Ellis & Isbell (1926) indicated that large amounts of C18:2 in the pig diets leads to soft fat, this effect results from changes in the proportion of SFA, which affects the consistency because of their high melting point and through changes in the distribution of the FA in the TAG (Enser et al., 1984). Wood et al. (1985) indicated that cohesiveness was best correlated with the C18:2 content. Backfat consistency was shown to be inversely correlated with the C18:2 concentration (Cameron et al., 1990; Whittington et al., 1986). Ellis & Isbell (1926) and Whittington et al. (1986) set the limit for C18:2 to be less than 15% to result in good quality fat. Enser (1983) observed a negative correlation ($r = -0.726$) between C18:2 content and slip point, but lower than the correlation between C18:0 and slip point ($r = 0.928$). Davenel

et al. (1999) indicated that C18:2 content was a poor predictor of SFC. Enser (1983) and Wood (1983) set the limit for C18:2 in the BF at 15%. Girard et al., according to Lizardo et al. (2002), indicated that the limit for C18:2 in BF of good technological quality ranges between 12 and 15%. Wood & Enser (1982) indicated that firmness and whiteness of fat were roughly in line with the C18:2 concentrations.

Linolenic acid was positively correlated with tenderness, unlike other PUFA and was essentially uncorrelated with flavour and juiciness (Cameron & Enser, 1991).

Combinations of Fatty acids

Saturated Fatty Acids:

The SFA (C12:0–C18:0) have a positive influence on firmness and cohesiveness of the carcass fat tissue (Madsen et al., 1992). Saturated FA make fat tissue hard (Enser, 1983). Cameron et al. (1990) stated that subcutaneous fat became more saturated and less moist as a result of increased C16:0 and C18:0. They observed that the correlation between the C16:0 + C18:0 combination and fat firmness was 0.48. Palatability of meat is positively correlated with SFA and MUFA content (Cameron & Enser, 1991; Okuyama & Ikemoto, 1999; Bryhni, Kjos, Ofstad & Hunt, 2002). Larsson & Quinn, according to Davenel et al. (1999) stated that SFA strongly influence SFC of lipids because of their high melting points (63–70°C). Häuser & Prabucki (1990) suggested that SFA content has be more than 41% of the total FA to obtain good quality BF.

Unsaturated Fatty Acids:

As more UFA, with low melting points, are included in feed, the BF becomes softer, and other undesirable characteristics mainly caused by oxidation, such as reduced storage stability, rancidity, off-flavours and discolouration of the carcass fat, are also encountered (Enser, 1983; Madsen et al., 1992). The degree of fat firmness was negatively correlated with the proportion of total UFA ($P < 0.01$) (Piedrafita et al., 2001). Less than 59% UFA in the BF will constitute fat with a good composition (Prabucki, 1991).

Mono-unsaturated Fatty Acids (MUFA):

Mono-unsaturated FA (C16:1 and C18:1) have a negative influence on firmness and cohesiveness of the carcass fat tissue (Madsen et al., 1992). Häuser & Prabucki (1990) suggested that MUFA content has to be less than 57% of the total FA to obtain good quality BF.

Polyunsaturated Fatty Acids (PUFA):

Polyunsaturated FA incorporation into fat is restricted by the resulting pork fat consistency and oxidative stability, the two important properties for meat curing industries (Warnants et al., 1996). Polyunsaturated FA content was found to be negatively correlated with eating quality (Cameron & Enser, 1991; Bryhni et al., 2002). A negative correlation exists between BFT and the essential FA (C18:2 and C18:3) (Cameron, 1990; Piedrafita et al., 2001). The consistency of the BF decreases with increased PUFA content (Rhee, Davidson, Knabe, Cross, Ziprin & Rhee, 1988b; Warnants et al., 1996). Several authors have proposed limits for PUFA levels in BF to ensure good quality fat. A limit of 12% and less PUFA in BF (Prabucki, according to Houben & Krol, 1983), a maximum value of 13% PUFA in BF (Wenk et al., according to Warnants et al., 1996) and a limit of 15% PUFA in the BF (Houben & Krol, 1983; Fischer et al., according to Warnants et al., 1996) were proposed to obtain good quality fat. Backfat with a PUFA content of less than 22% (Warnants et al., 1996) or

less than 23% (Warnants et al., 1998; Bryhni et al., 2002) produced no serious aberrations in consistency or oxidative stability in experiments. Warnants et al. (1996) indicated that a distinction should be made between meat intended for the fresh meat market and meat used for processing, as high PUFA content may cause problems during curing and in the keepability of products. When the proportion of PUFA in the BF increases, the storage stability decreases, as does the flavour and taste (Madsen et al., 1992).

Häuser & Prabucki (1990) suggested the following as criteria for good quality BF:

- Dienoic FA — less than 10% of the total FA
- Trienoic FA — less than 1% of the total FA
- Tetraenoic FA — less than 0.5% of the total FA
- Pentaenoic + hexaenoic FA — less than 1% of the total FA.

Limits for PUFA inclusion in feed have also been proposed namely 12% (Prabucki, according to Warnants et al., 1996) and 19–21% (Fischer et al., according to Warnants et al., 1996) while Bryhni et al. (2002) recommended that less than 50g PUFA/kg feed will reduce oxidative problems.

Ratios of Fatty Acids

Alam & Alam (1986) and Affentranger et al. (1996) used the DBI to determine fat quality. Prabucki (1991) proposed that a DBI of less than 80 would result in good quality BF. Pamplona, Portero-Otín, Riba, Ruiz, Prat, Bellmunt & Barja (1998) proposed the use of the peroxidizability index (PI) as an indicator of oxidative stability of fat.

Lea et al. (1970), Wood et al. (1978), Enser et al. (1984) and Whittington et al. (1986) found that the MUFA/SFA and (C16:1 + C18:1c9)/(C16:0 + C18:0) ratios were better related to the variation in melting and slip point of the lipids, consistency of pig adipose tissues and may be independent of carcass fatness (Lea et al., 1970). The MUFA/SFA ratio was negatively correlated with fat firmness (Wood et al., 1978; Cameron et al., 1990).

The C16:0/C18:2 ratio was observed in work done by Enser (1984) and Whittington et al. (1986) to measure firmness. Cameron et al. (1990) indicated that the correlation between this ratio and firmness was 0.54. Malmfors et al. (1978b) and Wood et al. (1978) suggested that pigs regulate the degree of saturation in the subcutaneous fat by reducing the C18:1c9 concentration when C18:2 content increases.

Pamplona et al. (1998) indicated that the C20:4/C18:2 and C22:6/C18:3 ratios express the activity coefficient of enzymes (desaturases and elongases) in the biosynthesis of C20:4 and C22:6, respectively.

Since C18:0 appears to be the most important FA in the regulation of the BF consistency, but feeding C18:2 is known to make the fat soft, there is clearly an important relationship between dietary C18:2 and the deposition of C18:0 (Enser, 1983). A C18:0/C18:2 ratio above 1.2 and below 1.2 will result in firm and soft BF, respectively (Honkavaara, 1989).

MEASUREMENT OF FAT QUALITY

Wood (1984) indicated that fat quality could be determined subjectively by an experienced assessor or objectively by using instruments to measure fat firmness. Enser (1983) stated that subjective assessment of BF firmness could lead to errors and inconsistencies. Objective methods are independent of the observer (Bruwer, 1992). For this reason objective procedures were developed.

GAS CHROMATOGRAPHIC ANALYSES

Gas chromatographic (GC) analyses have been used to separate and quantify FA methyl esters (FAME) in order to determine the FA composition (Rhee et al., 1988b; García-Olmo, De Pedro, Garrido, Paredes, Sanabria, Santolalla, Salas, García-Hierro, Gonzalez, García-Cachan & Guirao, 2002; Joo, Lee, Ha & Park, 2002). The disadvantages of this method are that it is an expensive procedure and a time-consuming lipid extraction is involved (Andersen et al., 1999; Irie, 1999). García-Olmo et al. (2002) concluded that in terms of the accuracy, reproducibility and repeatability, GC analysis was remarkable and satisfactory.

IODINE VALUE AND REFRACTION INDEX

Iodine value is an analytical value for halogen addition to the DB (Alais & Linden, 1991). Iodine value gives an overall estimate of FA unsaturation (Davenel et al., 1999). Fischer (1989a) indicated that IV could serve as an indicator of the percentage of the UFA. Iodine value is not only an index of fat firmness, but also of rancidity (Irie & Sakimoto, 1992). Martin, Freeden, Weiss & Carson (1972) indicated that IV was negatively and positively correlated with measures of fat and lean, respectively. Alais & Linden (1991) indicated that the higher the IV of fat, the more UFA it contains. Barton-Gade (1983) indicated that IV is used as an indicator of soft fat. Iodine value determination has the disadvantage that it is expensive and time-consuming (Andersen et al., 1999). To avoid problems arising from the use of unsuitable raw materials in the manufacture of firm-cutting sausage, BF employed should have an IV of no more than 60 (Fischer, 1989b). According to Lea et al. (1970) hard adipose tissues have IV lower than 65 and soft adipose tissues have IV higher than 70. Mortensen et al., according to Warnants et al. (1996) proposed an IV of below 65 in BF as critical from a quality point of view while Barton-Gade (1987) indicated that a maximum IV of 70 would produce firm fat. Other authors have agreed that the cut-off point for good quality BF should be 70 (Houben & Krol, 1983; Girard et al., according to Davenel et al., 1999). Barton-Gade (1983) concluded that IV changes with anatomical position is mainly due to C16:0; C18:0 and C18:1c9 contents. Hart, according to Houben & Krol (1983) indicated that BF would be soft at an IV of 66 or above, the corresponding limit for the RI in BF being 1.4598. The RI measurement has the advantage that it is rapid, but fat still have to be extracted, which can be a lengthy process.

MELTING POINT AND SLIP POINT

The physical property of FA that most affects quality is the melting point because it determines the firmness of fat at a particular temperature (Wood, 1984). Enser (1983) indicated that slip point could indicate the consistency of the BF. The slip point is the temperature at which the semi-solid fat slips up the melting point tube (this occurs at a lower temperature than clarification) (Lea et al., 1970). They stated that melting point is where clarification occurs. Other studies have also been devoted to an evaluation of the physical characteristics of lipids such as melting point or slip point of adipose tissues (Lea et al., 1970; Wood et al.,

1978). Alais & Linden (1991) noted that the increase in the melting point of SFA varies from 6.5°C to 9.5°C for every two additional carbon atoms. Melting point increases as the carbon chain lengthens and decreases as unsaturated linkages are introduced (Wood, 1984). Alais & Linden (1991) stated that the reduction in melting point with increasing number of DB is greater in the cis form than in the trans form. Wood et al. (1978) and Enser (1983) observed that variation in melting point and consistency of fat were strongly correlated with the C18:0 content ($r = 0.928$). Enser et al. (1984) and Wood (1984) suggested that C16:0 could also have a large effect on the melting point. Palmitic acid may have a greater influence on consistency at lower temperatures at which slip point is measured because of its lower melting point and its higher concentration relative to C18:0 (Enser et al., 1984). When C18:2 concentrations are above 15%, fat firmness and melting point are primarily determined by concentrations of C16:0 and C18:2 rather than C18:0 (Cameron et al., 1990). Melting and slip point measurements are, however, too tedious to be used for selecting adipose tissues on-line (Davenel et al., 1999).

Fat Score

Fat score, a semi-automated determination of DB in adipose tissue was established in Swiss slaughterplants as an on-line method to assess BF quality in pigs (Gläser, Scheeder & Wenk, 2000). This procedure was carried out with a titroprocessor by the method of Scheeder et al., according to Gläser et al. (2000). Fat score was positively correlated with consistency (0.78) and oxidative stability (0.36). The lower the fat score, the firmer the fat. Fat score gives a useful at-line estimate of firmness of pig adipose tissue (Gläser et al., 2000).

Colour

As mentioned earlier, colour is one of the most important criteria by which consumers judge quality, it is therefore necessary to measure the colour of fat as Santoro (1983) observed that with advancing oxidation the colour of the oxidized fat turned from normal light yellow to an intense brownish orange. Colour measurement equipment like the Minolta chromometer and Hunter Labscan, according to Barton-Gade (1983), Warnants et al. (1998) and Corino, Magni, Pagliarini, Rossi, Pastorelli & Chiesa (2002) may be used to determine BF colour in terms of Lab *L* (L*) (lightness), Lab *a* (a*) (redness) and Lab *b* (b*) (yellowness) values. Colour measurements of pork fat are usually restricted to the BF only, as regular slices can normally be obtained here (Barton-Gade, 1983). Maw et al. (2003) stated that FA were poor predictors of red colouration and good predictors of translucency

Methods for Rapid Lipid Measurement

According to Wood (1984) the force required to separate muscle and fat layers was related to BFT and was indicatory of the cohesiveness of the fat (Wood, 1983). Irie & Sakimoto (1992) used a texturometer to measure fat firmness. Consistency of fat has also been measured by a penetrometer (Chrystall et al., according to Warnants et al., 1998), a texture analyser (Gläser et al., 2000) and an Instron materials testing machine (Dransfield & Jones, 1984). Objective fat softness measurements, taken by the penetrometer, is not as accurate as the more reliable techniques, such as IV, for the determination of fat softness (Bruwer, 1992). Results given by the puncture test indicated that the consistency of adipose tissue was essentially related to the physical state of the lipids and was only weakly influenced by water and collagen content (Enser et al.,

1984; Whittington et al., 1986). Davenel et al. (1999) indicated that the above method was prone to error if BFT was less than 12 mm, which is the case in most industrial pigs.

Davenel et al. (1999) proposed that the NMR test could be used as a rapid alternative. They stated that one of the simplest methods to characterize the physical state of the fat is to measure its SFC, which depends on the melting points of the TAG, by NMR. They also observed a linear relationship between IV and SFC at 20°C (SFC20). The Bristol Fat Hardness Meter has also been used to measure hardness of fat (Sather et al., 1991, 1995).

Fibre-optic methods are rapid and useful techniques for evaluating porcine fat quality (Irie, 1999). He indicated that an insertion type probe is best suited to measure soft fat, but he suggested that further research was needed to optimize the use of this instrument with regard to fat quality measurement. Andersen et al. (1999) indicated that a hand held NIR based measuring system could be used for detection of soft fat, which might cause problems in pork carcasses anywhere on the slaughter line. They indicated that only 2.41% carcasses were misclassified using this system and stated that this measurement has to be done on dehided carcasses. Fernández, de Pedro, Núñez, Silió, García-Casco & Rodríguez (2003) stated that biopsies of subcutaneous fat samples as well as loin samples could be analysed by using NIR spectroscopy. Ripoche & Guillard (2001) indicated that Fourier transform infrared spectroscopy could determine the FA composition of BF, while middle infrared and NIR measurements evaluated the SFA, MUFA, PUFA, C16:0, C18:1c9 and C18:2 contents. The closest approaches to the use of spectroscopic instruments for on-line carcass grading measurements are the Colormeter Colour vision, the use of the reflectance value of from the Fat-O-Meter and the HGP (Brøndum, Munck, Henckel, Karlsson, Tornberg & Engelsen, 2000).

With the exception of the HGP and Intrascope, these methods are not applicable in South Africa, as the carcasses are not split, ribbed or dehided. Allen & Bray (1964) indicated that in this case quality could best be determined by using an indirect method such as carcass grading procedures, like e.g. the one used by the French, with the necessary adjustments for South African conditions, as already discussed in the first chapter.

FACTORS INFLUENCING FAT QUALITY IN PIGS

BREED OR RACE

The quality attributes of fat regarding content, composition and uniformity as well as oxidative stability are mainly affected by genotype and feeding strategy (Rosenvold & Andersen, 2003). Genetics account for 30% of the variation in meat quality (Casteels, Van Oeckel, Boschaerts, Spincemaille & Boucqué, 1995; De Vries, according to Andersen, 2000) and by implication on fat quality. The genetic influence on pork quality comprises differences among breeds as well as differences among animals within the same breed (Rosenvold & Andersen, 2003). A pig's genetic potential is determined by its ability to grow lean meat. Once lean meat deposition declines, pigs grow slower and will tend to fatten easily if feed intake is not reduced according to the reduction in lean meat deposition (Sharlach, 1998). He stated that early maturing pigs reached their maximum lean deposition at 40–70 kg live weight, while this occurred at 100–130 kg live

weight in late maturing pigs. Genetic variation in fat deposition is mainly due to differences in the rate of fat synthesis (Metz, 1983; Freire, Mourot, Cunha, Almeida & Aumaitre, 1998). The ratio between dietary and *de novo* FA incorporation into the body fat is affected by the rate of fat deposition. Permanent differences in the FA composition of pigs already develop early in the growth cycle. (Metz, 1985). Fatter breeds have a higher proportion of subcutaneous fat (Walstra, Bergström & Mateman, 1983). Kühne (1983) indicated that FA composition of BF was not breed-specific, but it depended on the total fat content of the carcass. The apparent tendency of lean breeds to have poorer fat quality was mostly attributable to their leanness rather than other inherent breed differences (Warriss, Brown, Franklin & Kestin 1990). According to Cameron (1990) and Warriss et al. (1990) this was attributable to fat being less firm due to increased moisture and UFA contents, making it was more likely to separate from underlying muscle.

According to Santoro (1983) some pigs, such as pure-bred Large White pigs, are genetically more suited for the processing industry, because they are more stress resistant than e.g. Landrace pigs (Naudé, 1985). Wood (1973) observed that Pietrains accumulated less saturated fat than Large Whites because the level of fat deposition in Pietrains was smaller than in Large Whites. According to Honkavaara (1989) breed has a larger effect on FA profiles of subcutaneous BF than porcine stress. He indicated that Duroc x Landrace x Yorkshire crosses were better than Landrace x Yorkshire crosses from a technological point of view, in terms of the C18:0/C18:2 ratio. Duroc subcutaneous fat was less firm and contained more moisture than Landrace fat (Cameron et al., 1990). The Duroc has been associated with better eating quality, due to a higher level of IMF (Bejerholm & Barton-Gade, 1986) which is a breed effect (Cameron et al., 1990). They observed that Duroc pigs was more tender, but less juicy than Landrace pigs. According to Fernández, et al. (2003), fat from castrated Iberian pigs, slaughtered at 160 kg live weight, are used for the manufacturing of dry-cured products, which has high sensory characteristics. Hairless Mexican pigs have the ability to deposit large quantities of fat in and on their carcasses, which reduces their market value (Delgado, Gómez, Rubio, Capella, Méndez & Labastida, 2002). Breeds with a low incidence of genetic susceptibility to stress and high concentrations of marbling fat in relation to FT are beneficial (Wood et al., 1992).

PSE AND DFD CONDITIONS AND THE RN^- GENE

According to Andersen (2000) genetics influence quality attributes, like the halothane and RN^- gene, which cause inferior quality pork. Selection pressure on the decrease in fat deposition accordingly leads to a reduction in lipogenesis as well as a simultaneous increase in lipolysis and glycogenolytic rate, favouring development of PSE meat (Müller, 1983). Ahn, Nam, Du & Jo (2001) indicated that DFD muscle was very stable and resistant to oxidative change. It was hypothesized that PSE meat would be more susceptible to oxidative changes and produce more off-flavour volatiles than normal and DFD pork when irradiated (Ahn et al., 2001). According to Nilzén, Babol, Dutta, Lundeheim, Enfält, Lundström (2001) lipid oxidation occurred more rapidly during storage in especially female carriers of the RN^- gene, which had a higher lean meat percentage. Jeremiah (1982) indicated that BF of DFD pigs had lower C16:0 and PUFA contents and higher SFA than PSE and normal pigs. Honkavaara (1989) showed that halothane positive (stress susceptible) pigs had higher C18:2, C18:3 and PUFA than halothane negative (stress resistant) pigs. Piedrafita et al. (2001) showed that C14:0, C16:0 and C16:1 decreased while C18:0 increased in stress susceptible pigs.

BACKFAT THICKNESS

Since BFT is a major index of fatness, its lipogenic activity can give an estimation of overall fat synthesis in the body (De Wilde, 1983). Wasltra et al. (1983) and Wood (1983) indicated that research shows that fat quality is influenced by FT and that the class with the thickest BF, have the highest percentage subcutaneous fat, thus it is best in fatter pigs. Whittington et al. (1986) and Cameron et al. (1990) observed that the C18:2 content decreased with increased BFT. Piedrafita et al. (2001) found a positive correlation between LMC and C18:2 and C18:3, while the correlation of BFT and these two FA were negative. Gandemer (2002) stated that more developed BF has more SFA and MUFA (from *de novo* synthesis) and less PUFA (from the diet). Shoulder and leg cuts and their LMC in pigs increased as BFT decreased (Martin et al., 1972). Walstra et al. (1983) stated that leaner animals had thinner BF in the more caudal regions and the lowest proportions of subcutaneous fat. BFT could influence juiciness (Wood et al., 1986b) while flavour, tenderness and overall acceptability are only minimally influenced (Wood et al., 1986b; De Vol et al., 1988). Hugo, Osthoff & Jooste (1999) stated that technological properties, chemical composition and oxidative stability of BF would improve with increased BFT.

AGE AND SLAUGHTER WEIGHT

Increasing age at slaughter could result in an improvement of pork quality (Candek-Potokar, Zlender, Lefaucheur, & Bonneau, 1998, Lebret, Noblet & Bonneau, 1999). Kühne (1983) stated that age and SLW were reduced, in order to supply the consumer with lean pigs. Increasing carcass weight concomitantly increases age (Beattie, Weatherup, Moss & Walker, 1999) and the amount of adipose tissue at slaughter (Nürnberg et al., 1998). The chemical fat content of BF increased with growth of pigs and the rapid adipose tissue growth in pigs (100–180 days of age) is followed by a phase when adipocyte growth is minimal (180–220 days of age) (Nürnberg et al., 1998). They indicated that UFA content decreases up to 180 days of growth after which there is no change in FA composition. As pigs age and if they are slaughtered at 100 kg live weight, they would have, according to Osterhoff (1988), deposited all their fat tissues, including the IMF. Bruwer et al., (1991) stated that younger pigs deposit more unsaturated lipids and fat tends to be softer, while older pigs have harder, firmer, more saturated fat, preferred by a butcher and processor. Sink et al. (1964) also indicated that the proportion of SFA increased with age.

With increasing SLW, animals convert their food less efficiently and produce carcasses with a higher fat content (García-Macías, Gispert, Oliver, Dietstre, Alonso, Muñoz-Luna, Siggens & Cuthbert-Heavens, 1996) and BF with a more saturated profile (Sink et al., 1964; Martin et al., 1972; Cameron et al., 1990; Bruwer et al., 1991; García-Macías et al. 1996; Nürnberg et al., 1998). Wood, Enser, Whittington, Moncrieff & Kempster (1989) confirmed that increase of weight and subcutaneous FT increased the C16:0, C18:0 and C18:1c9 contents while C18:2 and C18:3 contents decreased. Mourot, Kouba & Peiniau, (1995) did not find significant effects on the FA with increased SLW. Beattie et al. (1999) indicated that with increased SLW, eye muscle area as well as subcutaneous fat content increased while LMC decreased, with intermuscular fat left unaffected. García-Macías et al. (1996) found that increasing SLW significantly improves fat quality.

The ideal pig reaches a SLW of about 100 kg by growing at a rate that precludes the excessive deposition of fat by the time it is ready for marketing (Anon, 1995). When slaughtering occurs at a lower live weight, the lower cohesiveness of fat becomes increasingly important, especially in boars (Metz, 1985). Several authors

have observed an increase in BFT for every 10 kg increase in SLW, namely 1.1 mm, measured at the last rib over the loin at 90–120 kg SLW (García-Macías et al., 1996), 2.9 mm, measured on the midline at the last rib at 70–130 kg SLW (Hansson, Lundström & Malmfors, 1975), and 3.7 mm, measured on the midline at the last rib at 85–112 kg SLW (Fortin, 1980). Fat quality defects are more frequently present in pigs from very lean strains, commonly slaughtered at low live weights (Santoro, 1983). The meat industry, especially retail butchers have complained about the increasing incidence of meat quality problems in meat from leaner animals (Kempster et al., 1986). Vervoort (1997) reported that in European countries and the USA the average SLW of pigs are increasing towards 90 kg, while in Germany it already exceeds 90 kg. In South Africa the usual carcass weight is 50–55 kg (porkers) or 70–75 kg (baconers) with a maximum of 85 kg (Vervoort, 1997). Bruwer (1991) indicated that South African pigs weighing less than 20 kg are classified as suckling pigs, while those weighing more than 90 kg are known as sausage pigs. Pieterse, Loots & Viljoen (2000) stated that the average SLW of pigs in South Africa is 70 kg. Hugo et al. (1999) indicated that the low SLW of pigs in South Africa results in low BFT. Santoro (1983) stated that SLW and age should be high when pigs are to be used for cured and seasoned uncooked products. Cisneros, Ellis, McKeith, McCaw & Fernando (1996) indicated that belly yields increased with SLW.

SEX AND GENDER

Moss (1992) indicated that in farm animals differences regarding gender (male/female) and sex status (castrated or entire animals) exist. According to Van Oeckel, Casteels, Warnants, Van Damme & Boucqué (1996) entire (uncastrated) male pigs have more lean meat per carcass and have better feed conversion ratios than castrates. The FA composition of BF is also significantly affected by gender (Malmfors et al., 1978a; Nilzén et al., 2001). The difference in sex hormone metabolism between males and females may be responsible for the effects on fat composition (Wood et al., 1989; Nürnberg et al., 1998). Bruwer et al. (1991) indicated that barrow (castrate) carcasses contained the most fat, gilts were intermediate and boars had the highest LMC. Gilts are much better than barrows and boars for the manufacture of products such as canned hams where the protein content of the raw material determines the yield of product (Barton-Gade, 1987). Females have more UFA (Malmfors et al., 1978a; Nilzén et al., 2001; Piedrafita et al., 2001) and less SFA (Nilzén et al., 2001) than barrows. Warriss et al. (1990) indicated that fat from gilts separated slightly more from muscles than that of castrates, while Bruwer et al. (1991) stated that fat separation occurs more frequently in boars than in gilts. This separation causes handling difficulties in meat experienced by packers as well as decreasing the quality of the cuts (Kempster et al., 1986; Wood et al., 1986b).

Boars are leaner than barrows and contain more water and less lipid in fat tissues, at the same FT (Wood, 1983; Wood et al., 1985; Bruwer et al., 1991; Phelps, 1991). There is however, no evidence that boars have inherently less firm or cohesive fat tissues than barrows or gilts at the same FT levels (Wood, 1983; Wood et al., 1985). According to Wood & Enser (1982) boars had a higher FFDM content than barrows, which indicated that synthesis of connective tissue was higher in boars. Vold & Moen (1972) and Wood & Riley (1982) indicated that boars had a thicker skin and that testosterone possibly had the primary effect on the synthesis of collagen in skin and BF. Bruwer et al. (1991) stated that because boars are late maturing, their fat would accumulate at a later stage than barrows and gilts. Boar fat tissues are reputed to be soft and floppy and boar sides are said to lose more weight during Wiltshire curing than barrows (Wood & Enser, 1982). The most likely reasons for the lower processing yields for boar meat were its lower fat level and

higher UFA level, as well as its higher water content (Wood & Enser, 1982). Babol & Squires (1995) indicated that boars only have slightly lower processing yields compared to the other genders.

Siebrits, Kemm & Ras (1987) found the C14:0 content to be higher in gilts than in boars. Martin et al. (1972), Malmfors et al. (1978a) and Wood et al. (1986a) stated that boars contained a higher proportion of C18:2 and C20:4, less C16:0 and C18:1c9, with no difference in C18:0 content. Boars, therefore, had higher UFA and PUFA contents than barrows and gilts were intermediate to the two. Martin et al. (1972) found barrows to have more C14:0 and C16:0 than gilts or boars. Bruwer et al. (1991) confirmed this as they found fat from boars to be softer than that of gilts and barrows, the latter having the hardest fat. According to Barton-Gade (1987) the higher SFA content in barrows was due to C16:0, while the high UFA content in boars was the result of elevated C18:2 levels. Wood & Enser (1982) stated that soft fat was a feature of lean pigs of either sex and Bonneau (1998) confirmed this by stating that the poorer quality of boars was due to their leanness rather than their sex. By feeding boars at a relatively high level, many problems associated with excessively soft fat can be avoided (Babol & Squires, 1995).

Johns (1941) reported that IV of BF ranged from boars to gilts to barrows, in decreasing order and varied inversely with BFT among all sexes. Barton-Gade (1987) stated that, in terms of IV $\geq$ 70, 20% of boars had inferior fat quality while 7% of gilts and 1% of barrows had this problem. Moss (1992) indicated that their aggressive nature has limited the use of boars in animal production mainly because this leads to glycogen depletion and causes DFD meat. Sex differences are more marked in the IMF than in the BF (Malmfors et al., 1978a; Hugo, 2000).

Currently Great Britain, Ireland, Spain and Denmark produce boar meat (Babol & Squires, 1995; Verbeke et al., 1999). The most important limitation to the use of entire males is the existence of boar taint, which can displease the consumer and potentially result in a lower acceptability of pork (Wood & Enser, 1982; Bonneau, 1998). Boar taint is produced by a steroid (androstenone) and a degradation product of tryptophan, skatole, which are both deposited in the fat and released upon heating (Andersen, 2000).

Verbeke et al (1999) stated that it is a general custom in pig rearing to castrate male pigs to prevent boar taint. Potgieter, Heinze, Anderson & Viljoen (1996) warned that feeding boars a high protein diet will cause them to reach puberty faster, leading to an increase in androstenone production. Lopez-Bote & Ventanas (1988) indicated that treating neonatal pigs with 100 mg of testosterone propionate would lead to a reduction in the endocrine secretion of the testes and a subsequent decrease in boar odour. They also observed a more saturated profile in the fat of these pigs, which can be beneficial to the processor. Abnormal (boar) flavour was negatively correlated with C16:0 and positively with C18:2 and C18:3 content (Cameron et al., 1990).

GROWTH PROMOTERS

The main role of porcine somatotropin is to change the partitioning of absorbed nutrients rather than altering the digestibility of ingested nutrients (Squires, Adeola, Young & Hacker, 1993). Backfat thickness could be reduced between 20 and 45% by porcine somatotropin and feed conversion can be significantly improved (Cannon, Morgan, Heavner, McKeith, Smith & Meeker, 1995). Solomon, according to Jiménez-Colmenero,

Carballo & Cofrades (2001) showed that administration of somatotropin to pigs can lead to a 60% reduction in carcass fat, a 70% increase in carcass protein content and 27% less lipid in lean tissues. Porcine somatotropin reduces the rates of lipogenesis, glucose oxidation and insulin stimulated glucose metabolism (Squires et al., 1993). While being effective in reducing BF, porcine somatotropin has the potential to have a negative impact on pork quality (D'Souza & Mullan, 2002).

According to Squires et al. (1993) the β-adrenergic agonists, ractopamine, cimaterol and salbutamol, interact with β-adrenergic receptors in the cell membrane. Cannon et al. (1995) indicated that ractopamine improves feed efficiency, increases lean growth rate, reduces the amount of carcass fat and improves cutting yields. They also stated that IMF is not significantly changed by ractopamine, mainly the subcutaneous and intermuscular fat are reduced. Perkins, according to Cannon et al. (1995), showed that tissue cholesterol content is reduced by ractopamine treatment. In general, β-adrenergic agonists reduce the rate of lipogenesis through a reduction in the number of insulin receptors and in the binding of insulin to adipocytes (Squires et al., 1993).

Martinez, López-Bote, Sancho & Ventanas (1992) indicated that the use of anabolic agents like implanted trenbolone acetate (300 mg) had no effect on FT in gilts but significantly reduced fatness and tended to make fat more unsaturated in barrows.

DIET

According to Nürnberg et al. (1998) the potential for dietary manipulation of the FA composition of monogastric animals (like pigs) are much greater than for ruminants, because FA from the diet pass through the digestive system and are deposited unchanged in the different depots. Manipulation of the FA profile by dietary means may also alter the sensory profile of the meat (Verbeke et al., 1999). Intramuscular fat is much less affected by diet than subcutaneous fat, probably because the latter fat grows at a faster rate (Brooks, 1971).

Adding fat to pig diets will improve the energy content thereof (Kouba & Mourot, 1999). The most important factors for the evaluation of fats in pig diets are palatability, content of metabolizable energy and the influence of fat intake on the performance and the carcass composition of the animals (Berschauer, 1983). Dietary fat supplementation decreases the endogenous fat synthesis and increases the deposition of the dietary fat into the fatty tissues of the pig (De Wilde, 1983). Depending on the protein source, the lipid content of conventional pig diets can vary, but rarely exceeds 3–4% (Farnworth & Kramer, 1987). Metz (1983) indicated that with leaner pigs, the level of fat in rations should be kept very low or feed should have a very saturated profile in order to produce good quality fat.

Lebret et al, according to Verbeke et al. (1999) and Ellis et al, according to Andersen (2000) stated that *ad lib* feeding leads to more depot fat and it has a positive effect on eating quality, mediated by a higher IMF level. Backfat from *ad lib* fed pigs was firmer and had a lower moisture content than that of restricted fed pigs (Cameron et al., 1990). Hilditch, Lea & Pedelty (1939) found that fat produced from a restricted diet was softer, because it contained less C16:0, but more C18:2 and C18:1c9. Feed restriction increased carcass leanness and decreased IMF content, but combined with a decreased lysine/energy ratio led to a similar

carcass composition, but with a higher IMF content than *ad lib* feeding (Lebret et al., 1999). Increasing dietary crude protein or lysine to energy ratio, improves growth rate, LMC and gain to feed ratios, but reduces marbling and sensory appeal (Madsen et al., 1992; Castell et al., 1994).

Verbeke et al. (1999) stated that dietary MUFA incorporation in pork fat is less pronounced, because MUFA is the predominant FA in pigs and therefore MUFA from endogenous origin also plays an important role. Polyunsaturated FA in pork fat are exclusively of dietary origin and the effects thereof are reflected in the adipose tissue of the pig (Ellis & Isbell, 1926; Warnants et al., 1996; Verbeke et al., 1999). Pigs fed high PUFA diets had less SFA (mainly C16:0 and C18:0) and more total PUFA (mainly C18:2 and C18:3) in their BF (Bryhni et al., 2002). Morgan, Noble, Cocchi & McCartney (1992) found that, as a consequence of increased unsaturation in pork, fat became soft and difficult to handle and process. Special attention should be paid to the C18:2 content of the diet (Wood, 1984). Backfat thickness has decreased over the years, but the intake of C18:2 has been unchanged or even increased, leading to more C18:2 being deposited in BF (Madsen et al., 1992). Therefore, carcass fat is softer in the modern type of pig than in older ones. The technological qualities of C18:2-rich meat are poor (soft BF with a decrease in storage stability) (Kouba & Mourot, 1999).

According to Enser (2000) corn, sunflower and safflower oils have high C18:2 contents. Koch et al. (1968b) found that BF from pigs fed safflower oil was more unsaturated than that from control pigs. Brooks (1971), Wood (1984), West & Myer (1987) and Jónsdóttir, Porkelsson & Haraldsson (1996) indicated that peanuts and soybeans are major sources of C18:2, which causes soft fat and decreases BF firmness. When measured in terms of C18:2 content, RI and IV, wheat results in better BF quality than maize (a major ingredient in South African pig rations) (Siebrits et al., 1987). The lipid, C18:2 and cholesterol contents were higher in the adipose tissue of pigs fed maize (Kouba & Mourot, 1999). Feedstuffs such as maize meal, fish meal, sunflower oil cake meal and soybean oilcake meal are commonly used in pig diets in South Africa (Viljoen & Ras, 1991).

Coconut fat and palm oil are characterized by a high content of C12:0 and C14:0 (Madsen et al., 1992; Lauridsen, Andersen, Andersson, Danielsen, Engberg, Jakobsen, 1999) resulting in very firm BF with an IV of 35. In a study by Van Schalkwyk (2002) barley, feed wheat, hominy chop and poultry by-product were identified as feed ingredients with the most potential to improve technological fat quality of South African pigs. With these ingredients he showed that it was possible to produce pigs with good fat quality (a more SFA profile) in the lowest BFT ranges (P and O classification groups).

Elliot & Bowland (1968) and Wood (1984) observed that adding copper to the diet at a level of 250 ppm, which is enough to promote growth, results in soft fat. Copper probably increases the ratio of C18:1c9 to C18:0, possibly by activating the desaturase enzymes (Thompson, Allen & Meade, 1973). It could also be ascribed to an increase in C16:1 and a decrease in C16:0 (Elliot & and Bowland, 1968) and/or to a change in the structure of the TAG (Christie & Moore, 1969). According to Wenk, Gebert & Pfirter (1995) chromium supplementation increased body weight gain and the feed conversion ratio. Page, Southern, Ward & Thompson (1993) indicated that supplementing the diet of growing pigs with chromium picolinate led to decreased tenth rib FT in growing and finishing pigs.

Used oils can be considered a high-energy food source for animal feed and are utilized, to a large extent, in South Africa (Kock, Botha, Bloch & Nigam, 1996). The increased susceptibility to oxidation and off-flavour through enrichment of pork fat and meat with oxidized oils and PUFA can be counteracted and delayed by raising the Vitamin E level in pork tissues (Buckley & Connolly, 1980; Monahan, Buckley, Gray, Morrissey, Asghar, Hanrahan & Lynch, 1990; Monahan, Buckley, Morrissey, Lynch & Gray, 1992a; D'Arrigo, Hoz, Lopez-Bote, Cambero, Pin, Rey & Ordóñez, 2002). Vitamin E, administered in the feed, is incorporated in cell membranes and prevents oxidation of unsaturated TAG and phospholipids (Buckley & Connoly, 1980; Verbeke et al., 1999). Vitamin E can also be obtained through grazing green feed (Nilzén et al., 2001).

The n-6/n-3 balance of lipids changes according to its balance in the feed (Okuyama & Ikemoto, 1999). This is an important nutritional ratio. Ahn, Lutz & Sim (1996) indicated that elevation of C18:3 in the diet decreases the n-6 levels in pigs. Feeding n-3 PUFA to pigs to improve the quality of pork in human nutrition increases the susceptibility to oxidation further (Sheard, Enser, Wood, Nute, Gill & Richardson, 2000). Fish oils, added to pig feeds, either directly or in the form of fishmeal, provide energy and Vitamins A and D (Trout, Hanrahan, Dinh & Chai, 1998) and increase the levels of C20:5 and C22:6 (n-3 PUFA) in BF (Hertzman, Göransson & Rudérus, 1988; Morgan et al., 1992; Irie & Sakimoto, 1992). According to Irie & Sakimoto (1992) inclusion of fish oil in pig diets, increase IV and RI-values and decrease fat hardness, without affecting fat colour. As a result of environmental and other concerns about the use of fish oil in animal feeds, many studies have been carried out to lower the n-6/n-3 ratio and SFA content of BF by feeding linseed or canola as a source of C18:3 (Rhee et al., 1988a; Shackelford, Miller, Haydon & Reagan, 1990; Cherian & Sim, 1995; Ahn et al., 1996; Warnants et al., 1996; Okuyama & Ikemoto, 1999). Canola is the name reserved for rapeseed that is low in glucosinolates and erucic acid (C22:1), both undesirable to humans (Rhee et al., 1988a). Nilzén et al. (2001) found that grass, barley and oats were very rich in C18:3. Johansson, Lundström & Jonsäll (2002) stated that feeding red clover silage to pigs lowers both the n-6/n-3 ratio and the SFA content. The increase of n-3 PUFA in meat, by feeding grass or fish oil to farm animals, improves its value for human nutrition, but careful attention must be paid to the risk of increased rancidity (Nürnberg et al., 1998).

Conjugated linoleic acid (CLA) occurs naturally in ruminants and ruminant products as the 9- cis, 11- trans conjugated isomer of octadecedienoic acid (C18:2) (Enser, 2000). It is formed by a bacterial isomerase (enzyme) in the rumen as the first stage in the biohydrogenation of C18:2 to C18:0 (Kepler & Tove, according to Enser, 2000) by which hydrogen is added to DB of UFA (Khosla & Hayes, 1996) by the action of the bacterium *Butyrivibrio fibrisolvens* (Kepler et al., according to Lee, Park, Ha, Shin, Joo & Park, 1999). Conjugated linoleic acid in pig muscle can only be elevated by dietary CLA (Lee et al., 1999). The many benefits of CLA consumption have generated considerable interest in feeding large animals CLA to determine if CLA can improve carcass composition and growth performance, while providing CLA-enriched products for human consumption (Dugan, Aalhus, Jeremiah, Kramer & Schaefer, 1999). A potential use for CLA in animal nutrition is to use it to partition energy towards protein deposition rather than lipogenesis (Enser, 2000). Feeding 2% dietary CLA to pigs increased IMF, with no detrimental effect on pork quality (Dugan et al., 1999). An increase in C14:0, C16:0, C18:2, C20:4, CLA (Lee et al., 1999) and C18:0 (Averette Gatlin, See, Larick, Lin & Odle, 2002) and a decrease in C18:1c9 (Lee et al., 1999; Averette Gatlin et al., 2002) as well as C18:2 (Joo, et al., 2002) were observed when pig diets were supplemented with CLA.

Conjugated linoleic acid supplemented pigs had reduced susceptibility to oxidation, improved colour stability and better WHC (Joo et al., 2002) but inferior flavour, tenderness, juiciness and overall acceptability (D'Souza & Mullan, 2002).

REARING CONDITIONS

A new generation of consumers chooses meat products not only according to eating quality and price, but also considers the ethical quality of the meat, involving animal welfare issues and the degree of impact on the environment caused by the production system (Nilzén et al., 2001; Rosenvold & Andersen, 2003). Extensive production systems, such as free-range or other forms of environmentally enriched production and pigs fed natural feeds, have become one of the new targets for European and North American pig meat industries (Lebret et al, according to Rosenvold & Andersen, 2003; Sather et al., according to Rosenvold & Andersen, 2003). No general trends regarding the influence of pig rearing systems on meat quality can be found (Lebret, Massabie, Granier, Juin, Mourot & Chevillon, 2002). These studies produced conflicting results. Pig rearing systems did not influence the lipid content of BF, but strongly modified its FA composition (Lebret et al., 2002). Nilzén et al. (2001) found that outdoor rearing resulted in higher PUFA in IMF, reduced WHC and lower crude protein content, without affecting other technological meat quality traits than traditionally reared pigs. Högberg, Pickova, Babol, Andersson & Dutta (2002) indicated that the PUFA content in the neutral lipids of indoor reared pigs were higher than outdoor reared ones, while females had more unsaturated fat than barrows. Nilzén et al. (2001) stated that pigs with access to green feed (barley, peas and oats) had higher PUFA levels in their BF. Högberg et al. (2001) found a slight increase in the amount of trans FA in free-range pigs, especially elaidic acid (C18:1t9). Morrison, according to Högberg et al. (2001), indicated that C18:1t9 and C18:1t7 are not found in plants, which form the bulk of the diet of free-range pigs. Högberg et al. (2001) indicated that they might obtain these acids from other materials (worms and other organisms) in the free-range environment or that microorganisms in the free-range pig's digestive tract cause hydrogenation of PUFA to trans FA. They proposed further research to establish the origin of the elevated trans FA in free-range pigs.

Outdoor rearing may influence growth performance and carcass composition of pigs differently, depending on climatic conditions and probably the level of physical activity of the animal (Lebret et al., 2002). They observed that pigs exposed to cold weather showed an increase in MUFA and a decrease in SFA and PUFA content (although slight in the latter). Dworschák, Barna, Gergely, Czuczy, Hóvári, Kontraszti, Gaál, Radnóti, Bíró & Kaltenecker (1995) observed 15% less cholesterol in muscles and less C18:2 in all tissues of free-range pigs, while protein, zinc, copper and iron were elevated in free-range pigs. Van der Wal et al., according to Smulders & Van Laack (1992) indicated that there were no differences regarding tenderness, colour, juiciness, flavour and odour and confirmed the higher C18:2 content of "scharrelvarkens" (as free-range pigs are known in the Netherlands). Finishing pigs outdoors may improve pork colour and tenderness but may also increase the BFT when they are fed conventional diets (Gentry, McGlone, Miller & Blanton, 2002).

ENVIRONMENTAL TEMPERATURE

Close (1983) and MacGrath, Vander Noot, Gilbreath & Fischer (1968) indicated that deposition of fat is more temperature-dependent than protein deposition. They indicated that the physical characteristics of the fat,

including melting point and unsaturation, were also temperature-dependent. During the past years, both the utilization of genetically leaner pigs and the development of intensive production systems, in which large numbers of pigs are reared on totally slatted floors, have increased the animals' sensitivity to environmental temperature (Rinaldo & Le Dividich, 1991). Animals will be fattest in the thermoneutral zone (where environmental demand is minimal and available energy is maximal); any departure from there (higher or lower temperature) will result in a leaner animal (Close, 1983; Rinaldo & Le Dividich, 1991). In the cold, when voluntary metabolizable energy is sufficient to maintain energy retention, protein and fat deposition are independent of environmental temperature (Rinaldo & Le Dividich, 1991). Pigs in high ambient temperatures will voluntarily decrease their feed (protein and energy) intake to lower the burden of heat dissipation. This results in reduced body fatness and growth rate because of diminished net energy available for tissue deposition (Stahly & Cromwell, 1979; Rinaldo & Le Dividich, 1991). The latter authors indicated that above the lower critical temperature, i.e. 25 to 31.5°C, less fat was deposited in BF and more fat was retained in leaf and viscera fat. They also indicated that heat production was minimal in this temperature range. Dietary supplementation of fat at 35°C increased BFT and percentage body fat by 7 and 15%, respectively (Stahly & Cromwell, 1979). This increase in body fat deposition was due to the lower heat production with high fat diets (Chilliard, 1993). Stahly & Cromwell (1979) observed that fat supplementation in the diet of finishing pigs in cold environments increased BFT with 3% and body fat content by 4%, but dietary fat depressed fat deposition in growing pigs from a cold environment. MacGrath et al. (1968) reported an inverse relationship between body temperature and the degree of BF unsaturation (IV) for pigs receiving diets without added fat, suggesting that temperature mediate this effect.

Swine increase feed intake in response to low ambient temperatures as well as in thermoneutral environments, in an effort to meet their thermal demand of maintaining body temperature (Lopez, Jesse, Becker & Ellersieck, 1991), but not in hot environments (Stahly & Cromwell, 1979). Lopez et al. (1991) indicated that, in cold temperatures, pigs grew slower and had a poorer feed conversion ratio than pigs from a thermoneutral environment. According to Stahly & Cromwell (1979) this happens in order for the pig to produce heat to maintain its body temperature. Lefaucheur, Le Dividich, Mourot, Monin, Ecolan & Krauss (1991) stated that pigs in colder environments (12°C) had more subcutaneous fat than pigs from 28°C. At 12°C they observed increased lipogenic enzyme activities and BF unsaturation, which led to softer fat. Stahly & Cromwell (1979) and Close (1983) indicated that animals will become morphologically adapted to their environment. Stahly & Cromwell (1979) indicated that dietary fat supplementation in cold environments would not affect the efficiency of energy utilization, whereas in hot environments, body heat production will be reduced and should result in improved efficiency of energy utilization. MacGrath et al. (1968) observed that animals exposed to cold environments had fat with a more unsaturated profile than animals exposed to warm environments. Close (1983) observed higher C16:0 and C18:0 contents in pigs kept in warm environments. The rate, efficiency and composition of growth in pigs fed *ad lib* is influenced by the environmental temperatures in which they are maintained and the response of the pig to dietary fat supplementation is altered by the environmental temperature at which it is fed (Stahly & Cromwell, 1979).

INFLUENCE OF FAT QUALITY ON TECHNOLOGICAL PROPERTIES

In 3000 BC, when meat products were first mentioned, the objective of manufacturing meat products was most probably to enhance shelf-life. Later, the flexibility in the formulation thereof led to new benefits. Meat products offer a rational way to use different parts of a carcass (Puolanne, 1999). Andersen (2000) indicated that technological quality include attributes like WHC, pH-value, protein content, lipid content, connective tissue content, particle size and antioxidative status. Production and slaughter factors can be used to control technological quality traits (Rosenvold & Andersen, 2003).

Pork fat is categorized into lard, flare, jowl and belly fat (Fischer, 1989a). The properties of the fat determines the product in which it can be used (Wood, 1993). Fischer (1989a) recommended that pure lard had to be used in the manufacture of high quality products, while fatty tissue should be used for products of median or lower quality grades. Santoro (1983) stated that, in Italy, the outer layers of the BF, the jowl fat and part of the trimmed belly are classified as firm fat and are used in the manufacture of cooked and uncooked comminuted processed meat products. He also indicated that the inner layer of the BF, perinephric and part of the trimmed belly, which are classified as soft fat, were melted and used as shortening in bakery products. Very little information regarding the suitability and/or requirements of fat for the manufacture of meat products are available (Fischer, 1989a). He indicated that selecting fat for various meat products depends, to a large extent, on the experience and empirical data of the specific manufacturer. However, some products require a specific type of fat, e.g. salami, in which only BF of high quality is used. Apart from such exceptions, a mixture of different fatty tissues is usually processed.

FRESH MEAT

No clear cut quality requirements regarding fat quality of fresh meat are available in literature although it is clear that requirements are not as severe as for processed meat products (Warnants et al., 1996). The selection for genetically leaner pigs led to the production of carcasses with inferior fat quality (Metz, 1985). One of the consequences of breeding leaner pigs has been a decline in the saturation of the pig fat (Warkup, according to Sheehy, Morrissey, Buckley & Wen, 1997). Softer fat, with increased PUFA levels, is more susceptible to oxidation (Moran, 1996; Chizzolini, Zanardi, Dorigoni & Ghidini, 1999). This more unsaturated fat might cause problems for the major retailers, turning towards centralized butchery and modified atmosphere packaging (MAP), as the meat will be exposed to higher oxygen levels for longer periods prior to sale (Warkup, according to Sheehy et al., 1994). Modified atmosphere packaging of meat is a complex and dynamic system (Bertelsen, Jakobsen, Juncher, Møller, Kröger-Ohlsen, Weber & Skibsted, 2000) by which oxygen is displaced, enabling a longer shelf life for the product (Moran, 1996). He showed that higher amounts of UFA, especially C18:1c9, compromised the effectiveness of MAP in ground pork upon refrigerated storage. Houben, Eikelenboom & Hoving-Bolink (1998) indicated that MAP (initial gas mixture: $O_2/CO_2/N_2$ = 66/27/7) protected ground meat, originating from pigs supplemented with Vitamin E, against oxidation. Meat from unsupplemented pigs showed an increase in oxidation when MAP was employed.

Fresh pork has a limited shelf and storage life, even during frozen storage, because of the development of oxidative rancidity and off-flavours (Benedict, Strange & Swift, 1975). Lipoperoxidation occurs in meat during storage, particularly in membranes that are exposed to aqueous systems and oxygen. Frozen storage reduces the rate of peroxidation, however PUFA losses in phospholipids can still be extensive after extended

storage periods, especially with cooked products (Moran, 1996). Igene & Pearson (1979) indicated that the amount of PUFA in the phospholipids might induce autoxidation and ultimately warmed-over flavour (WOF) in meat. Warmed-over flavour is mainly related to pre-cooked meat products intended for reheating (Bertelsen et al., 2000). They found that the outer BF layer could contain up to 22% PUFA without causing problems in fresh and frozen meat while Bryhni et al. (2002) found that rancidity was higher when BF contained 23% PUFA. The typical marine PUFA (C20:5, C22:5 and C22:6) are risk factors for off-flavour in pork after frozen storage (Hertzman et al., 1988; Brynhi et al., 2002). Fresh pork patties were especially susceptible to oxidation (Buckley, Gray, Asghar, Price, Crackel, Booren, Pearson & Miller, 1989) because partial disintegration of the compartementalized organisation of the muscle structure during grinding facilitates the contact between oxidizable cellular components and pro-oxidants (salt, haem, etc.) (Gray & Pearson, 1987; Asghar, Gray, Booren, Gomaa, Abouzied, Miller & Buckley, 1991). This leads to the incorporation of air or oxygen into the tissues which accelerates the oxidation process (Buckley et al., 1989). Care therefore has to be exercised when formulating pork patties for long term frozen storage to ensure that PUFA content of fat is not to high.

During recent years, the increasing interest in improving the oxidative stability of fresh pork (improved colour stability and reduced rancidity development) have resulted in a large number of studies that examined the effects of dietary Vitamin E on the oxidative stability of fresh pork (Ashgar et al., 1991; Andersen, 2000). In meats held at refrigeration temperatures, increased muscle α-tocopherol may be more beneficial, by exhibiting antioxidative properties, in meats containing higher proportions of UFA (Rhee et al., 1988a) and hence having an increased tendency to oxidize (Monahan, Gray, Booren, Miller, Buckley, Morrissey & Gomaa, 1992b). Monahan et al. (1990) indicated that dietary Vitamin E supplementation resulted in improved oxidative stability of raw and cooked pork muscle during refrigerated storage at 4°C for up to 8 days. Vitamin E stabilized membrane-bound lipids against oxidation and this might be one of the most effective ways of extending shelf life of restructured and pre-cooked meat products. Mono-unsaturated FA enrichment offers a good alternative to PUFA enrichment, as the MUFA already constitutes the bulk of the pig's fat. Restructured pork chops and ground pork patties, prepared from animals fed on a diet containing 12% high oleic sunflower oil, had nutritionally desirable FA compositions, i.e. high MUFA/SFA ratios, even after cooking. Cooking loss was not affected by dietary high oleic sunflower oil treatment (Rhee, Ziprin & Davidson, 1990). The tenderness, juiciness and flavour of meat enriched with MUFA increased (Rhee et al., 1988b).

Contrary to fresh pork where few problems are to be expected when properly stored, meat products manufactured from PUFA-rich pork fat might suffer from taste aberrations, a higher frequency of dislikes and an impaired consistency, due to soft BF (Houben & Krol, 1980; Kunz, 1991; Warnants et al., 1998).

RAW FERMENTED AND CURED SAUSAGES

Consistency has been recognised as the most important quality trait to consider in the choice of adipose tissue for dry-cured meat product processing (Whittington et al., 1986). An inferior (soft/weak) consistency, as a result of added PUFA, is often experienced when manufacturing dry fermented products, as the melted fat can drip out of the product during the drying or ripening phase, preventing the product from drying by impairing gel formation and water release. As a result of unsatisfactory hardness, a fatty smear upon cutting

or slicing can be observed on the cutting surface of the knife (Houben & Krol, 1980, 1983; Fischer, 1989b; Warnants et al., 1998; Gandemer, 2002). Houben & Krol (1980, 1983) found that soft fat obstructed the flow of the dough in the bowl chopper. They also observed that soft fat exuded during stuffing as well as upon smoking and ripening. In dried meat products, cohesiveness of fat is an important factor, because pieces of muscle tend to separate from soft fat, especially in dry-sausages (Gandemer, 2002). Even when sufficiently frozen to approximately –8°C, soft fat starts to smear in the cutting process (Fischer, 1989b). Soft fat is highly susceptible to oxidation (Houben & Krol, 1983).

Salami products consist of proteins of high value as well as animal fat, rich in SFA and cholesterol. Pork BF is the main fat source of salami and plays a significant role in the flavour, texture, colour and drying process of these products (Severini, De Pilli & Baiano, 2003). In non-cooked (raw) sausages granulated fat helps to loosen the sausage mixture, which aids in the continuous release of moisture from the inner layers of the product (Wirth, according to Papadima & Bloukas, 1999). The FA composition of BF is affected by dietary treatment and gender variations. Consequently, the variations in the fat quality observed in the BF will be reflected in the salami. The gender of the pig affects the lipolytic activity in the salami, presumably because the endogenous lipases of the BF are more active in the more unsaturated gilt fat (Warnants et al., 1998). Fat accounts for at least 30% of the raw material of dry-cured sausages and therefore determines several quality attributes thereof (Gandemer, 2002). He indicated that dry-cured sausages of high quality, such as French saucission and Milano salami, required firm adipose tissue. Fresh and matured Milano salami sausages, on average, contained around 40% SFA, 47% MUFA and 13% PUFA (Zanardi, Dorigoni, Badiani, Chizzolini, 2002).

Opinion consensus prevails both in the literature and in the practical processing field that solid, gritty, firm pork fat (originating from the nape or back) should be used for firm-cutting, uncooked (raw) sausage (Scheid, according to Fischer 1989b). This particular type of fat will frequently be in short supply, particularly in plants with a high output of hard raw sausage. Fat pork bellies, the fatty top layers of hams and, to a lesser degree, leaf or flare fat might therefore also be successfully processed into hard raw sausages (Fischer, 1989b). Various limits for the C18:2 and PUFA contents in dry-cured firm cutting sausages have been proposed. Ten Cate, according to Fischer (1989b) indicated that fats with an IV of 66 and C18:2 content of 11% will cause problems in firm-cutting sausages. To avoid problems in the manufacture of firm-cutting sausage, BF employed should have and IV of no more than 60 and fat should be as fresh as possible (Fischer, 1989b). He indicated pork fat should therefore be frozen directly after slaughter at –10°C (short term) and –25°C (long term). Houben & Krol (1980) observed that inclusion of 30% C18:2 in BF did not present major problems in products except for cervelat type sausage. Backfat of pigs supplemented with 25 g PUFA/kg feed contained 23% PUFA. Salami manufactured from this BF resulted in salami with an acceptable taste, even though it contained 15% PUFA. The texture or consistency of the salami is, however, more important. Warnants et al. (1998) therefore recommended that less than 21g PUFA/kg feed be the highest level of PUFA supplementation in pig rations. Backfat from these pigs will then contain about 20% PUFA. They also indicated that, for salami to have a good consistency, the BF added should not contain more than 14% PUFA. Problems in terms of taste are not likely to occur if C18:2-rich fat sources (i.e. soybeans) are used in the feed, but C18:3-rich feedstuffs (linseed) might cause a fishy taint to develop (Warnants et al., 1998). If BF containing more than 21% PUFA is used in the manufacture of dry sausage, the risk of problems with

consistency and drying is undeniable (Stiebing, Kühne & Rödel, 1993). They recommended that the maximum PUFA content of BF used for dry sausage manufacture should be 14% (if stored for a moderate length of time) or less than 12% (if stored for longer periods). Hugo (2000) found that supplementation with α-tocopheryl acetate retarded oxidative rancidity in salami manufactured from PUFA-rich fat. Houben & Krol (1983) indicated that by adding this antioxidant directly to the dough of Dutch style cervelat sausage (of which the fat contained 15% PUFA) was more effective than supplementation of the diet of the pigs. Experimental investigations into the fat quality requirements for spreadable raw sausage are non-existent (Fischer, 1989b). There is either the generalized statement that, for finely cut varieties, softer fat tissue is also appropriate (Frey, according to Fischer 1989b) or, as an alternative, the use of lardy BF and of the fatty ham-covering layer is recommended (Scheid, according to Fischer, 1989b). Since temperatures higher than +18°C can, however, occur during storage and the smoking process, processing soft fat tissue runs the risk of being partly liquefied, leaving an oily film of fat on the sausage's outer casing (Fischer, 1989b).

Cooked and Uncooked Cured Whole Muscle Meat Products

We generally expect that cooked cured products will have a juicy quality, an attractive colour and will keep for a reasonable time (Müller, 1991). Brine accumulation between muscles and BF layers is considered to be a quality defect in bacon, which are aggravated by the curing of lean pigs. (Barton-Gade, 1983). Although soft pork fat has a significantly higher water content than hard pork fat, this difference was reversed by curing, when the hard samples retained more brine (Enser et al., 1984). Fat with a soft consistency was not caused by differences in water content, but by the lower fat contents of the leaner animals – lean pigs have higher proportions of C18:2 (Wood & Enser, 1982). Enser et al. (1984) indicated that C18:2 does not cause soft fat, but that a change in the proportions of SFA was responsible for soft fat. He stated that saturated glycerides would affect the consistency of the lipids at higher temperatures, while the unsaturated glycerides (with low melting points) would affect the consistency of the fat at 4°C (Enser et al., 1984). They indicated that C18:2 was the main culprit causing unsatisfactory bacon, but that C16:1 also contributed to the soft consistency. For the manufacture of bacon, the C18:2 content of BF should not be more than 15% (Whittington et al., 1986), but Houben & Krol (1983) found no serious problems, regarding consistency, in bacon made from meat and fat containing up to 40% PUFA. Firmness is particularly important in vacuum-packaged rindless bacon rashers, in which soft fat leads to individual rashers losing definition and loss of pack stiffness (Enser, 1983) because of more UFA (C18:2) and less SFA (C18:0 and C16:0) (Enser et al., 1984). Bacon will have a satisfactory consistency if it contains less than 9.2% C18:2 or has a C18:0/C18:2 ratio of more than 1.47 (Enser, 1983; Enser et al., 1984). Honkavaara (1989) indicated that the C18:0/C18:2 ratio should be above 1.2 for good quality bacon. In the production of bacon the presence of UFA is critical, because both salt and smoke may act as pro-oxidants, which may enhance the degradation of the lipids (Christensen, 1983).

Rancidity is rarely observed in cured (salt, nitrite/nitrate and ascorbate) meat products (with low fat contents), due to the antioxidative action of nitrate (Enser et al., 1984). Freezing increases the risk of rancidity, regardless of diet, presumably because it increases the concentration of salt, which might act as a pro-oxidant in the unfrozen liquid (Sheard et al., 2000). Rancidity causes BF in bacon to have a yellowish colour (Barton-Gade, 1983). Rancidity development in pork fat containing fish oil FA seems to be a greater problem in cured products, such as bacon, than in uncured fresh pork (Trout et al., 1998). When enriching a cured meat product with, more specifically n-3 PUFA, off-flavours are likely to occur unless display time is reduced.

A supplemental antioxidant (Vitamin E) is therefore added (Verbeke et al., 1999; Sheard et al., 2000). Dietary supplementation with α-tocopheryl acetate (500 mg/kg) improved oxidative stability and Hunter a (redness) values of all low nitrite (50 mg/kg) products (like bacon) (Walsh, Kerry, Buckley, Morrissey, Lynch & Arendt, 1998). Santoro (1983) stated that pigs used for the production of cured products should have high SLW resulting in well defined, structurally mature subcutaneous fat layers.

In terms of consistency or taste, the incorporation of MUFA in pork fat utilized in cured meat products does not seem to cause any problems (Myer, Johnson, Knauft, Gorbet, Brendemuhl & Walker, 1992), because C18:1c9 constitutes the bulk of the FA in pork (Verbeke et al., 1999). According to Ziprin, Rhee & Davidson (1990) inclusion of MUFA in bacon can also be beneficial from a health point of view. They stated that bacon made from fat containing high C18:1c9 levels was more stable to oxidation, as C18:1c9 has a slower rate of oxidation than C18:2 and C18:3. The MUFA/SFA ratio plays an important role in the consistency of the BF (Lea et al., 1970).

The subcutaneous fat of cooked cured products, like hams, must have a firm consistency otherwise fat separation will occur. Uncooked cured products require firm and white intramuscular and subcutaneous fatty tissues. These products are exposed to high temperatures during storage and smoking (up to approximately + 28°C) and may even be stored for several months. It is therefore important for these products to have a low fat transpiring tendency and high oxidative stability (Fischer, 1989b).

Many sensory traits of dry-cured meat products (e.g. Italian Parma ham) depend on the properties of the lipids in muscle and adipose tissues of the fresh meat. The degradation of these lipids during processing, through a complex set of lipolytic and oxidative reactions, occur more intensively in the subcutaneous than in the IMF. Volatile components, formed by lipid oxidation, contribute to the typical aroma notes of dry-cured meat products, e.g. rancid, aged ham and dry-cured odours (Timón et al., 2001; Gandemer, 2002). Differences in volatile patterns are influenced by the FA composition of the lipids, which is related to the composition of the diet (Timón et al., 2001). The amount and physical state of IMF also affects many sensory quality traits of dry-cured hams such as appearance, flavour, colour, the dry-curing process, rancidity development and cohesiveness of the cut (Bailey et al., 1973; Fernández et al., 2003). Free fatty acids occur in low amounts in fresh meat products, but rise sharply during the dry-curing process (Gandemer, 2002). At the end of processing, FFA (mainly from phospholipid hydrolysis) account for 8–20% of the total muscle lipids in dry-cured hams. The FFA content of the finished product differs according to the composition of the raw material and the technology used (Buscailon, Gandemer & Monin 1994). The larger proportion of C18:2 in FFA, compared to that of the TAG, suggests that lipolysis preferentially affects the TAG containing C18:2 (Coutron-Gambotti & Gandemer, according to Gandemer, 2002). According to Davenel et al. (1999) the TAG containing C18:2 is much more liquid than other TAG. Delgado et al. (2002) studied the FA profiles of subcutaneous and IMF of raw and cooked hams from Hairless Mexican pigs and found that curing decreased the %UFA (C18:1c9, C18:2), %di- as well as the %TAG and increased the %SFA (C14:0, C16:0 and C18:0). Oleic acid is considered to be responsible for the changes that occur in fat during the curing process, because it degrades to aldehydes and compounds that are responsible for the special aroma of the final product (Delgado et al., 2002). Fat composition changes during the curing process as a result of added salt and evaporative losses (Delgado et al., 2002). A high level of C18:2 is undesirable because it can affect

water migration and impair the drying process (López-Bote, according to Fernández et al., 2003). Hams containing 100 mg residual nitrite/kg and processed with pork supplemented with 500 mg α-tocopheryl-acetate/kg feed, were found to produce the most stable product in terms of thiobarbituric acid (TBA) value (Walsh et al., 1998).

COOKED AND EMULSION-TYPE SAUSAGES

Frankfurters, viennas, liverwurst and jellywurst are examples of cooked sausages (Fischer 1989b). Emulsion type sausages vary according to fat content. The fat content could range between a maximum fat of 30% (with 10% added water) or a minimum of 5% (with 35% added water) (Keeton, 1994). Bologna and frankfurters have an average fat content of 28% (USDA, according to Keeton, 1994). Lee, according to Fischer (1989b) stated that products like frankfurters contain fat in emulsified as well as in suspended form.

Backfat has to be firm to withstand the double heat treatment required in the manufacture of some emulsion type products. Many cooked sausages are made from pre-boiled materials so that renewed heat treatment is involved in the manufacture of the finished product. Soft fatty tissue or leaf fat are processed into finely comminuted cooked sausages, while firm fat is used for finely cut products (e.g. bacon sausage) (Fischer 1989b). Bryhni et al. (2002) indicated that rancidity was easily detected in sausages made with fat from pigs fed PUFA-rich diets. They indicated that it was important to be aware of the interactions between PUFA and fish oil. Dietary supplementation of pig rations with fish oil alone did not affect sensory quality of sausages, but when PUFA and fish oil were supplemented together, TBA reactive substances and rancid odour of sausages increased. Kunz (1991) investigated the effect of fat with a high PUFA content in Mettwurst and found reduced oxidative stability, which can be improved by addition of Vitamin E to the diet of the pigs. Gray, Gomaa & Buckley (1996) indicated that vacuum packaging was suitable for many products for improving oxidative stability, including sliced meat products.

Fatty tissue used in scalded sausages, like frankfurters, is supposed to be hefty and gritty according to Fischer (1989b). Backfat, belly, nape and jowl fat have higher melting points and contain a greater share of connective tissue and are therefore suited for use in these products (Wirth, according to Fischer, 1989b). These requirements are very important in applications where fatty tissue undergoes coarse cutting (e.g. Göttinger type sausage) or where inclusions are specified (fat cubes in Mortadella) (Fischer, 1989a). In the case of finely size-reduced fat in frankfurters (of the scalded sausage variety), the type of fatty tissue are of lesser importance with respect to the stable binding of fat than the formation of a uniform, narrow meshed protein network (Fischer, 1989b). He indicated that if this was not accomplished, fat will form a sediment in the dough and bowl chopper during processing. One of the meat products showing considerable potential for reduction of fat and inclusion of beneficial FA is the frankfurter (Park, Rhee, Keeton & Rhee, 1989). St John, Buyck, Keeton, Leu & Smith (1986) manufactured frankfurters with a reduced fat content from meat and fat originating from pigs fed on a diet containing canola oil, with a high-MUFA content, without experiencing problems. In the manufacture of emulsion-type products such as frankfurters, product constituents largely determine the stability of the emulsion and processing conditions (Park et al., 1989). Low-fat frankfurters had very stable emulsions, in spite of the inclusion of substantial amounts of low melting fats (high oleic sunflower oil and fish oil) (Park et al., 1989).

SUMMARY OF THE TECHNOLOGICAL FAT QUALITY CRITERIA

CARCASS AND CHEMICAL PARAMETERS

Carcass parameters

Backfat Thickness (BFT)

> 15 mm (Davenel et al., 1999)

> 18 mm (Prabucki, 1991)

17.5–20 mm (Cannon et al., 1996)

Lean meat content (LMC)

< 57% (Davenel et al., 1999)

Chemical parameters

Iodine Value (IV)

< 60 (firm cutting sausage) (Fischer 1989b)

< 65 (Lea et al., 1970; Mortensen et al., according to Warnants 1996)

< 66 (Hart, according to Houben & Krol, 1983; Ten Cate, according to Fischer, 1989b – for firm cutting sausage)

< 70 (Lea et al., 1970; Houben & Krol, 1983; Barton-Gade, 1983; 1987; Girard et al., according to Davenel et al., 1999).

Refraction index (RI)

< 1.4598 (Hart, according to Houben & Krol, 1983)

Extractable fat content (EFC)

84–90% (Prabucki, 1991)

FATTY ACIDS

Composition

C18:0 content

> 12% (Houben & Krol, 1983; Girard et al., according to Lizardo et al., 2002)

C18:2 content

< 9.2% (in bacon) (Enser, 1983)

11% (in raw fermented sausages) (Ten Cate, according to Fischer, 1989b)

12–15% (Girard et al., according to Lizardo et al. 2002).

< 15% (Ellis & Isbell, 1926; Houben & Krol, 1980; Enser, 1983; Wood, 1983; Whittington et al., 1986)

30% in BF (Houben & Krol, 1980)

Combinations

SFA content

> 41% (Häuser & Prabucki, 1990)

MUFA content

< 57% (Häuser & Prabucki, 1990)

Dienoic acid content

< 10% (Häuser & Prabucki, 1990)

Trienoic acid content

< 1% (Häuser & Prabucki, 1990)

Tetraenoic acid content

< 0.5% (Häuser & Prabucki, 1990)

Penta- + Hexaenoic acid content

< 1% (Häuser & Prabucki, 1990)

PUFA content

< 12% (Prabucki, according to Houben & Krol, 1983; Stiebing et al., 1993)

< 13% (Wenk et al., according to Warnants et al. 1996)

< 14% (in dry sausage stored for moderate length of time and salami) (Stiebing et al., 1993; Warnants et al., 1998)

< 15% (Houben & Krol, 1983; Fischer et al., according to Warnants et al. 1996, Warnants et al., 1998)

20% (Warnants et al., 1998)

< 21% (dry sausage) (Stiebing et al., 1993)

< 22% (Bertelsen et al., 2000)

< 23% (Warnants et al., 1998; Bryhni et al., 2002)

PUFA in feed

12% (Prabucki, according to Warnants et al., 1996)

19–21% (Fischer et al., according to Warnants et al., 1996)

25 g PUFA/kg feed (Warnants et al., 1998)

26 g PUFA/kg feed for dry sausage manufacture (Warnants et al., 1998)

< 50g PUFA/kg feed (Bryhni et al., 2002)

UFA content

< 59% (Prabucki, 1991)

Ratios

C18:0/C18:2 ratio

< 1.2 (Honkavaara, 1989)

< 1.47 in bacon (Enser, 1983; Enser et al., 1984)

Double Bond Index (DBI)

< 80 (Prabucki, 1991)

HEALTH AND NUTRITIONAL ASPECTS OF FAT

In industrialized countries animal fats contribute substantially to the total fat intake (Sandström, Bügel, Lauridsen, Nielsen, Jensen & Skibsted, 2000). Nutritionally speaking, fat is a high-energy source, providing essential FA and aiding in the absorption of fat-soluble vitamins (A, D and E) (Honkavaara, 1989; Suess, 1993). Carotene from carrots can only be resorbed in the gut in the presence of fat (Suess, 1993). Pork meat has often been blamed to be too high in fat, especially in SFA and should thus be avoided by those who

suffer from elevated serum cholesterol and hypertension (Warnants et al., 1998). However, a pork chop, trimmed of all visible fat usually contains 2–2.5% fat (Warnants et al., 1998). Fat content can vary from about 1–2% in fresh meat, to 25% (Chizzolini et al., 1999) or over 30% in some meat products (Keeton, 1994). Fat constitutes from about 10–15% to above 80% per 100g serving of meat The contribution thereof to total calorific value may range from about 100 to over 300 kcal (Chizzolini et al., 1999). Dietary cholesterol is strictly linked with foods of animal origin. All animals contain cholesterol since it is an essential constituent of animal cells (Chizzolini et al., 1999). Honikel & Arneth (1996) indicated that the cholesterol content of a pork chop amounts to 54 mg /100g.

Since modern man evolved as a meat eater, his life expectancy has increased and animals were domesticated, leading to a cheap supply of meat. With increased life expectancy came different causes of mortality (Enser, 2000). Consumers are presently more conscious of diet, health and nutritional concerns than in the past (Rhee et al., 1988b). The primary chronic diseases in the Western world are coronary heart disease (CHD), many types of cancer, stroke and type II (maturity-onset) diabetes mellitus (Weisburger, 1997) and autoimmune disfunctions such as arthritis and obesity (Enser, 2000). Greater fat intake is a major cause of obesity and hypertension, diabetes, gallbladder disease, (Kuller, 1997) gallstones and gout (Suess, 1993). The association between dietary fat consumption and risk of cancer, especially colon, breast, prostate and ovary cancer, has been debated for many years (Kuller, 1997). Epidemiological studies relating dietary fats to cancer risk have generally shown weak and inconsistent patterns of association (AHA, 2001). The n-3 PUFA , found in fish and fish oils, have a pronounced inhibitory effect in models of colon and breast cancer (Weisburger, 1997). He indicated that lowering dietary fat intake to approximately 20–25% energy from total fat and including n-3 PUFA and MUFA could lower the risk of some nutritionally linked cancers.

Ideally, one would like to consume a dietary fat that lowers low-density lipoproteins (LDL) while enhancing high-density lipoprotein (HDL) concentration (Sundram, Hayes & Siru, 1995). Almost half of the FA in pork are MUFA (± 47% of total FA), which play a neutral to favourable role in cardiovascular diseases (Warnants et al., 1998). Oleic acid, the main MUFA, is hypolipidemic, reducing both cholesterol and LDL TAG without decreasing HDL cholesterol in human patients (Mattson & Grundy, 1985). Hegsted et al., according to AHA (2001) have shown that SFA (C12:0–C16:0) raise total LDL and cholesterol levels. In certain circumstances dietary C16:0 may be neutral, or at least less cholesterolemic than the combination of C12:0 and C14:0 (Sundram et al., 1995). However, in part because of its predominance in saturated fats and in part because it is typically consumed as animal fat containing cholesterol, C16:0 has long been considered the primary cholesterol raising FA, especially when compared to C18:1c9 and C18:2 (Mattson & Grundy, 1985). Stearic acid is associated with lowering plasma cholesterol levels (Bonanome & Grundy, 1988). Unsaturated FA apparently improve receptor-mediated LDL uptake and enhances cholesterol excretion via bile acids (Bonanome & Grundy, 1988). According to Mattson & Grundy (1985) PUFA decrease both the HDL and LDL cholesterol. Current dietary guidance in general recommends a diet that contains ≤ 30% of energy as fat; ≤ 10% as SFA, up to 10% as PUFA and < 300 mg of cholesterol per day (AHA, 2001). Kaeferstein & Clugston, according to Papadima & Bloukas (1999) stated that a diet with 15–20% fat will avoid energy deficiency and at the same time preventing obesity and chronic diseases. More recently, the Committee on the Medical Aspects of Food Policy (COMA), according to Verbeke et al. (1999) indicated that 7% of energy should be obtained from PUFA.

COMA, according to Warnants et al. (1998) recommended a P/S ratio of 0.45. According to Verbeke et al. (1999) a more recent recommendation from COMA was that the P/S ratio should be between 0.6 and 0.7. P/S ratios of 0.4–1 (Enser, 2000), 0.45–0.50 (Honkavaara, 1989; Levnedmiddelstyrelsen, according to Madsen et al., 1992) and 0.23–.45 (COMA, according to Wood et al., 1989; Phelps, 1991) have been proposed for maintenance of a healthy lifestyle. By incorporating oilseeds in pig feed, P/S ratios in BF around the dietary guideline of 0.6–0.7 could easily be achieved (Warnants et al., 1998). An increase of the PUFA – at the expense of the SFA – in pork fat can lead to a better agreement with the dietary guidelines and consequently to a better image of pork for the consumer (Warnants et al., 1998). The swine industry has responded to changing consumer preferences by developing leaner genotype pigs and by supplementing pig diets with unsaturated fat sources (Viljoen & Ras, 1991). It is difficult to achieve an ideal unsaturated to saturated ratio while accommodating the desires of both the consumer and pork processors (Warnants et al., according to Averette Gatlin et al., 2002). However, the P/S ratio does not differentiate between the variable effects of different SFA (Bonanome & Grundy, 1988), overlooks the significant effects of C18:1c9 (Mattson & Grundy, 1985), and does not differentiate between the physiological effects of PUFA of the n-6 and n-3 families (Lands, according to Kinsella, 1988).

More recent studies have shown that long-chain n-3 PUFA are hypotriglyceridemic, favourably affect platelet function and decrease blood pressure slightly in hypertensive individuals while trans FA are hypercholesterolemic (AHA, 2001). Trans FA have recently been reported to have deleterious effects on humans (Högberg et al., 2001). Trans FA appear to raise LDL cholesterol and/or total serum cholesterol, like SFA, but unlike SFA they tend to lower HDL cholesterol, thus adversely affecting CHD risk (Khosla & Hayes, 1996; Ascherio & Willet, according to Högberg et al., 2001). There appears to be scant support for the notion that trans FA consumption affects risk for cancer (Khosla & Hayes, 1996). The optimal diet for reducing risk of chronic diseases is one in which SFA are reduced and trans FA from manufactured fats are virtually eliminated (AHA, 2001). A mixture of UFA in the diet will confer the greatest health benefits within the context of a total fat intake that is considered moderate (AHA, 2001). Kinsella (1988) indicated that n-6 PUFA (e.g. C18:2) were precursors of eicosanoids (e.g. C20:4) and n-3 PUFA (e.g. C20:5 and C22:6) were considered inhibitors thereof. The eicosanoids (prostaglandins and leukotriens) are important signalling agents which affect cell behaviour and cell-to-cell interactions (Kinsella, 1988). The n-6/n-3 ratio of tissue lipids affects many aspects of animal physiology including behavioural performance and health (Okuyama & Ikemoto, 1999) and resistance to infections (Kinsella, 1988). According to medical opinion, modern diets are too high in n-6 PUFA and people are now encouraged to consume more n-3 PUFA for optimum cardiovascular health (Wood et al., 1999). Okuyama, Kobayashi & Watanabe (1997) found that when C18:2 was consumed in large amounts, it led to a subsequent deficiency in n-3 FA. This imbalance in the n-6/n-3 ratio and not high intake of cholesterol and hypercholesterolemia, was the major risk factor for western-type cancers, CHD, atherosclerosis, cerebrovascular disease, allergic hyper-reactivity (Okuyama & Ikemoto, 1999). This imbalance might also lead to problems in the immune responsiveness of tissues (Enser, 2000). For the prevention of diseases in the 21st century, it is recommended to decrease the n-6/n-3 ratio of human foods to as low as 2 (Okuyama, 1997). Leaf & Weber (1987) proposed that primitive hunter-gatherers had n-6/n-3 ratios of 1 in their food. Various limits for an n-6/n-3 ratio have been proposed, namely 3:1 (Kinsella, 1988), less than 4 (Enser, 2000), 4–6 (Gerster, according to Högberg et al., 2001) and finally 6:1 (Verbeke et al., 1999). As pigs are used as a model for lipid metabolism study in humans, these results may provide

insight into where n-3 PUFA will be incorporated in human organs (Cherian & Sim, 1995). Pork is a potentially good source of C18:3 and long chain n-3 PUFA (Wood et al., 1999). Increasing n-3 PUFA levels in meat could, however, reduce shelf life and adversely affect flavour (Wood et al., 1999). Since the synthesis of C20:5 and C22:6 appears to be limited in man, even at the recommended n-6/n-3 ratio, a doubling the intake of long-chain n-3 PUFA from 100 mg to 200 mg/day has been recommended (Enser, 2000). One specific aim of raising n-3 PUFA is to decrease the thrombotic tendency of blood and lower the risks of CHD (Enser et al., 1996). Both from a food quality point of view and regarding the nutritional value, it is important to balance the UFA with a sufficient content of antioxidants (Bonanome et al., according to Sandström et al., 2000). Antioxidants, especially Vitamin E, have received considerable attention as potential antiatherogenic agents (Tomeo, Geller, Watkins, Gapor & Bierenbaum, 1995).

Lipid oxidation in muscle foods is one of the major degrative processes responsible for loss of quality (Tappel, according to Pearson, Gray, Wolzak & Horenstein, 1983). Addis & Park, according to Kanner (1994) stated that toxins are formed when UFA and cholesterol undergo autoxidation. Among lipid oxidation products (COP), are probably best known due to their toxicity (Chizzolini et al., 1999). Pearson et al. (1983) indicated that the oxidation products, malonaldehyde and cholesterol oxides, may be involved in cancer development. Lipid oxidation products and a few COP in particular, are considered atherogenic agents and appear to have mutagenic, carcinogenic and cytotoxic properties (Chizzolini, Novelli & Zanardi, 1998; Zanardi, Novelli, Campanini, Madarena & Chizzolini, 1998; Addis & Warner, 1991; Kanner, 1994). A number of strategies are being used to enhance antioxidant activity in meat systems and to reduce the formation of oxidation products with their subsequent impact on ageing, cancer and cardiovascular disease (Decker & Xu, 1998). Food processing subjects cholesterol in the food to conditions conducive to oxidation (Pearson et al., 1983). The rate of cholesterol oxidation in pork is greatly accelerated during storage, following cooking and seems to follow the same trend as lipid oxidation in general (Buckley, Morrissey & Gray, 1995). Heat treatment has negative effects on cellular structure, inactivates enzymes (including those with reducing activity) and releases oxygen from oxymyoglobin, creating the conditions for hydrogen peroxide production (Chizzolini et al., 1998). Cooking, especially at low temperatures for long times, also has the effect of releasing iron ions from haem groups (Chizzolini et al., 1998) and concentrates cholesterol as the moisture is driven off (Pearson et al., 1983). Pearson et al. (1983) found that DNA reacts with malonaldehyde, released on cooking, leading to changes in the DNA structure.

An increased MUFA content (e.g. rapeseed oil) in pig feed changes the FA composition of food products produced for the pig meat and fat in such a way that it has the potential to reduce blood cholesterol concentrations in human subjects (Sandström et al., 2000). Reduction of SFA and elevation of MUFA in meat and meat products may be achieved through modifications in the diet of the animal (Rhee et al., 1988b). Severini et al. (2003) substituted BF with extra-virgin olive oil (with a high MUFA content) in salami and found that it was possible to produce this type of product, similar to the traditional one, but with healthier features without detrimental effects on the taste. Nutraceuticals are foods with perceived medicinal or health benefits that may prevent, ameliorate or cure a disease (LaBell, according to Swan, Farouk, McBeth & De Manser, 1997; Jiménez-Colmenero et al., 2001). Nutraceuticals may include isolated nutrients, dietary supplements, fat replacers, n-3 PUFA, fibre, oligosaccharides, lactoferrin, garlic, ginseng, honey, vitamins, minerals, proteins and peptides, bacteria and phytochemicals (Bello, according to Swan et al., 1997). Incze

(2000) and Jiménez-Colmenero et al. (2001) stated that meat could be marketed as probiotic food, but sausages must have viable probiotics that could survive in the gastro-intestinal environment as well as being safe for human consumption and not damage the sensory quality of the food. Conjugated linoleic acid has immense potential as a nutraceutical (Roberfroid, according to Averette Gatlin et al., 2002). The potential effects of CLA on human health has led to many researchers recently evaluating CLA as a swine feed additive (Averette Gatlin et al., 2002). A potential use for CLA in animal nutrition is to use it to partition energy toward protein deposition rather than lipogenesis (Enser, 2000). Averette Gatlin et al. (2002) indicated that data for human subjects are inconclusive, but a possibility exists to reduce cancer risk and the incidence of obesity as well as atherosclerosis by supplementing foods with CLA. Conjugated linoleic acid supplementation increases C18:1t9 content, which might be a problem, but they also observed an increase in C18:0 content, a beneficial FA from a health as well as a processing point of view. Verbeke et al. (1999) stated that in terms of FA composition, it appears that pork is somewhere between ruminants (beef and sheep) and poultry. Pork is particularly rich in C18:1c9 and in the near future it could be sold as a nutraceutical, which has positive effects on the health of humans (Verbeke et al., 1999).

SUMMARY OF HEALTH AND NUTRITIONAL RATIOS

P/S ratio

0.23-0.45 (COMA, according to Wood et al., 1989; Phelps, 1991)

0.45 (COMA, according to Warnants et al. ,1998)

0.45–0.50 (Honkavaara, 1989; Levnedmiddelstyrelsen, according to Madsen et al., 1992)

0.6–0.7 (Verbeke et al., 1999)

0.4–1.0 (Enser, 2000)

n-6/n-3 ratio

1 (Leaf & Weber, 1987)

2 (Okuyama, 1997)

3 (Kinsella, 1988)

< 4 (Enser, 2000)

4-6 (Gerster, according to Högberg et al., 2001)

6 (COMA, according to Verbeke et al., 1999)

CONCLUSIONS

Apart from contributing to the flavour, fat plays a role in the texture, colour and other sensory qualities of meat. Fat is therefore important in the overall acceptability of meat to the meat technologist and the consumer. The fact that consumers are increasingly concerned about health and food-borne health risks, as well as being more interested in production and processing methods, urges adequate response strategies by agribusiness and food companies (Verbeke et al., 1999).

The basic composition of fat and the metabolism thereof in pigs were discussed in detail. Several factors influencing fat quality were investigated and discussed. With a changed genetic pool, introduction of alternative production systems and new quality demands, a new holistic approach is needed to understand the influence of production and peri- and post-mortem factors on pork quality. These factors can subsequently be used in the control of the quality of pork products in the future (Rosenvold & Andersen, 2003).

Colour and consistency were found to be the two main criteria by which fat quality was judged. Backfat of good technological quality was defined as firm and white. Criteria for good quality fat were also investigated and it seemed that the most important criteria were the IV, C18:2 content, C18:0/C18:2 ratio and the DBI. Consequently, it was concluded that saturated fats are needed for the manufacture of good quality products. The increasing health consciousness of consumers has led to increased leanness in pigs which has caused a lot of problems in the meat industry in terms of soft fat, in which C18:2 is the main role player. The problems associated with poor fat quality were discussed in detail.

Methods for the measurement of fat quality were also investigated. Gas chromatography was found to be the most accurate method, but not applicable to abattoirs, which require a rapid on-line method for fat quality determination. A possibility may be to use NIR spectroscopy, but it is a very expensive and it is unlikely that abattoirs will invest such a huge amount of money. Fat score determination, as used by Swiss plants could be employed in South Africa, as this is a fast on-line procedure that can be used for fat firmness determination. It was concluded that in South Africa, fat quality would best be predicted by using the French method, with the necessary adjustments.

The influence of fat on the technological properties of meat and meat products were discussed. The properties of the fat determines the product in which it can be used (Wood, 1993). Although literature is scarce on this subject, it was concluded that less problems are encountered in fresh meat than in meat products. In products of high economical value, like bacon and salami, the fat quality is very important.

Pork is perceived as unhealthy even though it has a high content of Vitamin B1, B2, iron and zinc (Wenk, 2000). Several attempts at improving the health and nutritional value of pork have been made (e.g. enrichment with n-3 PUFA, manufacturing low-fat meat products, like frankfurters). This has presented the meat industry with a lot of challenges and caused them to reformulate their products to meet consumer demands. It is important to realise that nutritional and technological quality are inversely correlated. Improvement of one will lead to deterioration of the other. This literature survey therefore indicated that from a health, nutritional as well as a technological perspective fat quality was of the utmost importance.

CHAPTER 3

MATERIALS AND METHODS

SAMPLING

Sampling was done at the Pork Packers abattoir (Olifantsfontein). Approximately 15% of the total number of pigs annually slaughtered in South Africa are slaughtered at this abattoir. Over a period of one year, at monthly intervals, a total of 2107 pig carcasses were sampled. This total consisted of 45 BF samples collected from each of the P, O and R classification (thinner BFT) groups and as much as available of the C, U and S (thicker BFT) groups during each monthly sampling. Every third pig carcass in the line, on its way from cold storage to the deboning area, was identified (marked and numbered) for sampling and the relevant information on the carcass was recorded. This information included the number of the carcass allocated by abattoir, classification group, gender, cold carcass mass and identification number of the producer. Backfat samples were collected ± 24 hours after slaughter in the deboning section of the abattoir.

After being divided into the six primal cuts, the identified carcasses were sampled next to the stationary bandsaw. The bonedust was removed by scraping the cut surface clean. Backfat thickness at the midline position, perpendicular to the hole made by the HGP on the side of the carcass, was measured by using a calliper and ruler. Approximately 2 g (inner and outer layer) of fat was removed from the same position (as shown in Figure 2).

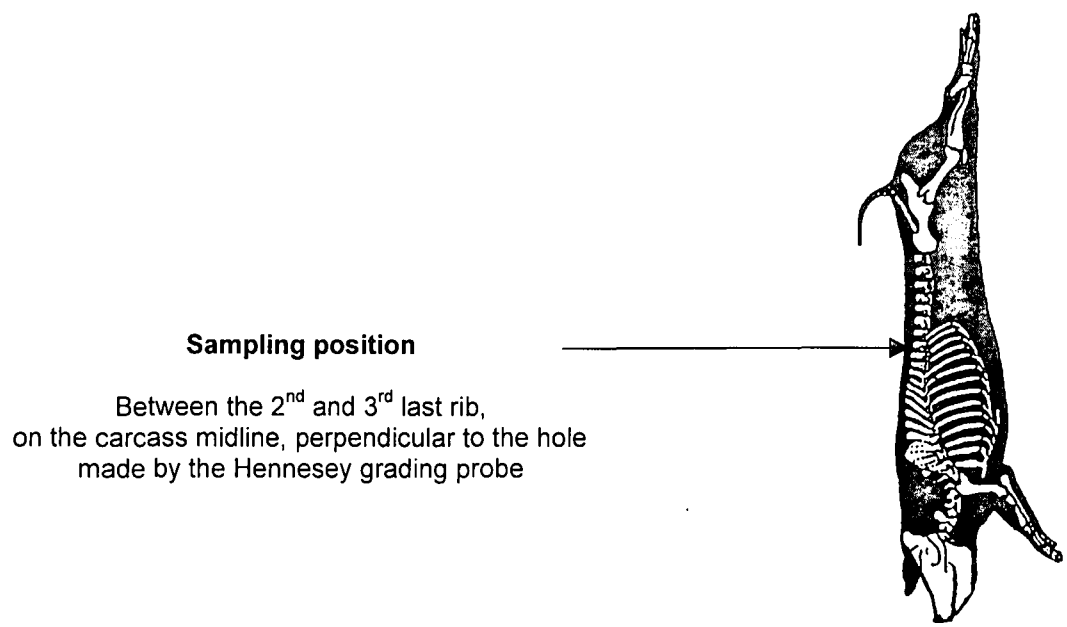


Figure 2: Schematic representation of a pig carcass, showing the sampling position.

Each sample was then packed into an impermeable, numbered plastic pouch and stored on ice in the abattoir as well as while being transported to Bloemfontein. These samples were cut into minute pieces and

well mixed to form a representative sample. The reason for using a mixed sample (consisting of inner as well as outer layer) is because South African meat processors do not separate the inner and outer layer, they use both layers together in the manufacturing of meat products. These samples were then transferred into marked Nunc cryotubes and stored in liquid nitrogen until analyzed. All the relevant grading information (warm carcass mass, cold carcass mass, BFT, muscle thickness and LMC of each pig) was withdrawn from the abattoir's computer system.

REAGENTS

Reagents were all of analytical grade and were obtained from Merck, Halfway House, South Africa, unless stated otherwise.

LIPID ANALYSES

LIPID EXTRACTION

Total lipid from approximately 1 g of BF was quantitatively extracted, according to the method of Folch, Lees & Sloane-Stanley (1957), using chloroform and methanol in a ratio of 2:1. An antioxidant, butylated hydroxytoluene was added at a concentration of 0.001 % to the chloroform:methanol mixture. A rotary evaporator was used to dry the fat extracts under vacuum and the extracts were also dried overnight in a vacuum oven at 50°C, using phosphorus pentoxide as moisture adsorbent. Total EFC was determined by weighing and expressed as %fat (w/w) per 100 g tissue. The FFDM content was determined by weighing the residue on a pre-weighed filter paper used for Folch extraction after drying. By determining the difference in weight, the FFDM could be expressed as %FFDM (w/w) per 100 g tissue. The moisture content of the BF was determined by subtraction (100 – %fat – %FFDM) and expressed as %moisture (w/w) per 100 g tissue. The extracted fat was stored in a polytop (glass vial, with push-in top) under a blanket of nitrogen and frozen at –20°C until further analyzed.

IODINE VALUE AND REFRACTION INDEX DETERMINATION

A sample of 0.5 g lipid, extracted by the above method, was used to determine the Hanus IV (AOAC, 2000). Iodine value was expressed as number of gram iodine absorbed by 100 g of fat, which indicates the unsaturation of the fat. Extracted fat was also used to determine the RI-value (AOAC, 2000) with an Abbe refractometer. Three drops of extracted fat (from the Folch extraction) were placed on the glass surface in the sample chamber of the refractometer by means of a disposable glass pasteur pipette. Readings of RI-values were made at a temperature of 50°C. The procedure was repeated. The average of the duplicate readings was determined and converted to a reading at 40°C by using the following equation: $RI_{40°C} = RI_{50°C} + K\ (50°C - 40°C)$ where K = 0.000365; thus $RI_{40°C} = RI_{50°C} + 0.00365$. As highly saturated fat might solidify at 40°C and still be liquid at 50°C the latter temperature was used for actual readings and converted to 40°C. Distilled water, with a known RI-value of 1.3290 at 50°C, was used as a blank to calibrate the refractometer after every 10^{th} sample.

FATTY ACID ANALYSES

Approximately 10 mg of total lipid (from Folch extraction) was transferred into a teflon-lined screw-top test tube by means of a disposable glass pasteur pipette. Fatty acid methyl esters (FAME) were prepared for GC analysis by methylation of the extracted fat, using methanol–BF_3 (Slover & Lanza, 1979). Fatty acid methyl

esters were quantified using a Varian GX 3400 flame ionization GC, with a fused silica capillary column, Chrompack CPSIL 88 (100 m length, 0.25 μm 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 (1μl) 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, at 45 psi, functioned as the carrier gas, while nitrogen was employed as the makeup gas. Varian Star Chromatography Software recorded the chromatograms. Fatty acid methyl ester samples were identified by comparing the relative retention times of FAME peaks from samples with those of standards obtained from SIGMA (189-19). Fatty acids were expressed as the relative percentage of each individual FA as a percentage of the total of all FA present in the sample.

The following FA combinations were calculated by using the above FA data: total SFA, UFA, MUFA, PUFA (dienoic, trienoic, tetraenoic, pentaenoic and hexaenoic FA and the penta- + hexaenoic FA combined) as well as the C16:0 + C18:0 combined. The following ratios were calculated using the individual FA data: (C16:0 + C18:1c9/C16:0 + C18:0); C16:0/C18:2; C18:0/C18:2; MUFA/SFA; PUFA/SFA (P/S); n-6/n-3 PUFA. Double bond index was calculated as follows: DBI = Σ %UFA x number of DB of each UFA (Alam & Alam, 1986). Peroxidizability index was calculated by the following equation 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).

STATISTICAL ANALYSES

One way analyses of variance (ANOVA) procedure and the Tukey-Kramer multiple comparison test (α=0.05) (NCSS, 2001) were carried out to determine whether significant differences between different classification groups, between genders, between seasons and within specific classification groups (where carcasses originated from different suppliers) existed. Pearson correlation analyses were performed for important fat quality (moisture content, FFDM, IV, RI, EFC and FA composition, combinations and ratios) and classification (warm and cold carcass mass, BFT at 45 mm and midline, muscle thickness and LMC) parameters to determine the relationship between these parameters and to ascertain the factors that best predict fat quality (NCSS, 2001). Individual scatterplots of IV against fat quality parameters (%EFC and RI) and FA (individual, combintations and ratios) of which guidelines were available, were constructed. Linear, power, logarithmic and exponential trendlines (options available in Excel 2000) were alternately fitted to each graph to determine the best fit (with respect to the R^2 value) between carcass classification parameters, fat quality parameters and IV. This was done in an attempt to determine alternative cut-off points for fat quality criteria, at selected IV (60 and 70), which could be used to modify the French system of predicting fat quality for South African conditions. From these scatterplots the corresponding IV for fat quality cut-off points proposed by literature were calculated by substitution of the y-value with the value of the cut-off point and calculating the corresponding x-value from the equation that produced the best fit (with respect to the R^2 value). The percentage of pigs conforming to different international fat quality requirements within each classification group were also calculated by expressing the number of pigs complying with international criteria as a percentage of total number of pigs in each group. These percentages were tabulated in order to determine the probability of selecting pigs with good fat quality from specific BFT groups.

CHAPTER 4

RESULTS AND DISCUSSION

CHARACTERISTICS OF PIG CARCASSES

The distribution of pigs within the respective classification groups, expressed as a percentage of the total number of pigs (2107) sampled, is depicted in Figure 3. The values in brackets refer to the actual number of pigs sampled in each classification group (PORCUS) during the study.

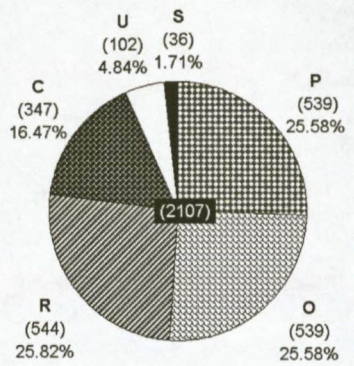


Figure 3: Pie chart representing the distribution of pig carcasses sampled in the various South African classification groups.

The average warm carcass weight of all the pigs (75.58 kg), as indicated in Table 2, suggests that the majority of pigs sampled could be classified as baconers. Baconers are generally considered to be suitable for the meat processing industry (Vervoort, 1997) and have carcass weights between 56 and 90 kg in South Africa (Vervoort, 1997; Anon, 2000). From Table 2 it is evident that the carcasses sampled during this study was representative of this range as the cold carcass weight of these pigs ranged between 51.40 and 95.50 kg. Only 0.33% of the total number of carcasses sampled in this study had carcass weights of less than 56 kg.

Significant differences ($P < 0.001$) were observed between classification groups for all carcass grading characteristics (warm and cold carcass weight, BFT, LMC and muscle thickness) (Table 2). The BFT (45 mm and midline) differed significantly between the PORCUS classification groups. The O, R, C, U and S groups had BFT (at both midline and 45 mm positions) of more than 15 mm, which was the minimum that Davenel et al. (1999) proposed for good quality BF, as depicted in Table 2. The R, C, U and S groups had BFT values (midline and 45 mm) of more than 17.5 mm (Cannon et al., 1996) and 18 mm (Prabucki, 1991), thus having the potential to produce good quality BF, according to international standards.

Table 2: Carcass characteristics of pigs within the different classification groups of the South African pig classification system.

Parameter	P	O	R	C	U	S	All pigs
Number of pigs	*539*	*539*	*544*	*347*	*102*	*36*	*2107*
Warm carcass weight (kg)	**71.82 ± 5.74^{a}**	**75.25 ± 5.70^{b}**	**76.72 ± 5.78^{c}**	**78.44 ± 5.52^{d}**	**80.10 ± 5.59^{d}**	**79.36 ± 6.10^{cd}**	**75.58 ± 6.25**
Min.	53.40	57.60	59.00	61.00	65.60	66.60	53.40
Max.	87.00	96.70	97.50	91.40	97.30	91.40	97.50
Cold carcass weight (kg)	**69.83 ± 5.73^{a}**	**73.25 ± 5.70^{b}**	**74.72 ± 5.78^{c}**	**76.44 ± 5.52^{d}**	**78.10 ± 5.59^{d}**	**77.36 ± 6.10^{cd}**	**73.58 ± 6.24**
Min.	51.40	55.60	57.00	59.00	63.60	64.60	51.40
Max.	85.00	94.70	95.50	89.40	95.30	89.40	95.50
BFT (45 mm)	**11.61 ± 1.15^{a}**	**15.05 ± 1.26^{b}**	**18.77 ± 1.32^{c}**	**22.97 ± 1.35^{d}**	**26.95 ± 1.39^{e}**	**31.41 ± 2.55^{f}**	**17.29 ± 5.00**
Min.	7.20	12.00	15.20	18.40	23.20	28.00	7.20
Max.	14.40	18.00	22.40	26.40	29.60	40.00	40.00
BFT (midline)	**13.50 ± 3.21^{a}**	**16.79 ± 3.44^{b}**	**20.08 ± 3.39^{c}**	**23.08 ± 3.87^{d}**	**25.72 ± 4.27^{e}**	**26.69 ± 5.84^{e}**	**18.43 ± 5.24**
Min.	5.00	8.00	8.00	10.00	10.00	11.00	5.00
Max.	28.00	28.00	34.00	37.00	35.00	41.00	41.00
MT (mm)	**53.86 ± 5.32^{e}**	**52.55 ± 5.13^{d}**	**51.20 ± 5.23^{c}**	**50.19 ± 5.74^{c}**	**48.22 ± 5.72^{b}**	**44.54 ± 7.70^{a}**	**51.80 ± 5.68**
Min.	38.40	35.60	23.60	24.40	26.40	24.00	23.60
Max.	69.20	67.60	64.40	64.80	59.20	59.20	69.20
LMC (%)	**70.10 ± 0.50^{f}**	**68.43 ± 0.56^{e}**	**66.64 ± 0.56^{d}**	**64.65 ± 0.57^{c}**	**62.70 ± 0.57^{b}**	**60.44 ± 1.15^{a}**	**67.36 ± 2.40**
Min.	69.30	67.50	65.50	63.50	61.50	56.60	56.60
Max.	72.00	69.40	67.40	65.40	63.50	61.40	72.00

Means with different superscripts within the same row differ significantly ($P < 0.001$).

BFT = backfat thickness; MT = muscle thickness; LMC = lean meat content.

Min. = minimum value observed.

Max. = maximum value observed.

According to Cannon et al. (1996) BF with optimum quality should be between 17.5 mm and 20 mm. Should this guideline be applied, only the R group would have the potential to produce optimum fat quality (Table 2). From this table it is obvious that with increased BFT, LMC significantly decreased; it can therefore be said that they were inversely correlated. Significant differences were also observed in %LMC between the different classification groups (Table 2). The P classification group had an average LMC of 70.10%, while the corresponding value in the S classification group was 60.44%. No classification group could conform to the maximum LMC of 57% proposed by Davenel et al. (1999) for good fat quality. The necessity of recalculating this value to be able to conform to South African conditions is therefore evident, as by far the majority of pigs did not conform to a maximum LMC of 57%.

CORRELATIONS BETWEEN IODINE VALUE AND CARCASS CHARACTERISTICS

Table 3 indicates Pearson correlation coefficients between the carcass characteristics (BFT, measured at 45 mm and at the midline, muscle thickness, LMC and carcass weights) and IV. Highly significant ($P < 0.001$) correlations were observed between all parameters except muscle thickness, which was poorly correlated with IV ($r = 0.0921$) and other carcass measurements. Backfat thickness (45 mm) ($r = -0.5610$) and LMC ($r = 0.5531$) measurements were respectively best and second best correlated with IV. Martin et al. (1972) indicated that IV was negatively and positively correlated with measures of fat and lean, respectively. The data in Table 2 is in full agreement with this statement. A high correlation existed between BFT (45 mm) and LMC ($r = -0.9918$) (Table 3). Although samples were removed from the midline position, the BFT (45 mm) was better correlated with most other carcass measurements (except for carcass weights which were better correlated with midline BFT) and IV, than the BFT (midline) measurement.

Table 3: Pearson correlation coefficients (r) and significance levels of correlations between Iodine value and carcass characteristics.

Parameter	IV	P	BFT (45 mm)	P	BFT (midline)	P	MT	P	LMC	P
Warm carcass weight (kg)	–0.3747	***	0.4532	***	0.4791	***	0.2847	***	–0.4004	***
Cold carcass weight (kg)	–0.3747	***	0.4531	***	0.4790	***	0.2845	***	–0.4003	***
BFT (45 mm)	–0.5610	***	1.0000	***	0.7821	***	–0.2097	***	–0.9918	***
BFT (midline)	–0.5294	***	0.7821	***	1.0000	***	0.0544	*	–0.7471	***
MT (mm)	0.0921	***	–0.2097	***	0.0544	*	1.0000	***	0.3321	***
LMC (%)	0.5531	***	–0.9918	***	–0.7471	***	0.3321	***	1.0000	***

* = $P < 0.05$; *** = $P < 0.001$.

IV = Iodine value, BFT (45 mm) = Backfat thickness 45 mm from midline; BFT (midline) = Backfat thickness at the midline position, MT = Muscle thickness, LMC = Lean meat content.

n = 2107.

CHEMICAL PROPERTIES OF PIG CARCASSES

In Table 4, EFC showed a significant increase ($P < 0.001$) with decreased LMC and increased BFT (i.e. from the P to the S classification group). None of the groups could reach the minimum value of 84% proposed by Prabucki (1991) for good quality fat. Although the U and S groups had average values of 79.94% and 79.95%, respectively, Table 4 indicates that individual pigs in the O and S groups could surpass the

Table 4: Chemical properties of subcutaneous fat of pigs within the different classification groups of the South African pig classification system.

Parameter	P	O	R	C	U	S	All pigs
Number of pigs	*539*	*539*	*544*	*347*	*102*	*36*	*2107*
Extractable fat (%)	**70.22 ± 5.07^{a}**	**74.43 ± 3.89^{b}**	**77.00 ± 3.01^{c}**	**78.69 ± 2.80^{d}**	**79.94 ± 2.16^{e}**	**79.95 ± 3.28^{de}**	**75.08 ± 5.03**
Min.	26.23	58.79	63.32	62.50	69.16	67.72	26.23
Max.	80.85	82.85	83.90	84.34	83.82	84.15	84.34
Fat Free Dry Matter (%)	**8.99 ± 2.13^{d}**	**8.05 ± 2.04^{c}**	**7.57 ± 1.79^{b}**	**7.08 ± 1.83^{a}**	**6.88 ± 1.58^{a}**	**7.87 ± 1.93^{abc}**	**7.95 ± 2.07**
Min.	3.17	1.02	1.28	1.48	0.59	3.57	0.59
Max.	24.71	13.55	13.42	14.05	12.16	13.02	24.71
Moisture(%)	**20.79 ± 4.45^{e}**	**17.52 ± 3.66^{d}**	**15.42 ± 3.14^{c}**	**14.24 ± 2.69^{b}**	**13.17 ± 2.31^{ab}**	**12.18 ± 3.20^{a}**	**16.97 ± 4.40**
Min.	11.33	8.76	7.20	4.60	8.36	6.95	4.60
Max.	49.06	32.02	27.39	26.50	22.26	19.25	49.06
Refraction index	**1.46152 ± 0.00061^{d}**	**1.46102 ± 0.00054^{c}**	**1.46073 ± 0.00049^{b}**	**1.46056 ± 0.00042^{a}**	**1.46047 ± 0.00044^{a}**	**1.46036 ± 0.00047^{a}**	**1.46096 ± 0.00064**
Min	1.45965	1.45965	1.45965	1.45965	1.45965	1.45940	1.45940
Max	1.46365	1.46365	1.46265	1.46190	1.46165	1.46165	1.46365
Iodine value	**76.95 ± 5.15^{d}**	**73.01 ± 4.61^{c}**	**70.65 ± 4.20^{b}**	**68.97 ± 4.00^{a}**	**68.21 ± 3.86^{a}**	**67.46 ± 3.67^{a}**	**72.42 ± 5.45**
Min.	62.75	62.05	60.26	59.26	58.15	62.12	58.15
Max.	96.13	98.46	86.73	81.56	82.09	78.81	98.46

Means with different superscripts within the same row differ significantly ($P < 0.001$).

Min. = minimum value observed.

Max. = maximum value observed.

84% limit (84.34% was observed in the O group and 84.15% in S group). The average %EFC for all pigs was 75.08%, approximately 9% lower than the proposed value of 84%. This value will therefore also have to be recalculated for South African conditions. The %EFC in pork fat is of economic importance for the production of lard (Barton-Gade, 1983).

Fat-free dry matter and moisture contents were inversely correlated with EFC; as EFC increased, the FFDM and moisture decreased. Consequently, with an increase in BFT (and concomitant decrease in LMC) the %FFDM and %moisture decreased significantly ($P < 0.001$), as illustrated in Table 4. Other studies have shown that the concentrations of water (moisture) and lipid in BF are affected by the amount of carcass fat (Aberle et al., 1977; Wood et al., 1989). From a meat technology perspective, these results are positive because higher water (moisture) content in subcutaneous fat results in insufficient processing firmness (Affentranger et al. 1996). Cameron (1990) and Warriss et al. (1990) attributed less firm fat to increased moisture and UFA contents. Although soft pork had a significantly higher water content than hard pork this difference was reversed by curing. The hard fat samples retained more brine than the soft fat samples (Enser et al., 1984). Soft consistency was not caused by a difference in the water content. Leaner pigs have lower fat contents with higher C18:2 contents (Wood & Enser, 1982). A high FFDM content is indicative of a high level of connective tissue (collagen) (Wood, 1984), which is also not desirable in good quality fat if it is to be used to manufacture good quality meat products. Collagen and water do not significantly affect the consistency of fat, whilst lipids make a major contribution (Enser et al., 1984; Whittington et al., 1986).

Hart, according to Houben & Krol (1983) proposed that the limit for RI-value, to result in good quality fat, should be 1.4598. From Table 4 it can be concluded that with increased BFT and decreased LMC the RI decreased significantly ($P < 0.001$). Siebrits et al. (1987) found that if maize (a major ingredient in South African pig rations) was included in the pig's diet, it resulted in higher C18:2 contents, RI-values and IV in BF than when wheat was included in the diet. When fish oil was included in the pig rations, Irie & Sakimoto (1992) observed an increase in RI-value and IV and a concomitant decrease in fat hardness, while fat colour was not significantly affected. Although individual pigs in all the classification groups realized values below the proposed limit of 1.4598 (Table 4), no classification group had a mean value that could comply with this requirement. The average RI-value for all pigs was 1.46096, also above the recommended value. It must however be noted, that Hart, according to Houben & Krol (1983) proposed this limit based on a corresponding IV of less than 66. The IV exhibited the same trend as the RI, in that it decreased significantly ($P < 0.001$) with increased BFT and decreased LMC (Figure 4). Fischer (1989b) indicated that the IV of BF employed in the manufacture of firm-cutting sausage had to be less than 60 to avoid any problems. This requirement could not be met by any of the classification groups (if mean values of each group are taken into account), but individual pigs in the C and U groups could comply with this requirement, highlighting the effect of breed, environmental and feeding differences. Technically, if this requirement is used as a limit, no firm-cutting sausages could be manufactured in South Africa. Lea et al. (1970) proposed that an IV of lower than 65 would result in hard adipose tissue, while an IV higher than 70 would lead to soft adipose tissue. Mortensen et al., according to Warnants et al., (1996) also proposed that an IV of below 65 in BF would result in good quality BF. Hart, according to Houben & Krol (1983) indicated that BF would be soft at an IV of 66 or above, while Ten Cate, according to Fischer (1989b) indicated that fats with an IV of 66 will cause problems in firm-cutting sausages.

U.O.V.S. BIBLIOTEEK

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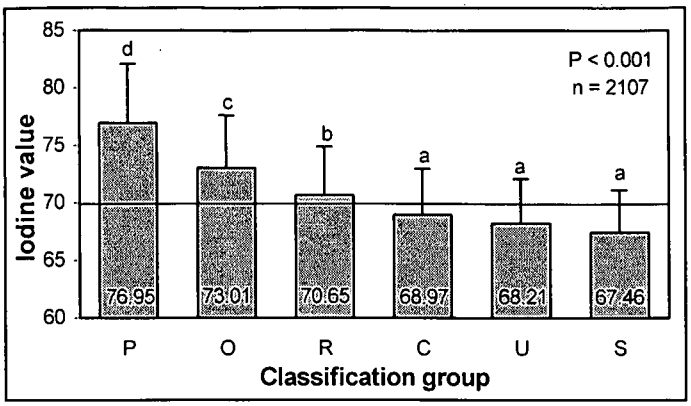


Means with different superscripts differ significantly.

Figure 4: Average Iodine values of pig carcasses in the different South African classification groups.

No mean value of any PORCUS-group could comply with the maximum limits of 65 and 66, but individual pigs in all groups had IV below 65 and 66 (Table 4). If an IV of less than 70 (Houben & Krol, 1983; Barton-Gade, 1983, 1987; Girard et al., according to Davenel et al., 1999) is taken as a measure of good quality BF, the C, U and S groups realized mean IV lower than 70. The average IV of 72.42 for all pigs was above the maximum IV of 60, 65, 66 and 70, respectively proposed, which would indicate that the average South African pig has soft BF, according to international standards. The IV is very important in Switzerland, because it is incorporated into their payment system (Affentranger et al., 1996). Should producers deliver pigs with unacceptably high IV, it would lead to a decrease in their gross profit margin. Previous work has shown that a thinner BF layer corresponds to a lower %EFC, a higher IV and water content as well as more UFA (Barton-Gade, 1983). The results of this study agree with this statement. Backfat from *ad lib* fed pigs is firmer and has less water than restricted fed pigs (Cameron et al., 1990).

The striking differences between the minimum and maximum values of the chemical (Table 4) and carcass characteristics (Table 2) are very interesting and hopeful. A good example of this variation can be seen in the case of the IV where pigs with highly acceptable IV (62.75) and highly unacceptable IV (96.13) can be found in the P classification group. Breed and feeding differences might account for this variation. Producers might also have different rearing conditions or employ growth promoters. Another factor that might influence this phenomenon is the environmental temperature. Pigs sampled in this study originated from 17 different producers. These results are very reassuring for the meat technologist, because it implies that farmers could produce pigs in the P classification group, with thin BF (less than 12 mm), without sacrificing good fat quality. Consequently, a farmer using the right combination of breed and feeding regime could produce pigs with good quality BF in the P classification group.

Correlations between Iodine Value, Carcass Characteristics and Chemical Properties of Backfat

Table 5 indicates the relationship between carcass characteristics, IV and the chemical properties of BF in terms of Pearson correlation coefficients. The same trend observed in Table 3, namely that BFT (45 mm) and LMC, followed by IV were best correlated with the chemical properties of the BF, was found. A negative correlation between % EFC and LMC as well as IV was observed, while %EFC was positively correlated with BFT (45 mm). Muscle thickness was again poorly correlated with all chemical properties. Once more, the

BFT (45 mm) measurement correlated better with the chemical properties than the midline BFT measurement. Refraction index values and IV were highly significantly correlated (r < 0.8695) (Table 5).

Table 5: Pearson correlation coefficients (r) and significance levels of correlations between Iodine value, carcass characteristics and chemical properties of backfat.

Parameter	IV	P	BFT (45 mm)	P	BFT (midline)	P	MT	P	LMC	P
Extractable fat (%)	–0.5117	***	0.6598	***	0.6628	***	0.0363	NS	–0.6315	***
Fat-Free Dry Matter (%)	0.2647	***	–0.3354	***	–0.3863	***	–0.0573	**	0.3157	***
Moisture(%)	0.4599	***	–0.5957	***	–0.5753	***	–0.0146	NS	0.5726	***
Iodine value	1.0000	***	–0.5610	***	–0.5294	***	0.0921	***	0.5531	***
Refraction index	0.8695	***	–0.5760	***	–0.5553	***	0.0803	***	0.5661	***

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

IV = Iodine value, BFT (45 mm) = Backfat thickness 45 mm from midline; BFT (midline) = Backfat thickness at midline position, MT = Muscle thickness, LMC = Lean meat content.

n = 2107.

FATTY ACID COMPOSITION OF PIG CARCASSES

Enser (1983) found that C18:1c9 was the major component of pig fat, usually exceeding 40% of the total fat content. In agreement with the findings of Jeremiah (1982), Enser (1983), Kühne et al. (1985), Fischer (1989a), Alais & Linden (1991) and Enser et al. (1996), this study also found that the long chained FA, in order of abundance, were C18:1c9 (40.53%) followed by C16:0 (21.95%) (Table 6). The order of abundance of the C18:2 (17.04%) and C18:0 (11.85%), as depicted in Table 6, deviate from the above authors' who found that C18:0 occurred in higher concentrations than C18:2, but agrees with the findings of Hilditch, according to Sink et al. (1964). The values in brackets refer to the mean percentage of all pigs sampled during this study. The deviation of the order of C18:0 and C18:2 from the order of the former authors' can possibly explained by feeding and breed differences.

Linoleic acid is not synthesized in the animal body; but must be supplied to animals as part of the feed (Okuyama & Ikemoto, 1999). Pigs in South Africa have a feeding regime rich in PUFA (especially C18:2) and the FA content of the feed is reflected in the BF of the pig, because it is incorporated unchanged in monogastric animals such as pigs. Maize-meal , fishmeal, sunflower oilcake meal and soybean oilcake meal are feedstuffs commonly used in the diets of South African pigs (Viljoen & Ras, 1991).

High C18:2 content in the diet of the animal has been implicated as critical in determining carcass fat quality (Wood, 1984). Enser (1983) observed that C18:2 content has a marked effect on the consistency of pigfat. This FA directly affects lipid melting point and its proportion is reduced as fatness is increased (Wood, 1983). Wood (1973) indicated that leaner pigs have more C18:2 in their fat. This trend was confirmed in this study as the P group had a mean C18:2 concentration of 20.13%, while the pigs from the S group had a mean C18:2 content of 14.27% (Table 6). Whittington et al. (1986), Cameron et al. (1990) and Phelps (1991) observed that the C18:2 content decreased with increased BFT, which was also measured with a mechanical probe, like in South Africa. This study observed the same trend: C18:2 content decreased

Table 6: Fatty acid composition of subcutaneous fat of pigs within the different classification groups in South Africa.

Parameter	P	O	R	C	U	S	Sign level	All pigs
Number of pigs	*539*	*539*	*544*	*347*	*102*	*36*		*2107*
C12:0	**0.01 ± 0.03**	**0.01 ± 0.02**	**0.01 ± 0.02**	**0.01 ± 0.02**	**0.01 ± 0.01**	**0.01 ± 0.01**		**0.01 ± 0.02**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00
Max.	0.17	0.12	0.14	0.10	0.07	0.06		0.17
C14:0	**1.04 ± 0.13^{a}**	**1.06 ± 0.11^{ab}**	**1.07 ± 0.11^{bc}**	**1.09 ± 0.11^{c}**	**1.11 ± 0.12^{c}**	**1.09 ± 0.10^{ac}**		**1.07 ± 0.12**
Min.	0.71	0.71	0.78	0.78	0.85	0.89	***	0.71
Max.	1.58	1.44	1.39	1.40	1.41	1.29		1.58
C15:0	**0.04 ± 0.05**	**0.02 ± 0.04**	**0.02 ± 0.04**	**0.01 ± 0.03**	**0.01 ± 0.03**	**0.01 ± 0.03**		**0.02 ± 0.04**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00
Max.	0.23	0.20	0.16	0.17	0.16	0.10		0.23
C16:0	**20.73 ± 1.37^{a}**	**21.73 ± 1.29^{b}**	**22.43 ± 1.22^{c}**	**22.92 ± 1.14^{d}**	**23.19 ± 1.05^{d}**	**23.53 ± 1.16^{d}**		**21.95 ± 1.52**
Min.	15.65	16.05	18.81	18.91	19.55	20.12	***	15.65
Max.	24.37	25.04	25.48	26.63	26.16	26.44		26.63
C16:1	**1.83 ± 0.32^{a}**	**1.94 ± 0.32^{b}**	**1.93 ± 0.29^{b}**	**1.92 ± 0.30^{b}**	**1.88 ± 0.29^{ab}**	**1.82 ± 0.23^{ab}**		**1.90 ± 0.31**
Min.	0.85	1.08	1.20	1.22	1.40	1.41	***	0.85
Max.	2.86	3.13	2.96	2.81	2.77	2.38		3.13
C17:0	**0.52 ± 0.23^{e}**	**0.49 ± 0.20^{d}**	**0.45 ± 0.18^{c}**	**0.40 ± 0.15^{b}**	**0.38 ± 0.15^{b}**	**0.37 ± 0.17^{abc}**		**0.46 ± 0.20**
Min.	0.17	0.18	0.19	0.18	0.19	0.16	***	0.16
Max.	1.61	1.59	1.17	1.17	0.89	0.91		1.61
C17:1	**0.36 ± 0.17^{d}**	**0.36 ± 0.16^{d}**	**0.34 ± 0.15^{cd}**	**0.30 ± 0.12^{b}**	**0.29 ± 0.13^{b}**	**0.27 ± 0.13^{abc}**		**0.34 ± 0.15**
Min.	0.10	0.12	0.13	0.12	0.12	0.11	***	0.10
Max.	1.12	1.27	0.98	1.00	0.79	0.70		1.27
C18:0	**11.06 ± 1.33^{a}**	**11.68 ± 1.27^{b}**	**12.15 ± 1.31^{c}**	**12.51 ± 1.26^{d}**	**12.66 ± 1.24^{d}**	**13.00 ± 1.25^{d}**		**11.85 ± 1.41**
Min.	7.77	7.60	8.43	9.39	9.17	10.74	***	7.60
Max.	14.64	15.57	17.08	17.10	15.94	16.17		17.10
C18:1c9	**39.13 ± 2.26^{a}**	**40.52 ± 2.00^{b}**	**41.15 ± 1.88^{c}**	**41.41 ± 1.96^{c}**	**41.45 ± 1.60^{c}**	**41.25 ± 2.02^{bc}**		**40.53 ± 2.20**
Min.	30.23	34.06	33.96	34.53	37.13	36.40	***	30.23
Max.	44.56	45.76	47.48	46.13	46.16	45.24		47.48
C18:1c7	**1.51 ± 1.02**	**1.64 ± 1.14**	**1.56 ± 1.05**	**1.53 ± 1.01**	**1.44 ± 1.05**	**1.41 ± 1.01**		**1.56 ± 1.06**
Min.	0.49	0.60	0.61	0.52	0.60	0.71	NS	0.49
Max.	5.42	5.77	5.66	5.78	5.14	4.91		5.78

Means with different superscripts within the same row differ significantly; NS = Not significant; *** = P < 0.001.

Min. = minimum value observed.

Max. = maximum value observed.

Table 6: Fatty acid composition of subcutaneous fat of pigs within the different classification groups in South Africa. (continued)

Parameter	P	O	R	C	U	S	Sign level	All pigs
Number of pigs	*539*	*539*	*544*	*347*	*102*	*36*		*2107*
C18:2(n-6)	**20.13 ± 3.44^{b}**	**17.27 ± 3.03^{b}**	**15.76 ± 2.63^{b}**	**14.89 ± 2.67^{a}**	**14.55 ± 2.42^{a}**	**14.27 ± 2.59^{a}**		**17.04 ± 3.58**
Min.	11.88	10.40	9.34	9.53	9.64	10.61	***	9.34
Max.	34.52	28.94	26.96	22.07	21.86	21.85		34.52
C18:3(n-3)	**0.80 ± 0.22^{d}**	**0.70 ± 0.14^{c}**	**0.66 ± 0.14^{b}**	**0.64 ± 0.14^{b}**	**0.65 ± 0.17^{bc}**	**0.63 ± 0.17^{abc}**		**0.70 ± 0.18**
Min.	0.44	0.42	0.41	0.41	0.40	0.33	***	0.33
Max.	2.08	1.71	1.54	1.16	1.39	1.15		2.08
C20:0	**0.21 ± 0.05^{a}**	**0.22 ± 0.05^{a}**	**0.23 ± 0.04^{a}**	**0.25 ± 0.05^{b}**	**0.26 ± 0.05^{b}**	**0.26 ± 0.05^{b}**		**0.23 ± 0.05**
Min.	0.07	0.10	0.11	0.11	0.16	0.16	***	0.07
Max.	0.39	0.43	0.42	0.42	0.38	0.38		0.43
C20:1	**0.59 ± 0.09^{a}**	**0.62 ± 0.09^{b}**	**0.66 ± 0.10^{c}**	**0.70 ± 0.11^{d}**	**0.73 ± 0.10^{e}**	**0.72 ± 0.12^{de}**		**0.64 ± 0.11**
Min.	0.35	0.36	0.38	0.45	0.48	0.55	***	0.35
Max.	0.95	0.92	1.03	1.15	0.97	1.02		1.15
C20:2(n-6)	**0.72 ± 0.13^{c}**	**0.65 ± 0.13^{b}**	**0.62 ± 0.12^{a}**	**0.62 ± 0.13^{a}**	**0.63 ± 0.14^{ab}**	**0.59 ± 0.09^{a}**		**0.65 ± 0.13**
Min.	0.40	0.38	0.36	0.36	0.39	0.42	***	0.36
Max.	1.18	1.13	1.09	1.00	0.99	0.75		1.18
C20:3(n-6)	**0.05 ± 0.05^{b}**	**0.04 ± 0.05^{a}**	**0.03 ± 0.04^{a}**	**0.03 ± 0.05^{a}**	**0.05 ± 0.05^{ab}**	**0.03 ± 0.04^{ab}**		**0.04 ± 0.05**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	***	0.00
Max.	0.24	0.16	0.22	0.16	0.21	0.13		0.24
C20:3(n-3)	**0.09 ± 0.05^{e}**	**0.07 ± 0.05^{d}**	**0.05 ± 0.05^{c}**	**0.04 ± 0.05^{b}**	**0.04 ± 0.04^{abc}**	**0.03 ± 0.04^{abc}**		**0.06 ± 0.05**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	***	0.00
Max.	0.19	0.17	0.16	0.18	0.13	0.15		0.19
C20:4(n-6)	**0.28 ± 0.07^{d}**	**0.23 ± 0.06^{c}**	**0.20 ± 0.05^{b}**	**0.18 ± 0.04^{a}**	**0.17 ± 0.04^{a}**	**0.16 ± 0.06^{a}**		**0.22 ± 0.07**
Min.	0.08	0.05	0.06	0.05	0.07	0.05	***	0.05
Max.	0.55	0.42	0.40	0.32	0.27	0.33		0.55
C20:5(n-3)	**0.02 ± 0.05**	**0.02 ± 0.05**	**0.01 ± 0.04**	**0.01 ± 0.04**	**0.01 ± 0.03**	**0.01 ± 0.04**		**0.02 ± 0.04**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00
Max.	0.27	0.26	0.28	0.26	0.14	0.14		0.28
C22:5(n-3)	**0.12 ± 0.12^{b}**	**0.11 ± 0.12^{b}**	**0.09 ± 0.11^{a}**	**0.08 ± 0.11^{a}**	**0.07 ± 0.10^{a}**	**0.07 ± 0.11^{ab}**		**0.10 ± 0.12**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	***	0.00
Max.	0.65	0.57	0.52	0.45	0.39	0.37		0.65
C22:6(n-3)	**0.13 ± 0.17^{d}**	**0.12 ± 0.16^{cd}**	**0.10 ± 0.14^{bc}**	**0.09 ± 0.15^{b}**	**0.07 ± 0.13^{ab}**	**0.07 ± 0.14^{abcd}**		**0.11 ± 0.15**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	***	0.00
Max.	0.94	0.75	0.72	0.63	0.66	0.47		0.94

Means with different superscripts within the same row differ significantly; NS = Not significant; *** = P < 0.001.

Min. = minimum value observed.

Max. = maximum value observed.

significantly ($P < 0.001$) from the P to S classification groups. The P to R groups differed significantly ($P < 0.001$) from the C to S groups. Although Ellis & Isbell (1926) indicated that large amounts of C18:2 in pig diets leads to soft fat, this effect is caused by changes in the proportion of SFA, which affects the consistency because of their high melting point and through changes in the distribution of the FA in the TAG (Enser et al., 1984; Wood et al., 1986b). Backfat thickness has decreased over the years, but the intake of C18:2 has been unchanged or has even increased. This led to an increase in the relative C18:2 concentration of the deposited fat (Madsen et al., 1992). Therefore, in the modern type of pig the carcass fat is softer. The technological qualities of meat enriched with C18:2 is poor, because the C18:2 causes soft BF that has decreased storage stability (Kouba & Mourot, 1999). Leaner pigs have a low FA synthesis potential and consequently the concentration of dietary FA has a larger influence on them than on fatter pigs (Martin et al., 1972; Wood et al., 1978).

Whittington et al. (1986) indicated that the C18:2 content of BF should not be more than 15% if good quality bacon is to be manufactured. Various limits for C18:2 content in BF have been proposed. If the limit of less than 15% (Ellis & Isbell, 1926; Houben & Krol, 1980; Enser, 1983; Wood, 1983; Whittington et al., 1986) is used as cut-off point, only the C, U and S classification groups could comply with this. No group could comply with a cut-off point of 9.2%, proposed by Enser (1983) as a requirement for BF used in the production of bacon. Girard, according to Lizardo et al. (2002), indicated that the limit for C18:2 in BF of good quality ranges between 12 and 15%, which no classification group could conform to. However, individual pigs in all classification groups could conform to the 12% C18:2 content requirement. Ten Cate, according to Fischer (1989b) indicated that fats with an IV of 66 and C18:2 contents of 11% will cause problems in firm-cutting sausages. If this requirement were to be met, BF from no classification group in South Africa would be suited for the manufacture of firm-cutting sausages. This is totally unrealistic as firm-cutting sausages like salami is manufactured on large scale in South Africa and is regarded as one of the most expensive and popular meat products available on the market. Individual pigs in the O, R, and C groups did however, conform to this requirement. The differences in feed composition in terms of C18:2 is reflected in the BF FA composition of the pigs. Houben & Krol (1980) observed that inclusion of 30% C18:2 in BF did not present major problems in products except for cervelat type sausage. All groups could conform to this requirement.

Although C18:1c9 occurs in BF at high concentrations, Enser (1983) and Davenel et al. (1999) observed that it was poorly related to the consistency of the fat. This might be the reason why no guideline for good fat quality in terms of C18:1c9 content is available. Close (1983) indicated that C16:0 and C18:0 occurred at 50 and 25% of the C18:1c9 concentration. In this study, C16:0 and C18:0 were present at 54.16% and 29.24% of the amount of C18:1c9, respectively. A significant increase ($P < 0.001$) in C18:1c9 was observed (Table 6) with increased BFT and decreased LMC (from the P to U classification groups). The reason for the decrease from the U to the S classification group might be attributed to the small amount of samples taken from the S group (36), leading to this deviation. Oleic acid concentration is affected by the C18:2 concentration, the former decreases as the latter increases (Whittington et al., 1986). This trend was also confirmed by this study. Malmfors et al. (1978b) and Wood et al. (1978) suggested that pigs regulate the degree of saturation in the subcutaneous fat by reducing the C18:1c9 concentration as the C18:2 content increases. With increased percentages of C16:0, C18:0 and C18:1c9 and decreased percentages of C18:2 and C18:3, Maw et al. (2003) observed a decrease in translucency of the fat. Unfortunately this study did not encompass the

measurement of colour. Moran (1996) showed that higher amounts of UFA, especially C18:1c9, compromised the effectiveness of MAP in ground pork upon refrigeration because the concentration of anaerobes, namely lactobacilli, as well as *Pseudomonas* (a lipolytic aerobe) increased. Oleic acid is considered to be responsible for the changes that occur in fat during the curing process and the fine and special aroma of cooked hams are attributed to C18:1c9 (Delgado et al., 2002).

The C18:0 content increased significantly ($P < 0.001$) with increased BFT and decreased LMC (from the P to S classification groups). Stearic acid is the most significant FA involved in the regulation of the consistency of BF (Lea et al., 1970; Wood et al., 1978; Enser, 1983; Enser et al., 1984; Whittington et al., 1986). Melting point is the most important physical property of a FA, because it determines fat firmness at a particular temperature (Wood, 1984). Wood et al. (1985) indicated that C18:0 content was the single best predictor of fat firmness. If the FA deposited in BF are from dietary origin rather than from *de novo* synthesis, C18:2 will increase at the expense of C18:0 (Enser, 1983). Piedrafita et al. (2001) stated that stress susceptible pigs had higher C18:0 contents than normal pigs, while Jeremiah (1982) indicated that pigs exhibiting the DFD condition had higher amounts of C18:0 in their BF. Good quality fat should contain more than 12% C18:0 (Houben & Krol, 1983; Girard et al., according to Lizardo et al., 2002), a criterion only fulfilled by the R, C, U and S classification groups in this study. Individual pigs in the P and O groups had C18:0 values higher than the proposed 12%. Wood et al. (1989) confirmed that by increasing weight and subcutaneous FT, the contents of C16:0, C18:0 and C18:1c9 in BF increased while C18:2 and C18:3 contents in BF decreased. Cameron et al. (1990) stated that subcutaneous fat became more saturated and less moist as a result of increased C16:0 and C18:0. Stearic acid, synthesized from C16:0 by the elongase enzyme (by the same mechanism by which C20:4 is formed from C18:2 in Table 1), can either be incorporated into TAG or converted to C18:1c9 by the desaturase enzyme.

Palmitic acid can therefore be regarded as the parent compound of C18:0. Enser et al. (1984) and Wood (1984) suggested that C16:0 could also affect the melting point of fat. Palmitic acid may have a larger influence on consistency at lower temperatures because of its lower melting point and it also occurs in higher concentrations than C18:0 (Enser et al., 1984). Table 6 indicates that during this study a significant increase ($P < 0.001$) was observed from the P to S classification groups (increased BFT and decreased LMC). Unfortunately no guideline is available for this FA, although it constitutes the second largest amount in the FA composition of the BF of pigs.

Malmfors et al. (1978b) indicated that C14:0 and C16:0 were negatively correlated with good flavour. Christensen, according to Madsen et al. (1992) indicated that the medium-chained FA, C12:0 and C14:0 have to be present in the feed if they are to be deposited in the depot fat. Piedrafita et al. (2001) found that stress susceptible pigs had lower C14:0, C16:0 and C16:1 contents than normal pigs. The mean C14:0 content of all pigs was 1.07%, and there was a significant increase in its concentration from the P to U classification groups. The deviation observed in the S group was probably because only 36 carcasses from the S group were sampled. Consequently, it can be concluded that C14:0 was present in the feed of the pigs. Myristic acid, together with other FA have been implicated in influencing the WHC of meat. Jeremiah (1982) indicated that DFD pigs had lower C16:0, C16:1 and C18:2 and PUFA contents in their BF and higher C14:0, C18:0 and SFA contents in their BF than PSE and normal pigs. Honkavaara (1989) showed that

halothane positive (stress susceptible) pigs had higher C18:2, C18:3 and PUFA contents than halothane negative (stress resistant) pigs. Piedrafita et al. (2001) showed that C14:0, C16:0 and C16:1 concentrations decreased while C18:0 content increased in stress susceptible pigs. Elliot & Bowland (1968) observed an increase in the amounts of C16:1 and C18:1c9 and a decrease in C16:0 and C18:0 levels when copper was added to the diet of the pig.

No significant differences between the different classification groups were observed for the following FA: C12:0, C15:0, C18:1c7 and C20:5 (Table 6) and will therefore be excluded from further discussion. It is not likely that FA in concentrations below 1% would have a considerable effect on the technological quality of the fat, therefore the rest of the discussion concerning FA will focus on FA occurring in concentrations above 1%. Palmitoleic acid had a mean percentage of 1.90% for all pigs sampled and showed a significant decrease ($P < 0.001$) from the O to S classification groups. Enser et al. (1984) indicated that C18:2 was the main culprit in unsatisfactory bacon, but C16:1 also contributed to the soft consistency thereof.

If fed to pigs, C18:2 and C18:3 are also found in the fat depots, with C20:4, C20:5 and C22:6 present only in insignificant concentrations (Madsen et al., 1992). According to Wood (1984) dietary FA are incorporated unchanged into body fat of monogastric animals like pigs. Linolenic acid has been shown to be positively correlated with tenderness, unlike other PUFA and was essentially uncorrelated with flavour and juiciness (Cameron & Enser, 1991). A significant decrease ($P < 0.001$) was observed in C18:3 concentration from the P to S classification groups. Alpha-linolenic acid is converted to form C20:5(n-3) and C22:6(n-3) (Okuyama & Ikemoto, 1999). The same $\Delta 6$ desaturase enzyme is capable of reacting with ingested C18:2 and C18:3, yielding the n-6 and n-3 types of FA. The enzyme $\Delta 6$ desaturase shows high affinity for the most unsaturated substrate namely C18:3(n-3). Too much of this acid in the diet may inhibit the transformation of C18:2(n-6) to C20:4(n-6). According to Cherian & Sim (1995) a high level of C18:3 in pig rations leads to high C18:3 and C20:5 concentrations and a low concentration of C20:4 in the BF of pigs. As relatively high concentrations of C18:2 (mean of all pigs was 17.04%) and C20:4 (mean % of all pigs was 0.22) were observed and C18:3 occurred in relatively low levels (mean % of all pigs were 0.70), it can be deduced that no inhibition of the parent compound, C18:2, by C18:3 occurred, leading to the relatively high C20:4 content. The low concentration of C20:5 (mean % of all pigs was 0.02) also indicates that C18:3 occurred in low amounts. As the feed composition of these pigs were not known, it must be emphasized that the assumptions made here are based on literature alone. From the low amounts of C22:5 and C22:6 present in the BF of the sampled pigs it can be deduced that a fish compound (oil or meal) might have been added to some feeds in low concentrations. A significant decrease ($P < 0.001$) with increased BFT and decreased LMC (from the P to S classification groups) was observed in both C22:5 and C22:6 concentrations. The levels of C20 and C22 PUFA in adipose tissue of pigs can be changed by their level of inclusion in feed (Irie & Sakimoto, 1992; Morgan et al., 1992).

This study indicated that, in terms of FA composition, South African pigs had lower SFA contents than British pigs (expressed as % of total FA) as reported by Enser et al. (1996). Only C18:1c9, C18:2, and C20:4 were found in higher concentrations in the South African pigs. These differences might possibly be attributed to breed, feed or/and environmental differences.

CORRELATIONS BETWEEN IODINE VALUE, CARCASS CHARACTERISTICS AND BACKFAT FATTY ACID COMPOSITION

Table 7 indicates that the major FA (C16:0; C18:2; C18:0) showed the highest correlations with IV and the different carcass characteristics. Again, as in Tables 3 and 5, muscle thickness had very low correlations with all carcass characteristics and the BFT (midline) measurement was not as well correlated with the different FA as the BFT (45 mm) measurement. The only exception in this trend was that C14:0 was better correlated with the midline BFT measurement. Linoleic acid was best correlated with IV (r = 0.9152), followed by C16:0 (r = –0.8781), C18:0 (r = –0.7369) and C18:3 (r = 0.6909). Oleic acid was relatively well correlated with IV (r = –0.4764). Davenel et al. (1999) indicated that IV overestimates the weight of PUFA such as C18:2, because it binds twice as much iodine as C18:1c9. Davenel et al. (1999) and Lebret et al. (2002) indicated that fat firmness was better correlated with the variation in the SFA content than with PUFA concentration. In this study fat firmness was not physically measured but C16:0 was better correlated with BFT (45 mm) than C18:2 (Table 7).

Table 7: Pearson correlation coefficients (r) and significance levels of correlations between Iodine value, carcass characteristics and fatty acid composition of backfat.

Parameter	IV	P	BFT (45 mm)	P	BFT (midline)	P	MT	P	LMC	P
C12:0	0.0985	***	–0.1256	***	–0.0777	***	0.0298	NS	0.1254	***
C14:0	–0.3487	***	0.1523	***	0.1707	***	–0.0069	NS	–0.1477	***
C15:0	0.0740	***	–0.2195	***	–0.1921	***	–0.0247	NS	0.2085	***
C16:0	–0.8781	***	0.5716	***	0.5582	***	–0.0638	**	–0.5596	***
C16:1	–0.2617	***	0.0499	*	0.0143	NS	–0.1035	***	–0.0615	**
C17:0	–0.0316	NS	–0.2538	***	–0.2313	***	–0.0569	**	0.2376	***
C17:1	–0.1196	***	–0.1739	***	–0.1599	***	–0.0833	***	0.1571	***
C18:0	–0.7369	***	0.4141	***	0.4065	***	–0.0381	NS	–0.4044	***
C18:1c9	–0.4764	***	0.3730	***	0.3436	***	–0.0562	**	–0.3673	***
C18:1c7	–0.0578	**	–0.0333	NS	–0.0814	***	–0.0733	***	0.0225	NS
C18:2	0.9152	***	–0.5456	***	–0.5012	***	0.1135	***	0.5411	***
C18:3(n-3)	0.6909	***	–0.3236	***	–0.2870	***	0.0855	***	0.3234	***
C20:0	–0.3344	***	0.3225	***	0.2749	***	–0.0499	*	–0.3175	***
C20:1	–0.3919	***	0.4043	***	0.3191	***	–0.1191	***	–0.4056	***
C20:2(n-6)	0.6956	***	–0.2797	***	–0.2772	***	0.0515	*	0.2764	***
C20:3(n-6)	0.3249	***	–0.0758	***	–0.0957	***	–0.0044	NS	0.0725	***
C20:3(n-3)	0.4250	***	–0.3466	***	–0.3500	***	0.0049	NS	0.3347	***
C20:4(n-6)	0.6306	***	–0.5570	***	–0.4950	***	0.1097	***	0.5517	***
C20:5(n-3)	0.0385	NS	–0.0695	**	–0.1197	***	–0.0797	***	0.0563	**
C22:5(n-3)	0.0665	**	–0.1491	***	–0.2007	***	–0.0781	***	0.1334	***
C22:6(n-3)	0.0157	NS	–0.1323	***	–0.1872	***	–0.0785	***	0.1172	***

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

IV = Iodine value, BFT (45 mm) = Backfat thickness 45 mm from midline; BFT (midline) = Backfat thickness at midline position, MT = Muscle thickness, LMC = Lean meat content.

n = 2107.

The BFT (45 mm) measurement was best correlated with C16:0 (r = 0.5716) content, followed by C20:4 (r = –0.5570) and C18:2 (r = 0.5456) contents. Lean meat content was most affected by the concentrations of C16:0, C20:4 and C18:2, in decreasing order (Table 7). These observations confirm the findings of Cameron (1990) and Piedrafita et al. (2001) who also found a positive correlation between LMC, C18:2 and C18:3, while a negative correlation was detected between BFT and these two FA. It is clear that the same FA influence LMC and BFT (45 mm), leading to the conclusion that LMC and BFT can indeed be used to

determine fat quality. Wood et al. (1985) indicated that cohesiveness was best correlated with the C18:2 content. When C18:2 concentrations are above 15% in BF, fat firmness and melting point are primarily determined by concentrations of C16:0 andC18:2 rather than C18:0 (Cameron et al., 1990). If this assumption is applied to the data of this study, one could postulate that if the mean of all classification groups were taken as a reference, the C16:0 concentration would determine the fat firmness and melting point, as appears to be the case from Table 7, where C16:0 is better correlated with both LMC and BFT (45 mm). Interestingly enough, this seems not to be the case in all the individual groups. The P, O and R classification groups all have mean C18:2 contents above 15% (Table 6), which would mean that mainly C16:0 contributed to firmness and melting point. In the C, U and S classification groups, with mean C18:2 concentrations below 15%, C18:0 would play the main part in determining fat firmness and melting point. It may therefore be the reason why the C, U and S groups, in which C18:0 is the main constituent, have a better constituency (lower mean IV and conforming to the cut-off point for IV of less than 70 proposed by Lea et al. (1970), Houben & Krol (1983), Barton-Gade (1983, 1987) and Girard et al., according to Davenel et al. (1999). Consequently, it may be suggested that feed used for pigs intended to be used in meat processing should contain more C18:0, even though C18:0 can also be synthesized *de novo* by the pig itself. Camara et al. (1996) observed that C16:1 and C18:0 concentrations were higher in adipose tissue than in dietary fat. They concluded that part of these two FA were either synthesized *de novo* or by elongation from FA provided by the diet. As fatness increases, the proportion of synthesized FA increases, creating a dilution effect (Wood et al., 1989). Backfat consistency was shown to be inversely correlated with the concentration of C18:2 (Cameron et al., 1990; Whittington et al., 1986).

Enser (1983) observed a negative correlation ($r = -0.726$) between C18:2 content and slip point, but lower than the correlation between C18:0 and slip point ($r = 0.928$). Stearic acid was positively correlated with BF consistency (Enser, 1983; Cameron, 1990; Piedrafita et al., 2001). Wood et al. (1978) observed that variation in melting point is most strongly correlated with C18:0 content, while Enser (1983) observed a positive correlation ($r = 0.928$) between the proportion C18:0 and consistency of fat. Linoleic acid only reacts when it is the precursor of other FA in the n-6 series, such as C20:4(n-6) and C20:3(n-6), the latter two FA are the departure points for the prostaglandins (Alais & Linden, 1991). Although C20:4 occurs in low amounts (Table 6) it still has a significant effect on both LMC and BFT (Table 7). Linolenic acid was positively correlated with tenderness, unlike other PUFA, and was essentially uncorrelated with flavour and juiciness (Cameron & Enser, 1991).

FATTY ACID COMBINATIONS OF PIG CARCASSES

The significant differences of the individual SFA were also reflected in the total SFA content (Σ C12:0, C14:0, C15:0, C16:0, C17:0, C20:0) of each classification group. A significant increase ($P < 0.001$) in saturation from the P to S classification group (increased BFT and decreased LMC) was observed. Table 8 showed that the P, O and R groups differed significantly ($P < 0.001$) from the other 3 groups. Total SFA content, according to international standards, has to be more than 41% of the total FA content (Häuser & Prabucki, 1990) to result in BF with good technological quality. No group as a whole could comply with this

Table 8: Fatty acid combinations of subcutaneous fat of South African pigs within the different classification groups.

Parameter	P	O	R	C	U	S	All pigs
Number of pigs	*539*	*539*	*544*	*347*	*102*	*36*	*2107*
SFA (%)	**33.61 ± 2.54^{a}**	**35.20 ± 2.35^{b}**	**36.36 ± 2.33^{c}**	**37.17 ± 2.16^{d}**	**37.60 ± 2.13^{d}**	**38.27 ± 2.17^{d}**	**35.59 ± 2.73**
Min.	26.86	26.62	29.17	30.53	31.84	33.22	26.62
Max.	40.56	41.51	44.16	43.99	43.98	42.67	44.16
C16:0 + C18:0(%)	**31.79 ± 2.44^{a}**	**33.41 ± 2.26^{b}**	**34.58 ± 2.24^{c}**	**35.43 ± 2.07^{d}**	**35.85 ± 2.04^{d}**	**36.54 ± 2.14^{d}**	**33.80 ± 2.67**
Min.	25.48	25.32	27.24	29.03	30.31	31.24	25.32
Max.	38.36	39.55	42.05	41.92	42.10	40.87	42.10
MUFA (%)	**43.42 ± 2.45^{a}**	**45.08 ± 2.19^{b}**	**45.64 ± 1.89^{c}**	**45.85 ± 2.11^{c}**	**45.79 ± 1.81^{c}**	**45.47 ± 1.98^{bc}**	**44.97 ± 2.35**
Min.	33.86	38.07	37.17	37.35	40.67	41.85	33.86
Max.	49.15	50.58	52.45	52.03	50.91	49.34	52.45
PUFA (%)	**22.33 ± 3.74^{d}**	**19.20 ± 3.23^{c}**	**17.53 ± 2.81^{b}**	**16.59 ± 2.88^{a}**	**16.23 ± 2.66^{a}**	**15.88 ± 2.73^{a}**	**18.94 ± 3.87**
Min.	13.21	11.82	10.70	10.72	11.12	11.93	10.70
Max.	38.59	32.91	30.07	24.83	25.18	24.14	38.59
Dienoic (%)	**20.85 ± 3.54^{d}**	**17.92 ± 3.13^{c}**	**16.38 ± 2.72^{b}**	**15.51 ± 2.78^{a}**	**15.18 ± 2.54^{a}**	**14.86 ± 2.66^{a}**	**17.69 ± 3.68**
Min.	12.34	10.86	9.80	9.95	10.16	11.12	9.80
Max.	35.70	30.04	27.84	23.01	22.84	22.60	35.70
Trienoic (%)	**0.94 ± 0.27^{c}**	**0.80 ± 0.19^{b}**	**0.74 ± 0.18^{a}**	**0.72 ± 0.19^{a}**	**0.74 ± 0.22^{ab}**	**0.69 ± 0.21^{ab}**	**0.80 ± 0.23**
Min.	0.44	0.44	0.41	0.41	0.43	0.33	0.33
Max.	2.47	1.99	1.84	1.41	1.60	1.29	2.47
Tetraenoic (%)	**0.28 ± 0.07^{d}**	**0.23 ± 0.06^{c}**	**0.20 ± 0.05^{b}**	**0.18 ± 0.04^{a}**	**0.17 ± 0.04^{a}**	**0.16 ± 0.06^{a}**	**0.22 ± 0.07**
Min.	0.08	0.05	0.06	0.05	0.07	0.05	0.05
Max.	0.55	0.42	0.40	0.32	0.27	0.33	0.55
Pentaenoic (%)	**0.13 ± 0.16^{c}**	**0.13 ± 0.16^{bc}**	**0.10 ± 0.15^{ab}**	**0.09 ± 0.14^{a}**	**0.08 ± 0.12^{a}**	**0.09 ± 0.14^{abc}**	**0.11 ± 0.15**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.	0.87	0.79	0.80	0.70	0.52	0.51	0.87
Hexanoic (%)	**0.13 ± 0.17^{c}**	**0.12 ± 0.16^{bc}**	**0.10 ± 0.14^{ab}**	**0.09 ± 0.15^{a}**	**0.07 ± 0.13^{a}**	**0.07 ± 0.14^{abc}**	**0.11 ± 0.15**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.	0.94	0.75	0.72	0.63	0.66	0.47	0.94
Penta- + Hexaenoic (%)	**0.26 ± 0.31^{c}**	**0.25 ± 0.30^{bc}**	**0.20 ± 0.28^{ab}**	**0.18 ± 0.29^{a}**	**0.15 ± 0.25^{a}**	**0.16 ± 0.27^{abc}**	**0.22 ± 0.30**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max.	1.81	1.52	1.52	1.30	1.06	0.95	1.81
UFA	**65.75 ± 2.46^{d}**	**64.28 ± 2.30^{c}**	**63.17 ± 2.28^{b}**	**62.44 ± 2.14^{a}**	**62.02 ± 2.12^{a}**	**61.34 ± 2.08^{a}**	**63.91 ± 2.64**
Min.	58.89	57.87	55.63	55.70	55.61	57.16	55.61
Max.	72.45	72.77	69.72	68.49	67.86	65.99	72.77

Means with different superscripts within the same row differ significantly ($P < 0.001$).

Min. = minimum value observed.

Max. = maximum value observed.

requirement, although individual pigs in each classification group had total SFA contents above 41% (Table 8). The SFA (C12:0–C18:0) have a positive influence on firmness and cohesiveness of the carcass fat tissue (Madsen et al., 1992). Saturated FA make fat tissue hard (Enser, 1983). Cameron et al. (1990) stated that subcutaneous fat became more saturated and less moist as a result of increased C16:0 and C18:0. Larsson & Quinn, according to Davenel et al. (1999) stated that SFA strongly influence SFC of lipids because of their high melting point (63–70°C).

An increase in the MUFA content was observed from the P to C classification groups, but a decrease in the MUFA content of the U and S groups were found. The P and O groups differed significantly from the other 4 groups (Table 8). The total MUFA content varies little with diet, as it already makes up the bulk of the FA found in pig adipose tissue and can be synthesized *de novo*. Okuyama & Ikemoto (1999) indicated that SFA (C16:0; C18:0) and MUFA (C16:1; C18:1) are synthesized in the animal body from carbohydrates and proteins and that excess energy was converted to these FA. Madsen et al. (1992) found that when *de novo* synthesis, resulting in SFA and MUFA, is predominant, BF will be firm, while deposition of dietary PUFA will result in soft BF. Mono-unsaturated FA constitute the largest part of pig adipose tissue. Consequently, MUFA in the diet does not have a major influence on fat deposition because MUFA from endogenous origin plays the most important role (Verbeke et al., 1999). Wood (1983) stated that the SFA and MUFA of C16 and C18 would best define the firmness of the BF. Enrichment of pig rations with MUFA has no deteriorating impact on the taste and acceptability of meat consumed immediately after purchase (Van Oeckel et al., 1996) or vacuum packed and stored for a maximum of six months at –18°C (Ahn et al., 1996).

The international guideline proposed for total MUFA content (Σ C16:1, C17:1, C18:1c7, C18:1c9, C20:1) to result in good quality fat is less than 57% of the total FA (Häuser & Prabucki, 1990). All groups complied with this requirement – no individual pig had a MUFA far below 57%. Mono-unsaturated FA (C16:1 and C18:1) have a negative influence on firmness and cohesiveness of the carcass fat tissue (Madsen et al., 1992). Fatty acid composition of fresh and matured dry-cured sausages (e.g. Milano salami) was characterized by average FA-values of around 40% SFA, 47% MUFA and 13% PUFA (Zanardi et al., 2002). Incorporating MUFA-rich pork fat in cured meat products does not seem to cause any problems in terms of consistency or taste (Myer et al., 1992) because C18:1c9 already constitutes the largest part of the pork FA pattern (Verbeke et al., 1999). St John et al. (1986) manufactured frankfurters with a reduced fat content from meat and fat from pigs fed on a diet which included canola oil (high in MUFA), with no technological problems. Mono-unsaturated FA are considered to be beneficial from a health point of view.

In line with the trend observed in the C18:2 content (the main constituent of the dienoic FA), the total dienoic FA (Σ C18:2, C20:2) content showed a decrease from the P to S group (Table 8). Furthermore, the P, O and R groups differed significantly from the C, U and S groups. The maximum total dienoic FA content has to be less than 10% of the total FA (Häuser & Prabucki, 1990) in order to result in good quality BF. This requirement could not be met by any of the classification groups, although individual pigs in the R and C groups had values less than 10%. These differences can mainly be attributed to different diets, containing different levels of C18:2. Special attention should therefore be paid to the dienoic FA content of South African pig diets.

The total trienoic FA (Σ C18:3, C20:3(n-6), C20:3(n-3)), tetraenoic FA (only C20:4), pentaenoic FA (Σ C20:5 and C22:5) as well as hexaenoic FA (only C22:6) also showed a significant decrease ($P < 0.001$) in unsaturation with increased BFT and decreased LMC (from the P to S classification groups) (Table 8). All groups complied with the requirements set by Häuser & Prabucki (1990) for good quality fat, namely less than 1% total trienoic FA, less than 0.5% total tetraenoic FA and less than 1% penta- + hexaenoic FA of the total FA content, respectively.

Total PUFA content is constituted by the sum of the di- to hexaenoic FA. From the above discussion it can be concluded that the dienoic FA content has the largest influence on the total PUFA content as all the other PUFA constituents were within the limits proposed for good quality. This might be the cause of the problem in the FA composition of South African pigs. Consequently, it can be deduced that by decreasing the dienoic FA level in BF, an improvement in fat quality could possibly be achieved. As expected, a significant decrease ($P < 0.001$) in total PUFA content was observed (Table 8) with increased BFT and decreased LMC (from the P to S group). In line with observations made regarding the dienoic FA content, the P, O and R groups differed significantly from the C, U and S groups. Backfat from pigs fed PUFA-rich diets had less SFA (mainly C16:0 and C18:0) and more total PUFA (mainly C18:2 and C18:3) (Bryhni et al., 2002). Adipose tissue with the lowest thickness lack consistency because they have the highest proportion of PUFA and the lowest proportion of SFA (Lea et al., 1970; Villegas et al., 1973; Wood, 1973). According to Verbeke et al. (1999) PUFA in pork fat are exclusively of dietary origin and it is easy to see the effects thereof in the adipose tissue of the pig. Högberg et al. (2002) indicated that the PUFA content in the neutral lipids of indoor reared pigs were higher than in outdoor reared ones and that females had more unsaturated fat than barrows. Nilzén et al. (2001) stated that pigs with access to green feed (barley, peas and oats) had higher levels of PUFA in their BF. Unfortunately this study did not encompass the survey of feed. Polyunsaturated FA incorporation into fat is restricted by the resulting pork fat consistency and oxidative stability, the two properties of importance to the meat curing industry (Warnants et al., 1996). Igene & Pearson (1979) indicated that the amount of PUFA in the phospholipids might induce autoxidation and ultimately WOF in meat. Warmed-over flavour is mainly related to pre-cooked meat products intended for reheating (Bertelsen et al., 2000).

Contrary to fresh pork where few problems are to be expected when properly stored, meat products from PUFA enriched pork fat might suffer from taste aberrations, a higher frequency of dislikes and an impaired consistency, due to soft BF (Houben & Krol, 1980; Kunz, 1991; Warnants et al., 1998). Warnants et al. (1996) indicated that a distinction should be made between meat intended for the fresh meat market and meat used for processing, as a high PUFA content may cause problems during curing and shelf-life of meat products. When the proportion of PUFA in the BF increases, the storage stability decreases, as does the flavour and taste (Madsen et al., 1992). According to Zanardi et al. (2002) matured Milano salami have a fat content of approximately 30% with PUFA constituting 13% thereof. An inferior consistency as a result of added PUFA is often experienced when manufacturing dry-fermented products, as the melted fat can drip out of the product during the drying or ripening phase. Inferior consistency can also become evident when the meat product is cut or sliced as a fatty smear occurs on the cutting surface of the knife (Houben & Krol, 1980; Warnants et al., 1998). Fats rich in PUFA show a soft/weak consistency and cannot be used for the production of bacon and fermented sausages (Houben & Krol, 1983). Firmness is particularly important in vacuum-packaged rindless bacon rashers in which soft fat results in the loss of definition of individual

rashers and loss of pack stiffness (Enser, 1983). The consistency of the BF decreases with increasing PUFA content (Rhee et al., 1988b; Warnants et al., 1996).

Several limits have been proposed for total PUFA content in BF of good technological quality. No group could conform to the limit of 12% or less PUFA in BF (Prabucki, according to Houben & Krol, 1983; Stiebing et al., 1993), but individual pigs in each group, except the P group, had PUFA values lower than 12% (Table 8). No group could meet either of the following requirements proposed to obtain good quality fat – a maximum value of 13% PUFA in BF (Wenk et al., according to Warnants et al., 1996) and a limit of less than 15% PUFA in the BF (Houben & Krol, 1983; Fischer et al., according to Warnants et al., 1996). Individual pigs from all groups had PUFA contents less than 15%, highlighting feed, breed and environmental differences. Hiner, according to Houben & Krol (1985) found that BF samples did not oxidize after 9 months of storage at –20°C even if they had a PUFA content of up to 15%. Individual pigs in the O to S groups had PUFA contents less than 13% and 15% (Table 8). Warnants et al. (1998) recommended that BF used in salami could contain up to 20% PUFA. If this requirement is to be met, the O to S groups would qualify, with individual pigs in the P group conforming to this limit. Up to 21% PUFA in BF may be used for dry sausage manufacture, but the risk of encountering drying and consistency problems is undeniable (Stiebing et al., 1993). They recommended that 14% PUFA in BF be the maximum PUFA content for dry sausage production intended to be stored for a moderate length of time, while the PUFA content should be less than 12% if the product has to be stored for longer periods. Warnants et al. (1998) indicated that salami should contain 14% PUFA. If the 21% PUFA level in BF requirement is to be met, BF of South African pigs from the O to S groups could be utilized for dry sausage manufacture. However, if the 12 and 14% limits are to be used, no group could conform to these strict requirements. Isolated pigs from all groups did conform to the 14% PUFA in BF requirement, while individual pigs from the O to S groups met the 12% requirement. Warnants et al. (1998) recommended that BF should contain 20% PUFA. The O to S groups could comply with this requirement. Warnants et al. (1996) observed that 22% PUFA in BF did not cause problems in fresh and frozen meat. Twenty three percent PUFA in BF can be added to salami without resulting in unacceptable taste (Warnants et al., 1998). All the groups could easily comply with this requirement. Bryhni et al. (2002) found that rancidity was higher when PUFA level in the BF was 23%. All groups had mean PUFA contents lower than 23%. Houben & Krol (1983) found no serious problems in the consistency of bacon made from meat and fat containing up to 40% PUFA. This is an interesting observation, but it may not be realistic in the South African context, although individual pigs in the P to R groups had values higher than 30% (Table 8) and no complaints regarding separation of fat in bacon has been documented in South Africa.

As more UFA, with low melting points, are included in feed, the BF becomes softer, and other undesirable characteristics mainly caused by oxidation, such as reduced storage stability, rancidity, off-flavours and discolouration of the carcass fat are also encountered (Enser, 1983; Madsen et al., 1992). The degree of fat firmness was shown to be negatively correlated with the proportion of total UFA (Piedrafita et al., 2001). With increased BFT and decreased LMC the UFA content decreased significantly ($P < 0.001$) from the P to S classification groups (Table 8). This observation is in agreement with the findings of Kühne (1983) who stated that thinner BF contains more UFA than SFA, leading to a softer consistency. Table 8 indicates that no group could conform to the requirement of an UFA content of less than 59% of the total FA, proposed by Häuser & Prabucki (1990) regarding good quality fat. As total MUFA and total PUFA constitutes total UFA, it

can be concluded that PUFA has a larger influence on total UFA than MUFA, because all the groups conformed to the limit proposed for MUFA, but no group could conform to the requirement proposed for the PUFA content. This led to the phenomenon that no group could comply with the limit set for total UFA content in good quality BF. The total UFA content of the P, O and R groups differed significantly from the C, U and S groups (Table 8). Individual pigs conformed to the maximum UFA content of 59% proposed for good fat quality, which, as mentioned before, might mainly be attributed to feeding differences (difference in PUFA content of feeds) but also feeding systems (restricted or *ad lib*) and environmental differences. Moran (1996) indicated that an oily sheen and softening, as a result of a high UFA content, can be noticed easier in the large fat depots of pigs and the soft fat was difficult to handle during processing. Enser et al. (1984) investigated lipids from unsatisfactory vacuum-packaged bacon and found that they contained more UFA (C18:2) and less SFA (C18:0 and C16:0), resulting in low melting points.

Correlations between Iodine Value, Carcass Characteristics and Backfat Fatty Acid Combinations

All the combinations, except hexaenoic content and the sum of penta- and hexaenoic FA, were best correlated with IV, rather than carcass characteristics, at a significance level of $P < 0.001$. Table 9 indicates that the parameters best correlated with IV, in decreasing order, were PUFA content (r = 0.9243), dienoic FA content (r = 0.9144), SFA content (r = –0.8894), C16:0 + C18:0 (r = –0.8888) and UFA content (r = 0.8823).

Table 9: Pearson correlation coefficients (r) and significance levels of correlations between Iodine value, carcass characteristics and fatty acid combinations of backfat.

Parameter	IV	P	BFT (45 mm)	P	BFT (midline)	P	MT	P	LMC	P
SFA (%)	–0.8894	***	0.5206	***	0.5116	***	–0.0606	**	–0.5099	***
C16:0 + C18:0(%)	–0.8888	***	0.5439	***	0.5323	***	–0.0564	**	–0.5320	***
MUFA (%)	–0.5314	***	0.3472	***	0.2904	***	–0.1099	***	–0.3494	***
Dienoic (%)	0.9144	***	–0.5402	***	–0.4970	***	0.1122	***	0.5358	***
Trienoic (%)	0.6839	***	–0.3376	***	–0.3147	***	0.0649	**	0.3342	***
Tetraenoic (%)	0.6306	***	–0.5570	***	–0.4950	***	0.1097	***	0.5517	***
Pentaenoic (%)	0.0622	**	–0.1347	***	–0.1887	***	–0.0828	***	0.1188	***
Hexanoic (%)	0.0157	NS	–0.1323	***	–0.1872	***	–0.0785	***	0.1172	***
Penta- + Hexaenoic (%)	0.0397	NS	–0.1370	***	–0.1929	***	–0.0828	***	0.1211	***
PUFA (%)	0.9243	***	–0.5540	***	–0.5147	***	0.1061	***	0.5482	***
UFA	0.8823	***	–0.5031	***	–0.4962	***	0.0576	**	0.4927	***

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

IV = Iodine value, BFT (45 mm) = Backfat thickness 45 mm from midline; BFT (midline) = Backfat thickness at midline position, MT = Muscle thickness, LMC = Lean meat content.

n = 2107.

This was to be expected as the previous discussion indicated that PUFA content influences the fat quality quite dramatically, even though it does not occur in the highest concentration. Polyunsaturated FA content was negatively correlated with eating quality (Cameron & Enser, 1991; Bryhni et al., 2002). Cameron et al. (1990) observed that the correlation between the C16:0 + C18:0 combination and fat firmness was 0.48. It was explained earlier that different SFA (either C16:0 or C18:0) could play the larger part in determining the consistency of the fat, depending on whether C18:2 occurs in concentrations above or below 15%. Palatability of meat is positively correlated with SFA and MUFA content (Cameron & Enser, 1991; Okuyama & Ikemoto, 1999; Bryhni et al., 2002). Correlations between BFT (45 mm), LMC and FA combinations were

not as high (not above 0.5600) as the correlations between IV and the FA combinations. A highly significant ($P < 0.001$) positive correlation existed between BFT (45 mm) and SFA and MUFA contents, while BFT (45mm) was negatively correlated with the PUFA (and constituents thereof) and UFA contents (Table 9). The opposite is true for LMC – it was negatively correlated with SFA and MUFA contents and positively with UFA and PUFA contents (and its constituents). Correlations between FA combinations and BFT (midline) measurements were lower than those for BFT (45 mm). Once more muscle thickness was poorly correlated with FA combinations.

FATTY ACID RATIOS OF PIG CARCASSES

The MUFA/SFA ratio and (C16:1 + C18:1c9)/(C16:0 + C18:0) ratio showed a significant decrease ($P < 0.001$) with increased BFT and decreased LMC (Table 10). These two ratios differed by only 0.01%. The MUFA/SFA ratio was negatively correlated with fat firmness, with the following Pearson correlation coefficients: ($r = -0.29$) (Cameron et al., 1990) and ($r = -0.28$) (Wood et al., 1978). Lea et al. (1970), Wood et al. (1978), Enser et al. (1984) and Whittington et al. (1986) found that the MUFA/SFA or (C16:1 + C18:1c9)/(C16:0 + C18:0) ratio were better related to the variation in melting and slip points of the lipids as well as the consistency of the fatty tissues and may be independent of carcass fatness (Lea et al., 1970). Unfortunately no guidelines are proposed for these ratios. In both cases the P, O and R groups differed significantly from the other three groups.

Since C18:0 appears to be the most important FA in the regulation of BF consistency, but feeding C18:2 is known to make the fat soft, there is clearly an important relationship between dietary C18:2 content and the deposition of C18:0 (Enser, 1983). This ratio increased with increased BFT and decreased LMC and the P, O and R groups differed significantly from the C, U and S groups. A C18:0/C18:2 ratio above 1.2 and below 1.2 will result in firm and soft BF, respectively (Honkavaara, 1989). No group could comply with this requirement, although individual pigs in all groups, except the P group, had values higher than 1.2 (Table 10). Honkavaara (1989) indicated that the C18:0/C18:2 ratio should be above 1.2 in good quality bacon. A C18:0/C18:2 ratio above 1.47 will produce bacon of good quality (Enser, 1983; Enser et al., 1984). Again, no group could comply with this requirement, except for isolated pigs in the R to S groups. Consequently, it can be said that if these requirements were to be met, no group would be suitable to produce pigs with fat to be used for bacon production in South Africa, which is not the case. It would be reasonable to suggest that these ratios are not realistic.

The C16:0/C18:2 ratio was observed in work done by Enser (1984) and Whittington et al. (1986) to measure firmness. Cameron et al. (1990) indicated that the correlation between this ratio and firmness was 0.54. This study observed a significant ($P < 0.001$) increase in this ratio from the P to S classification groups, with the P and O groups differing significantly from the rest of the groups. No guideline has been proposed for this ratio.

Table 10: Fatty acid ratios of subcutaneous fat of pigs within the different South African classification groups applicable to technological quality.

Parameter	P	O	R	C	U	S	Sign. level	All pigs
Number of pigs	*539*	*539*	*544*	*347*	*102*	*36*		*2107*
C16:1 + C18:1/C16:0 + C18:0	**1.29 ± 0.11^{d}**	**1.28 ± 0.11^{c}**	**1.25 ± 0.10^{b}**	**1.23 ± 0.09^{a}**	**1.21 ± 0.08^{a}**	**1.18 ± 0.09^{a}**		**1.26 ± 0.11**
Min.	1.00	1.00	0.98	0.92	1.01	1.00	***	0.92
Max.	1.68	1.67	1.63	1.50	1.44	1.34		1.68
MUFA/SFA	**1.30 ± 0.11^{c}**	**1.29 ± 0.10^{c}**	**1.26 ± 0.10^{b}**	**1.24 ± 0.09^{a}**	**1.22 ± 0.09^{a}**	**1.19 ± 0.09^{a}**		**1.27 ± 0.11**
Min.	1.02	0.99	0.98	0.91	1.01	1.06	***	0.91
Max.	1.66	1.72	1.64	1.51	1.44	1.34		1.72
C18:0/C18:2	**0.57 ± 0.15^{a}**	**0.70 ± 0.17^{b}**	**0.80 ± 0.20^{c}**	**0.88 ± 0.23^{d}**	**0.90 ± 0.22^{d}**	**0.95 ± 0.22^{d}**		**0.74 ± 0.22**
Min.	0.25	0.32	0.34	0.45	0.49	0.51	***	0.25
Max.	1.13	1.25	1.59	1.78	1.58	1.52		1.78
C16:0/C18:2	**1.07 ± 0.24^{a}**	**1.31 ± 0.29^{b}**	**1.47 ± 0.31^{c}**	**1.60 ± 0.35^{d}**	**1.65 ± 0.34^{d}**	**1.71 ± 0.34^{d}**		**1.36 ± 0.36**
Min.	0.45	0.55	0.71	0.86	0.89	0.92	***	0.45
Max.	2.04	2.34	2.71	2.65	2.59	2.33		2.71
C20:4/C18:2	**0.014 ± 0.003^{c}**	**0.014 ± 0.003^{bc}**	**0.013 ± 0.003^{b}**	**0.012 ± 0.003^{a}**	**0.012 ± 0.003^{a}**	**0.011 ± 0.003^{a}**		**0.013 ± 0.003**
Min.	0.00	0.00	0.00	0.00	0.01	0.00	***	0.00
Max.	0.03	0.03	0.02	0.02	0.02	0.02		0.03
C22:6/C18:3	**0.17 ± 0.23**	**0.19 ± 0.25**	**0.16 ± 0.24**	**0.16 ± 0.27**	**0.12 ± 0.25**	**0.13 ± 0.26**		**0.17 ± 0.25**
Min.	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00
Max.	1.32	1.13	1.04	0.97	1.11	0.87		1.32
DBI	**90.49 ± 6.12^{d}**	**85.61 ± 5.27^{c}**	**82.56 ± 4.86^{b}**	**80.73 ± 4.65^{a}**	**79.84 ± 4.59^{a}**	**78.79 ± 4.51^{a}**		**84.87 ± 6.48**
Min.	74.03	73.85	69.48	68.69	67.45	70.50	***	67.45
Max.	114.60	110.14	101.75	95.99	96.87	92.59		114.60
PI	**26.75 ± 4.35^{d}**	**23.32 ± 3.59^{c}**	**21.24 ± 3.23^{b}**	**20.06 ± 3.14^{a}**	**19.50 ± 2.96^{a}**	**19.14 ± 3.09^{a}**		**22.87 ± 4.44**
Min.	15.46	15.36	14.11	12.71	13.05	14.54	***	12.71
Max.	43.65	39.97	37.65	30.54	31.57	28.57		43.65

Means with different superscripts within the same row differ significantly.

NS = Not significant; *** = P < 0.001.

Min. = minimum value observed.

Max. = maximum value observed.

Pamplona et al. (1998) indicated that the C20:4/C18:2 ratio expresses the activity coefficient of the enzyme involved in the biosynthesis of C20:4. No guideline is available. This ratio decreased significantly ($P < 0.001$) from the P to the S classification group (Table 10), which indicates that the activity of the enzyme involved in the biosynthesis of C20:4 decreases with increased BFT and decreased LMC. This might be one of the causes of the decrease in the C20:4 content, as observed in Table 6. Another reason might be that the concentration of the parent compound, C18:2, decreased with increased BFT and decreased LMC, leading to a lower synthesis of C20:4. According to Pamplona et al. (1998) the C22:6/C18:3 ratio expresses the activity coefficient of enzyme involved in the biosynthesis of C22:6. This ratio did not differ significantly between the different groups in this study (Table 10).

Double bond index and PI indicate the level of unsaturation. Alam & Alam (1986) and Affentranger et al. (1996) used the DBI to determine fat quality. Prabucki (1991) proposed that a DBI of less than 80 would result in good quality BF. A significant decrease was observed from the P to the S groups, with the P to R groups differing significantly from the C to S groups. Only the U and S could comply with the maximum DBI requirement of less than 80, while individual pigs in all the groups had DBI less than 80. Pamplona et al. (1998) proposed the use of PI to serve as an indicator of oxidative stability of fat. Basically the same trend was observed for the PI: a significant decrease in PI was found from the P to S groups, with the P, O and R groups differing significantly from the other 3 groups. No guideline is available for PI, but it indicates that fat from thicker BF layers are more resistant to oxidative spoilage.

Correlations between Iodine Value, Carcass Characteristics and Fatty Acid Ratios of Backfat

Table 11 indicates that the FA ratios were better correlated with IV, rather than with carcass characteristics. Iodine value was best correlated with DBI ($r = 0.9552$). Affentranger et al. (1996) stated that the IV is highly correlated with the DBI. Peroxidizability index was also highly correlated with IV ($r = 0.9552$). The C16:0/C18:2 and C18:0/C18:2 ratios were highly significantly ($P < 0.001$) correlated with IV, with r-values of -0.8999 and -0.8902, respectively (Table 11). No significant correlation was found between IV and the C20:4/C18:2 ratio. None of the carcass characteristics had correlations with an r-value above 0.5816.

Table 11: Pearson correlation coefficients (r) and significance levels of correlations between Iodine value, carcass characteristics and fatty acid ratios of backfat.

Parameter	IV	P	BFT (45 mm)	P	BFT (midline)	P	MT	P	LMC	P
MUFA/SFA	0.4934	***	–0.2657	***	–0.2949	***	–0.0148	NS	0.2542	***
C16:1 + C18:1/ C16:0 + C18:0	0.5212	***	–0.2781	***	–0.2892	***	0.0087	NS	0.2693	***
C18:0/C18:2	–0.8902	***	0.5316	***	0.4971	***	–0.1035	***	–0.5263	***
C16:0/C18:2	–0.8999	***	0.5612	***	0.5233	***	–0.1151	***	–0.5563	***
C20:4/C18:2	–0.0185	NS	–0.2241	***	–0.1831	***	0.0284	NS	0.2200	***
C22:6/C18:3	–0.0970	***	–0.0606	**	–0.1150	***	–0.0893	***	0.0465	*
DBI	0.9552	***	–0.5816	***	–0.5622	***	0.0782	***	0.5711	***
PI	0.8775	***	–0.5762	***	–0.5613	***	0.0662	**	0.5643	***

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

IV = Iodine value, BFT (45 mm) = Backfat thickness 45 mm from midline; BFT (midline) = Backfat thickness at midline position, MT = Muscle thickness, LMC = Lean meat content.

n = 2107.

Only the C18:0/C18:2 and C16:0/C18:2 ratios were positively correlated with BFT (45 mm) and negatively with LMC. This indicates that the SFA component (C16:0 and C18:0) have a larger influence on this ratio than the C18:2 content. The rest of the ratios were negatively correlated with BFT (45 mm) and positively with LMC. With the exception of the MUFA/SFA, (C16:1 + C18:1)/(C16:0 + C18:0) and C22:6/C18:3 ratios, the BFT (45 mm) measurement was better correlated with the FA ratios than the BFT (midline) measurement. Lean meat content was also relatively well correlated with FA ratios, although no correlation was above 0.5800. Muscle thickness was poorly correlated with all of the FA ratios.

HEALTH AND NUTRITIONAL IMPLICATIONS OF PIG CARCASSES

As mentioned earlier, consumers are presently more aware of health and nutritional concerns as well as diet, than in the past, due to certain diet-disease theories, which have implicated meat and meat products as contributing to the increased incidence of heart disease and cancer. There is an increasing demand among health care professionals as well as the public for meat products with a lower SFA content (Rhee et al., 1988b). As discussed earlier in this chapter, the SFA content is regarded as very important in terms of consistency and ultimately fat quality. It can therefore be justified to say that improvement in the BF quality of pigs, in terms of technology, would result in a decrease of the health and nutritional properties of pork. However, in models of breast and colon cancer, SFA such as lard, and MUFA oils, such as olive oil, display only a weak promoting effect (Weisburger, 1997). Ideally, one would like to consume a dietary fat that lowers LDL cholesterol while enhancing the HDL cholesterol concentration (Sundram et al., 1995). The MUFA content of all pigs in this study is, on average 44.97% of the total FA (Table 8), which, according to Warnants et al. (1998), play a neutral to favourable role in cardiovascular diseases. Oleic acid (the main constituent of BF and of the total MUFA content) is hypolipidemic, reducing both cholesterol and LDL TAG without decreasing HDL cholesterol in human patients (Mattson & Grundy, 1985). From a nutritional point of view pork BF from this study could consequently be regarded as very favourable, as MUFA constitutes the bulk of the BF FA. Some authors have even proposed that in the near future pork could be marketed as a nutraceutical, because of its high MUFA content. Hegsted et al., according to AHA (2001) have shown that SFA (C12:0–C16:0) raise total LDL and cholesterol levels, while C18:0 and C18:1c9 (MUFA) play a neutral role and n-6 PUFA lower cholesterol and protects against CHD and atherosclerosis.

Jiménez-Colmenero et al. (2003) stated that only 25–35% of SFA have atherogenic properties. Stearic acid is associated with lowering plasma cholesterol levels (Bonanome & Grundy, 1988). This is good news from both a technological as well as nutritional point of view, because C18:0 (constituting the 4th largest amount of the total FA in this study, as depicted in Table 6) therefore serves a dual purpose in that it lowers plasma cholesterol levels and adds to firmness of BF. In certain circumstances dietary C16:0 may be neutral, or at least less cholesterolemic than the combination of C12:0 and C14:0 (Sundram et al., 1995). However, in part because of its predominance in saturated fats and in part because it is typically consumed as animal fat, containing cholesterol, C16:0 has long been considered the primary cholesterol raising FA, especially in comparison with C18:1c9 and C18:2 (Mattson & Grundy, 1985). The C16:0 profile of pigs in this study looks rather grim from a health perspective, it constitutes the 2nd highest amount (average C16:0 content for all pigs was 21.95% as seen in Table 6) of the total FA in these pigs. The C14:0 content of pigs in this study was low, although the average value of all pigs were 1.07% (Table 6), together with the C12:0 content it

would seem not to be too high to have a very significant influence on CHD and cholesterol problems. In normolipemic individuals, who typically consume a relatively low-fat diet (< 30% fat), it is extremely unlikely that exchange between natural fats rich in C16:0 or C18:1c9, or even modest exchange with C18:2, will have an appreciable effect on total serum cholesterol during consumption of whole food diets (Sundram et al., 1995).

According to Mattson & Grundy (1985), PUFA decrease both the HDL and LDL cholesterol. For the carcass fat in pigs, a P/S ratio of 0.5 would increase the IV (indicating softer BF) and decrease storage stability (Madsen et al., 1992). The P/S ratio consequently gives a good indication of the unsaturation of the fat, the higher it is, the more unsaturated the fat, a high value being more desirable from a health point of view. COMA, according to Warnants et al. (1998) recommended a P/S ratio of 0.45. Polyunsaturated FA/saturated FA ratios of 0.45–0.50 (Honkavaara, 1989; Levnedmiddelstyrelsen, according to Madsen et al., 1992) and 0.23–0.45 (COMA, according to Wood et al., 1989; Phelps, 1991) have also been proposed for maintenance of a healthy lifestyle. According to Verbeke et al. (1999) a more recent recommendation from COMA was that the P/S ratio should be between 0.6 and 0.7. The most recent recommendation regarding the P/S ratio was proposed by Enser (2000) who indicated that this value should be between 0.4 and 1.0. The PUFA and SFA were already discussed in detail. In this study the P/S ratio decreased significantly ($P < 0.001$) in increased BFT and decreased LMC, with the average value for all pigs being 0.54 (Table 12) which falls within the range of 0.4–1, proposed by Enser (2000). The P, O and R groups differed significantly from the C, U and S groups. A high P/S ratio is desired to result in fat having good nutritional quality. In a study conducted in the UK, Enser et al. (1996) found the P/S ratio of pigs to be 0.61 on average in adipose tissue. The aforementioned table shows that it would be unrealistic to expect the P/S ratio to be between 0.23 and 0.4 because this would exclude the P and O groups, which have the more unsaturated (healthier) fat. It would seem that the low values proposed by literature would benefit the technological properties, rather than the nutritional qualities. If the minimum value of 0.45 is taken as guideline the P, O, R and C groups (if average values are taken into account) will be included (Table 12). Should the P/S ratio requirement be between 0.45 and 0.50, only pigs from the R and C groups would have fat with a good P/S ratio, which is not in line with what is expected. The P/S ratio ranging between 0.6 and 0.7, proposed by Verbeke et al. (1999), led to the inclusion of pigs from only the P group (Table 12). This might be closer to the truth. However, the P/S ratio does not differentiate between the variable effects of different SFA e.g. C16:0 vs. C18:0 (Bonanome & Grundy, 1988); it overlooks the significant effects of C18:1c9 (Mattson & Grundy, 1985); it does not differentiate between the very different physiological effects of PUFA of the n-6 and n-3 families (Lands, according to Kinsella, 1988) and is rather outdated.

More recent studies have shown that long-chain n-3 FA are hypotriglyceridemic, favourably affect platelet function and decrease blood pressure slightly in hypertensive individuals while trans FA are hypercholesterolemic (AHA, 2001). Kinsella (1988) indicated that n-6 PUFA (C18:2) was precursors of eicosanoids (e.g. C20:4) and that the n-3 PUFA (e.g. C20:5 and C22:6) was considered inhibitors thereof. Okuyama & Ikemoto (1999) stated that an imbalance in the n-6/n-3 ratio and not high intake of cholesterol and hypercholesterolemia, was the major risk factor for western-type cancers, CHD, atherosclerosis, cerebrovascular disease and allergic hyper-reactivity. Enser (2000) also indicated that an imbalance in the n-6/n-3 ratio might not only lead to CHD, but also to problems in the immune responsiveness of

Table 12: Fatty acid combinations and ratios applicable to health and nutrition of subcutaneous fat of SA pigs within the different classification groups.

Parameter	P	O	R	C	U	S	Sign. level	All pigs
Number of pigs	*539*	*539*	*541*	*347*	*102*	*36*		*2107*
PUFA/SFA	**0.68 ± 0.16^{d}**	**0.55 ± 0.13^{c}**	**0.49 ± 0.11^{b}**	**0.45 ± 0.10^{a}**	**0.44 ± 0.09^{a}**	**0.42 ± 0.09^{a}**		**0.54 ± 0.15**
Min.	0.33	0.30	0.25	0.25	0.25	0.28	***	0.25
Max.	1.44	1.24	0.97	0.81	0.79	0.73		1.44
n-6 (%)	**21.18 ± 3.59^{d}**	**18.19 ± 3.18^{c}**	**16.62 ± 2.76^{b}**	**15.73 ± 2.83^{a}**	**15.39 ± 2.58^{a}**	**15.05 ± 2.69^{a}**		**17.95 ± 3.74**
Min.	12.53	10.97	9.99	10.10	10.37	11.28	***	9.99
Max.	36.26	30.62	28.31	23.38	23.27	22.97		36.26
n-3 (%)	**1.15 ± 0.41^{c}**	**1.01 ± 0.33^{b}**	**0.91 ± 0.32^{a}**	**0.86 ± 0.30^{a}**	**0.84 ± 0.29^{a}**	**0.82 ± 0.33^{a}**		**0.99 ± 0.36**
Min.	0.44	0.45	0.41	0.41	0.43	0.33	***	0.33
Max.	3.15	2.33	2.38	2.12	1.91	1.57		3.15
n-6/n-3	**20.09 ± 5.99**	**19.61 ± 6.08**	**19.97 ± 6.07**	**20.04 ± 5.83**	**19.99 ± 5.69**	**20.86 ± 7.48**		**19.94 ± 6.02**
Min.	7.50	6.46	7.05	7.69	8.07	8.58	NS	6.46
Max.	43.44	40.43	43.57	33.81	31.08	38.95		43.57

Means with different superscripts within the same row differ significantly.

NS = Not significant; *** = $P < 0.001$.

Min. = minimum value observed.

Max. = maximum value observed.

tissues. The n-6/n-3 ratio of tissue lipids affects many aspects of animal physiology including behavioural performance, health (Okuyama & Ikemoto, 1999) and resistance to infections (Kinsella, 1988). For the prevention of diseases in the 21st century, it is recommended that the n-6/n-3 ratio of human foods be decreased to as low as 2 (Okuyama, 1997). Leaf & Weber (1987) proposed that primitive hunter-gatherers had n-6/n-3 ratios of 1 in their food. Various limits for an n-6/n-3 ratio have been proposed, namely 3:1 (Kinsella, 1988), less than 4 (Enser, 2000), 4–6 (Gerster, according to Högberg et al., 2001) and finally 6:1 (Verbeke et al., 1999). Seven years ago, Enser et al. (1996) indicated that the n-6/n-3 ratio was already 10. Table 12 shows that the n-6/n-3 ratio did not differ significantly between the different classification groups, although significant differences ($P < 0.001$) were observed in each of the constituents (n-6 and n-3 PUFA). The reason for this might be that both n-6 and n-3 PUFA decrease in proportion to each other, leading to a non-significant difference between the ratio thereof. The P, O and R groups differed significantly from the C, U and S groups in both the n-6 and n-3 PUFA contents. No group could conform to any of the n-6/n-3 limits proposed by literature. Very high values for the n-6/n-3 ratios were observed in all groups, with regard to their mean values. No individual pig in any group could even reach the maximum value of 6, proposed by literature as an acceptable n-6/n-3 ratio.

Enser et al. (1996) found that UK pigs had an average n-6/n-3 ratio of 7.64 in their adipose tissue, while South African pigs, fed on a ration to which fishmeal was added, had an average n-6/n-3 ratio of 7.50 in their BF (Van Schalkwyk, 2002). Cherian & Sim (1995) indicated that pigs are used as a model for studying lipid metabolism in humans. Consumers have only recently become aware of the benefits related to the n-3 PUFA. Enrichment of pig feeds with n-3 PUFA, to improve the nutritional quality thereof (and of the resulting pork) with fish products are not employed in South Africa as fish products are rather expensive. This fact is reflected in the FA composition, as a low amount of C20:5, C22:5 and C22:6 (Table 6), which are FA typically associated with fish products, occurred in the animals studied. Commercial producers rather use soybean oilcake, which is high in n-6 PUFA, but much cheaper than fish products. Van Schalkwyk (2002) observed that fishmeal is also rich in C16:0, apart from being rich in n-3 PUFA and will therefore not have a detrimental effect on the consistency of the fat, from a technological point of view, but will negatively affect the health benefits thereof as it may raise the cholesterol level in humans, as indicated earlier. As a result of environmental and other concerns, including health concerns, about the use of fish oil in animal feeds, many studies have been carried out to lower the n-6/n-3 ratio by feeding linseed or canola as a source of C18:3 (Cherian & Sim, 1995; Ahn et al., 1996). The use of canola or rapeseed oil is not common practice in South Africa, although interest in this product as a feed ingredient is increasing. Feeding n-3 PUFA to pigs to improve the quality of pork in human nutrition increases the susceptibility to oxidation further (Sheard et al., 2000).

CORRELATIONS BETWEEN IODINE VALUE, CARCASS CHARACTERISTICS AND HEALTH RELATED FATTY ACID RATIOS AND COMBINATIONS

The PUFA/SFA ratio ($r = 0.9451$) and the n-6 FA content ($r = 0.9149$) were best correlated with IV, at a $P < 0.001$ (Table 13). Backfat thickness (45 mm) and LMC followed in being respectively 2nd and 3rd best correlated with both the PUFA/SFA ratio as well as the n-6 FA content. The same trend observed in other correlations (Tables 3, 5, 7 and 9) was repeated here – the BFT (45 mm) measurement was better correlated with the above-mentioned FA and ratio than the BFT (midline) measurement. Muscle thickness exhibited a

poor correlation with all the FA ratios related to health aspects. Interestingly enough, the n-3 and n-6/n-3 ratio was better correlated with BFT (midline) than with BFT (45 mm). Iodine value and the n-6/n-3 ratio was poorly correlated (r = 0.0845).

Table 13: Pearson correlation coefficients (r) and significance levels of correlations between Iodine value, carcass characteristics and fatty acid ratios of backfat applicable to health and nutritional aspects.

Parameter	IV	P	BFT (45 mm)	P	BFT (midline)	P	MT	P	LMC	P
PUFA/SFA	0.9451	***	–0.5560	***	–0.5251	***	0.0918	***	0.5483	***
n-6 (%)	0.9149	***	–0.5423	***	–0.4989	***	0.1123	***	0.5378	***
n-3 (%)	0.4269	***	–0.3179	***	–0.3464	***	–0.0257	NS	0.3031	***
n-6/n-3	0.0845	***	0.0226	NS	0.0588	**	0.0699	**	–0.0124	NS

NS = Not significant; ** = P < 0.01; *** = P < 0.001.

IV = Iodine value, BFT (45 mm) = Backfat thickness 45 mm from midline; BFT (midline) = Backfat thickness at midline position, MT = Muscle thickness, LMC = Lean meat content

n = 2107.

EFFECT OF SEX ON THE FAT QUALITY OF PIG CARCASSES

Although the frequency of boars sampled in this study was very low, the differences between sexes (barrows/boars) and genders (male/female) in terms of fat quality were investigated. It was also appropriate because boars are increasingly being utilized in the South African meat industry and constituted approximately 10% of the total amount of pigs sampled in this experiment. Table 14 compares the boars with the rest of the pigs (barrows and gilts combined) within each of the P, O and R groups. As expected, boars constituted a larger percentage of sampled pigs in the P group (13.54%), while the R group had the lowest amount of boars (8.86%). These percentages were calculated by expressing the boars as a percentage of the total amount of pigs within the specific group. The differences between animals of different gender are partially due to the amount of fat deposited (Nürnberg et al., 1998). In all three classification groups (P, O and R) boars had significantly lower (P < 0.001) average warm carcass weights than the rest of the pigs (Table 14). This indicated that the SLW of boars are on average approximately 4 kg lower than that of the other pigs. Claus, Weiler & Herzog (1994) indicated that increasing SLW in boars would lead to increased occurrence of boar taint in the carcasses. Sex differences are more marked in the IMF than in the BF (Malmfors et al., 1978a; Hugo, 2000). Siebrits et al. (1987) found that sex has a minor effect on BF composition. Only the R group showed a significant difference (P < 0.001) between boars and the rest of the pigs in terms of BFT (45 mm), although relatively small (Table 14).

As far as the chemical properties of the fat are concerned, Table 14 indicated that boars in all three groups had, on average, approximately 5% less EFC than the rest of the pigs. This observation is in agreement with Barton-Gade (1987) who found that boars had 5% less EFC, 1% more protein and 4% more water in BF compared to barrows. Johns (1941) reported that IV of BF ranged from boars to gilts to barrows in decreasing order and that IV varied inversely with BFT among all sexes. No significant differences were observed between the IV of boars and the rest of the pigs in this study. Barton-Gade (1987) stated that, in

Table 14: Comparison between boars and the rest of the pigs (barrows and gilts combined) within the P, O and R classification goups

Parameter	P		O		R	
	Boars	Rest	Boars	Rest	Boars	Rest
Number of pigs	*73*	*466*	*59*	*480*	*48*	*496*
Carcass characteristics						
Warm carcass weight (kg)	68.73 ± 3.97^{a}	72.30 ± 5.83^{b}	71.83 ± 3.14^{b}	75.67 ± 5.80^{c}	72.18 ± 2.24^{b}	77.16 ± 5.83^{d}
BFT (45 mm)	11.60 ± 0.85^{a}	11.61 ± 1.19^{a}	14.65 ± 1.29^{b}	15.10 ± 1.25^{b}	18.04 ± 1.38^{c}	18.84 ± 1.29^{d}
LMC (%)	69.95 ± 0.38^{c}	70.12 ± 0.51^{c}	68.44 ± 0.53^{b}	68.43 ± 0.56^{b}	66.74 ± 0.56^{a}	66.64 ± 0.56^{a}
Chemical properties:						
Extractable fat (%)	65.41 ± 6.84^{a}	70.97 ± 4.28^{c}	68.56 ± 4.42^{b}	75.15 ± 3.14^{d}	72.22 ± 3.80^{c}	77.47 ± 2.47^{e}
Iodine value	76.17 ± 4.77^{de}	77.07 ± 5.21^{e}	74.20 ± 3.76^{cd}	72.86 ± 4.68^{bc}	71.06 ± 3.40^{ab}	70.61 ± 4.27^{a}
Refraction index	1.46155 ± 0.00057^{d}	1.46151 ± 0.00061^{d}	1.46125 ± 0.00048^{c}	1.46099 ± 0.00054^{b}	1.46092 ± 0.00049^{ab}	1.46071 ± 0.00049^{a}
Fatty acid composition						
C16:0	21.22 ± 1.20^{b}	20.65 ± 1.38^{a}	21.33 ± 1.08^{bc}	21.78 ± 1.30^{cd}	22.27 ± 1.02^{de}	22.45 ± 1.24^{e}
C18:0	11.65 ± 1.44^{bc}	10.96 ± 1.29^{a}	11.89 ± 1.29^{bc}	11.66 ± 1.26^{b}	12.70 ± 1.45^{d}	12.10 ± 1.29^{c}
C18:1c9	37.87 ± 2.42^{a}	39.32 ± 2.17^{b}	39.13 ± 2.01^{b}	40.69 ± 1.93^{c}	39.82 ± 2.12^{b}	41.28 ± 1.81^{d}
C18:2(n-6)	18.95 ± 3.24^{c}	20.32 ± 3.44^{d}	17.63 ± 2.82^{bc}	17.22 ± 3.05^{b}	15.55 ± 2.10^{a}	15.78 ± 2.68^{a}
Fatty acid combinations						
SFA (%)	34.91 ± 2.34^{b}	33.40 ± 2.51^{a}	35.10 ± 2.09^{b}	35.21 ± 2.38^{b}	36.84 ± 2.17^{c}	36.32 ± 2.34^{c}
MUFA (%)	42.93 ± 2.68^{a}	43.49 ± 2.41^{a}	44.42 ± 2.13^{b}	45.16 ± 2.19^{b}	45.01 ± 1.88^{bc}	45.70 ± 1.89^{c}
PUFA (%)	21.51 ± 3.66^{de}	22.46 ± 3.74^{e}	19.96 ± 2.91^{cd}	19.10 ± 3.26^{bc}	17.70 ± 2.25^{ab}	17.52 ± 2.86^{a}
UFA	64.44 ± 2.31^{b}	65.96 ± 2.43^{c}	64.38 ± 2.07^{b}	64.27 ± 2.32^{b}	62.72 ± 2.11^{a}	63.22 ± 2.29^{a}
Fatty acid ratios						
C18:0/C18:2	0.64 ± 0.15^{b}	0.56 ± 0.15^{a}	0.70 ± 0.15^{bc}	0.71 ± 0.18^{c}	0.84 ± 0.18^{d}	0.80 ± 0.20^{d}
DBI	89.70 ± 6.22^{cd}	90.62 ± 6.10^{d}	87.74 ± 4.59^{c}	85.35 ± 5.29^{b}	83.76 ± 4.43^{ab}	82.45 ± 4.89^{a}
PUFA/SFA	0.62 ± 0.15^{c}	0.68 ± 0.16^{d}	0.57 ± 0.11^{bc}	0.55 ± 0.13^{b}	0.48 ± 0.08^{a}	0.49 ± 0.11^{a}
n-6/n-3	13.93 ± 4.82^{a}	21.06 ± 5.57^{b}	14.66 ± 5.62^{a}	20.22 ± 5.85^{b}	13.99 ± 6.13^{a}	20.55 ± 5.75^{b}

Means with different superscripts within the same row differ significantly ($P < 0.001$)

BFT = backfat thickness; LMC = lean meat content; SFA = Saturated fatty acids; MUFA = Mono-unsaturated fatty acids; PUFA = polyunsaturated fatty acids; UFA = unsaturated fatty acids; DBI = double bond index; PI = peroxidizability index.

terms of IV ≥ 70, 20% of boars had inferior fat quality. Boars in all groups had average IV above 70, which means that no boar had acceptable fat quality in terms of an IV of less than 70. There is no evidence that boars have inherently less firm or cohesive fat tissues at the same FT (Wood, 1983; Wood et al., 1985). On average, boars from the P and R groups did not differ significantly from the rest of the pigs in terms of RI. Boars in the O classification group had higher average RI values than the rest of the pigs in this group (Table 14).

The FA composition of BF is significantly affected by gender (Malmfors et al., 1978a; Nilzén et al., 2001). The difference in sex hormone metabolism between males and females may be responsible for the effects on fat composition (Wood et al., 1989). In terms of FA composition and combinations, significant differences ($P < 0.001$) were observed in the P group regarding SFA and UFA content, as well as in the main FA (C16:0, C18:0, C18:1c9 and C18:2). The FA profile of boars in the P group were found to be more saturated (higher C16:0 and C18:0 contents and lower C18:2 content) than the rest of the pigs from this group (Table 14). No explanation can be offered for this phenomenon and it is in direct conflict with the findings of Martin et al. (1972), Malmfors et al. (1978a) and Wood et al. (1986a) who stated that boars contained a higher proportion of C18:2 and C20:4, less C16:0 and C18:1c9 with no difference in C18:0 content than that of barrows. The small amount of boars sampled could also have influenced these findings. They indicated further that gilts were intermediate to the two. These authors also found that boars had a lower C18:1c9 content than the rest, which is in agreement with the findings of this study. Boars in all classification groups (P, O and R) had significantly lower ($P < 0.001$) C18:1c9 contents than the rest of the pigs in each group. In the R group, boars had significantly higher C18:0 contents. No significant differences were observed in the O and R groups with regard to the FA combinations (Table 14). As far as the FA ratios are concerned, no significant differences between boars and the rest of the pigs in the O and R groups were observed for the C18:0/C18:2 ratio (Table 14). However, this ratio differed significantly ($P < 0.001$) by being higher in boars than the other pigs in the P group, but not close to the recommended 1.2 for good technological fat quality. The DBI was significantly higher ($P < 0.001$) in boars than in the rest of the pigs from the O group, indicating that the boars in the O group had a more unsaturated profile than the rest of the pigs. Although significant differences were observed in the FA composition between boars and the rest of the pigs, these differences were numerically very small, confirming the results of Siebrits et al. (1987). They also indicated that sex had a minor effect on BF composition.

With regard to the health and nutritional ratios, the P/S ratio of boars in the P group was significantly lower ($P < 0.001$) than the rest of the pigs, because of the high SFA content (Table 14). In the O and R groups no significant differences regarding the P/S ratio were observed between boars and the rest of the pigs. The most interesting observation was made with regard to the n-6/n-3 ratio. In all three groups, the boars had significantly lower ($P < 0.001$) n-6/n-3 ratios than the rest of the pigs, although not nearly close to the proposed n-6/n-3 levels for a healthy lifestyle. This indicates that boar fat is healthier than fat of the other pigs. This might be positive from a nutritional as well as a technological point of view, because it will make it easier to differentiate between the different markets. Low SLW boars can be directed more towards fresh meat retail sales, with lower utilization in the processing industry. Gilts are much better than barrows and boars for the manufacture of products such as canned hams where the protein content of the raw material determines the yield of the product (Barton-Gade, 1987). Boar fat tissues are reputed to be soft and floppy

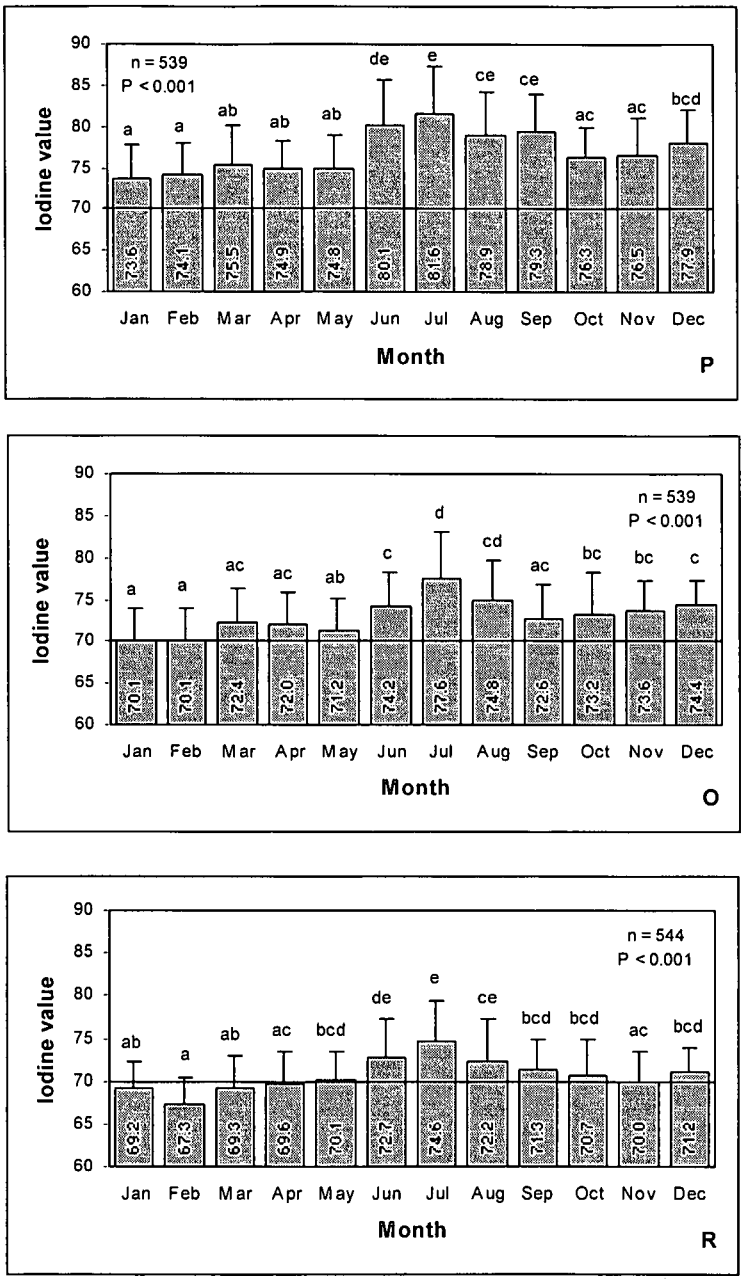
and boar sides are said to lose more weight during Wiltshire curing than barrows (Wood & Enser, 1982). Babol & Squires (1995) indicated that boars only have slightly lower processing yields compared to the other genders. Wood & Enser (1982) stated that soft fat was a feature of lean pigs of either sex. Bonneau (1998) stated that the poorer quality of boars was due to their leanness rather than their sex. By feeding boars at a relatively high level, many problems associated with excessively soft fat can be avoided (Babol & Squires, 1995).

SEASONAL VARIATION IN THE FAT QUALITY OF PIG CARCASSES

A statistically significant seasonal trend was observed in the BF IV of the different classification groups, as depicted in Figure 5. Only figures of the P, O and R groups were constructed. The significant ($P < 0.001$) differences between winter (July) and summer (January) IV were striking (Figure 5). The high IV, reached in July, indicated poor fat quality. The low IV, observed in January and February, were below the cut-off point (< 70), indicating good quality fat, in the case of the O and R groups, while in the P group the IV was significantly lower ($P < 0.001$) than that of the other months. Häuser & Rhymer (1991) conducted a similar study and also found unsatisfactory fat quality in terms of IV in Swiss pigs. Their study extended over a period of two and a half years, during which they also observed a seasonal trend in fat quality. They found that fat quality during the summer months was good, with a summit being reached in June (summer in the Northern Hemisphere), while an increase in pigs with poor fat quality was observed towards the end of the year (December – winter in the Northern Hemisphere). More recently, Lebret et al. (2002) stated that pigs reared during winter have lower BF firmness than pigs reared in summer. There is a complex mechanism at work and the effect of temperature on fat quality is not easy to explain. Three possibilities exist that might lead to a satisfactory explanation. The first possibility is that the differences between the ambient winter and summer temperatures may play a significant role. Environmental temperature has been shown to greatly influence carcass, muscle and adipose tissue traits (Lefaucheur et al., 1991). The effect of temperature on depot fat is not simple (Close, 1983). Factors such as variations in temperature during daytime and day to day, feeding level and/or physical activity might also influence tissue traits and meat quality (Lebret et al., according to Lebret et al. 2002). Both nutrition and environment have a major influence on the growth of an animal and hence on its tissue deposition (Close, 1983). He indicated that deposition of fat is more temperature-dependent than protein deposition and that the physical characteristics of the fat, including melting point and unsaturation, were also temperature-dependent. Melting point is the physical property of FA that most affects quality as it determines the firmness of the fat at a particular temperature (Wood, 1984). Under cold conditions, when the animals' maintenance requirement is high, more energy is used for thermoregulatory purposes and when energy intake is fixed, less energy is available for retention as protein and fat (Close, 1983). Rinaldo & Le Dividich (1991) stated that the environmental temperature at which overall performance is optimal is higher than the lower critical temperature while remaining in the thermoneutral zone (where environmental demand is minimal and available energy is maximal). Close (1983) indicated that animals will be fattest in the thermoneutral zone and any departure from there (higher or lower temperature) will result in a leaner animal.

In the cold, when voluntary metabolizable energy is sufficient to maintain energy retention, protein and fat deposition are not dependent on environmental temperature (Rinaldo & Le Dividich, 1991). Pigs in a high

ambient temperature will voluntarily decrease their feed (protein and energy) intake to lower the burden of heat dissipation, which results in reduced body fatness and growth rate because of diminished net energy available for tissue deposition (Stahly & Cromwell, 1979; Rinaldo & Le Dividich, 1991).



Means with different superscripts differ significantly.

Letter in right hand corner indicates classification group.

Value in bars represents the mean Iodine value of each group in each month.

Figure 5: Seasonal trend in backfat Iodine value in each of the P, O and R groups.

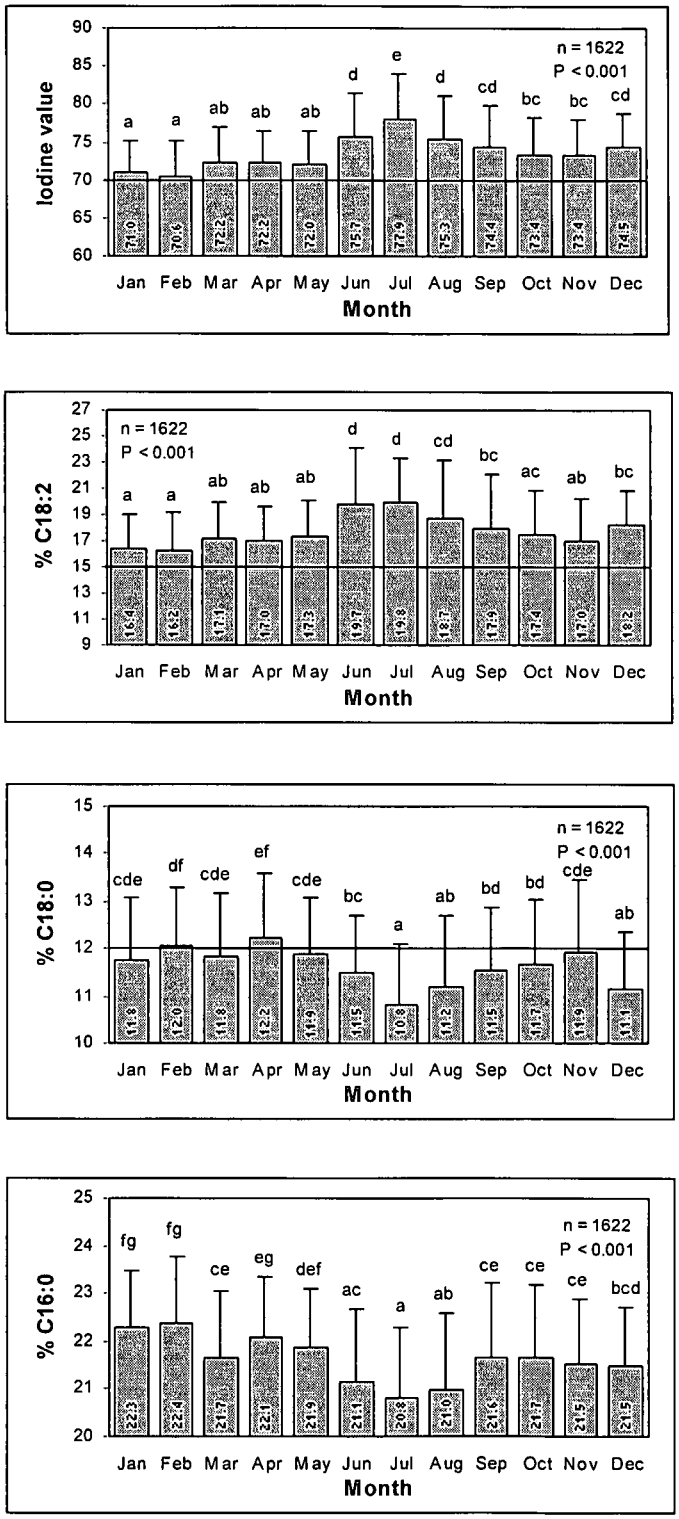
Rinaldo & Le Dividich (1991) indicated that above the lower critical temperature, i.e. 25 to 31.5°C, less fat was deposited in BF and more was fat retained in leaf and viscera fat and that heat production was minimal in this temperature range.

Lefaucheur et al. (1991) stated that pigs in colder environments (12°C) had more subcutaneous fat than pigs from 28°C. At 12°C they observed increased lipogenic enzyme activities and BF unsaturation, which led to softer fat. They found that cold temperatures can be even more detrimental to stress sensitive pigs, leading to a higher incidence of PSE. During the past years, both the utilization of genetically leaner pigs and the development of intensive production systems, in which large numbers of pigs are reared on totally slatted floors, have increased the animals' sensitivity to environmental temperature (Rinaldo & Le Dividich, 1991). According to Close (1983) some breeds of pigs cannot respond to sudden changes in environmental temperature, leading to stress and ultimately to development of PSE meat. Swine increase their feed intake in response to low ambient temperatures in an effort to meet their thermal demand of maintaining body temperature. (Lopez et al., 1991). They also indicated that these pigs grew slower and had a poorer feed conversion ratio than pigs from a thermoneutral environment. According to Stahly & Cromwell (1979) this happens in order for the pig to produce heat to maintain its body temperature. Stahly & Cromwell (1979) stated that pigs eat to satisfy their energy requirement in cold and thermoneutral environments, but not in hot environments. What the pigs eat may provide the second explanation of the observed seasonal trend. It may be possible that feedstuffs rich or poor in saturated or unsaturated fats may be more prevalent during certain times of the year. The findings of this study is in agreement with the observation of MacGrath et al. (1968) that animals exposed to cold environments possess fat with more unsaturated profiles than animals exposed to warm environments.

Close (1983) observed lower C16:0 and C18:0 concentrations in pigs kept in cold environments as opposed to those kept in warm environments. In Figure 6 the P, O and R pigs were combined and all four graphs were constructed from average values of all three groups combined in an attempt to explain the seasonal trend in terms of FA composition. Close (1983) observed that pigs had lower C16:0 and C18:0 concentrations during the winter than in summer. The same trend was found during this study. As mentioned before, the pig synthesizes C16:0 and C18:0 *de novo*. Camara et al. (1996) observed that C18:0 concentrations were higher in adipose tissue than in dietary fat. They concluded that part of this FA was synthesized either *de novo* or by elongation from FA provided by the diet. The SFA (C16:0 and C18:0) therefore originate from two sources: *de novo* and from feed. The relationship between depot fat unsaturation and environmental temperature is influenced by the intake of PUFA, which are not synthesized by the pig (MacGrath et al., 1968). The seasonal variation in the composition of feed, more specifically the C18:2 concentration thereof, must therefore also be taken into account.

MacGrath et al. (1968) indicated that melting point and physical consistency of fats were dependent on FA unsaturation. They indicated that in the absence of PUFA in the diet, C18:1c9 would be the bulk of the UFA while, if PUFA are present in the diet, the physical characteristics of the fat will depend more on structural features of the TAG and less on total unsaturation. Figure 6 shows a very interesting similarity in the distribution of the IV and in the C18:2 concentrations during the course of the year. This might have been expected as C18:2 concentration were highly significantly ($P < 0.001$) correlated with IV (Table 7). There was a peak in July in both the C18:2 content and IV, while the lowest values were observed during January and February. It confirms that C18:2 (from feed) has a large influence on the fat quality of pigs, as it influences the unsaturation, of which IV is an indicator, according to Madsen et al. (1992). In winter, feeds rich in UFA might be available, consequently influencing the C18:2 concentration in pigs, thus leading to a seasonal

variation in fat quality. If the C16:0 and C18:0 concentrations are viewed in relation to the IV, it is evident that it is inversely correlated. Table 7 also indicated that C16:0 was better correlated with IV than C18:0. These two FA show almost exactly the opposite trend than that of the IV.



Means with different superscripts differ significantly.

Value in bars represents the mean value of the P, O and R group in each month.

Figure 6: Seasonal trend in backfat Iodine value, C18:2, C18:0 and C16:0 content of the P, O and R groups.

This indicates that fat is more saturated during summer, probably because feeds rich in SFA are more prevalent during summer. The high environmental temperatures in summer may also play a significant role. As indicated above, these hot temperatures causes the pig to decrease voluntary feed intake. The rate, efficiency and composition of growth in pigs fed *ad lib* is also influenced by the environmental temperature in which they are maintained (Stahly & Cromwell, 1979). Lebret et al. (2002) indicated that pigs reared in winter, thus colder temperatures, had higher processing yields for dry-cured ham.

The third possibility that may offer a reasonable explanation for the occurrence of the seasonal trend is that a combination of the availability of feedstuffs and the influence of the environmental temperature during certain times of the year may influence the fat quality. If taken under close scrutiny, it can be seen that in all individual groups (Table 4), IV, C16:0, C18:0 and C18:2 concentrations were not that far above the IV cut-off point of 70, recommended for good quality by international standards, except during the winter months and in the case of the P group. It can therefore be concluded that by improving the fat quality during the winter months, an overall improvement in fat quality might be possible. By including feed rich in SFA during winter, an improvement in winter fat quality might be accomplished.

A matter that deserves some attention is the deviation observed in December. A distorted slaughter pattern at the abattoir where the sampling took place was caused by the outbreak of foot-and-mouth disease during December 2000. Outbreaks of this disease were also documented in South Korea and Japan towards the end of 2000 and early in 2001 in the UK (Brown, 2003).

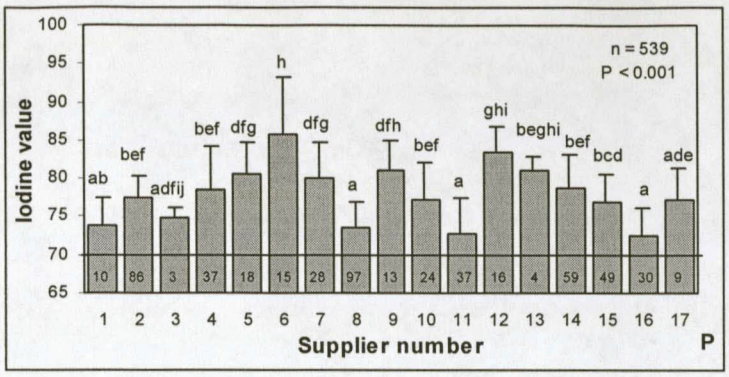
VARIATION IN THE FAT QUALITY OF PIG CARCASSES ORIGINATING FROM DIFFERENT SUPPLIERS

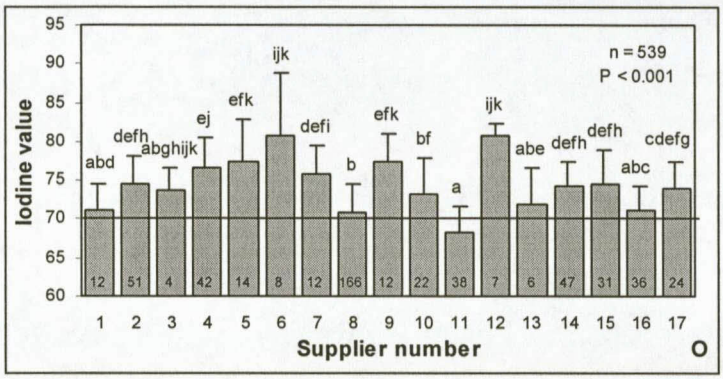
As mentioned earlier in Tables 2, 4, 6, 8, 10 and 12, a large variation exists within the different classification groups and it can be ascribed to the variety that existed between the different producers. Pigs originating from 17 different producers were sampled during the course of this study. These tables indicated that some pigs had IV that were well within the specifications for good fat quality, while others were very far from these specifications. For instance, Table 12 indicated that the DBI ranged between a minimum of 67.45 (observed in a pig from the U group) to a maximum of 114.60 (found in a pig from the P group), while the international standard states that this value has to be less than 80. A similar, well defined difference between the minimum (9.34% from a pig in the R group) and maximum (34.52% from a pig in the P group) C18:2 content was also observed (Table 6), while the international guideline ranges between 9.2 and 15% for C18:2 content in good quality BF. From these observations it is evident that some pigs from even the lower BFT groups did comply with certain of these requirements set for good quality. The South African pig industry would therefore benefit by taking an in depth look into the feeding regimes and breeds, especially if the same trend as overseas is to be followed. In Europe it is proposed that pigs are produced with the end purpose in mind. This implies that pigs intended for meat processing, with the subsequent fat quality requirements could be produced for which the producer would be paid according to fat quality. As previously stated, IV is included in the payment system in Switzerland, according to Affentranger et al. (1996). They also proposed that the DBI and pH-value should be included in their payment system. The main causes for differences in fat quality could be ascribed to feeding and breeding differences as well as environmental temperature.

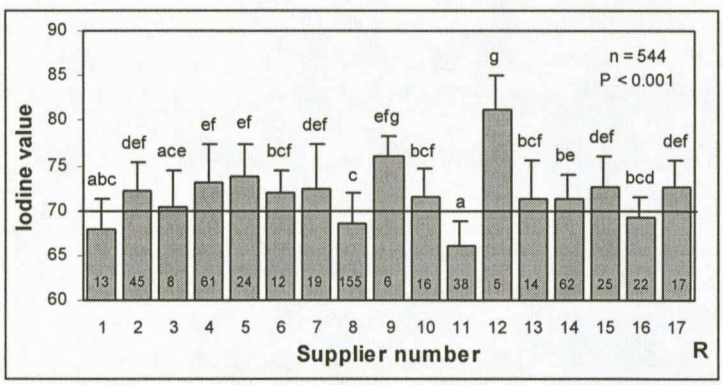
Several other factors, as mentioned in Chapter 2, may contribute to differences in fat quality of pigs. Growth stimulants are allowed in South Africa, but even copper supplementation can influence fat quality, as indicated earlier. It is not easy to explain differences, because a whole array of factors contribute to fat quality. For example, the SLW in this study ranged between 51.4 and 95.5 kg, which also has an influence on the maturity of the fat tissue. Although currently not common practice in South Africa, it is possible that some of the producers in this study employed free-range rearing. It is likely that in future, as consumers become more aware of animal welfare and look to the trends world-wide, they will insist on free-range reared animals, especially if the benefits become known to the public. Dworschák et al. (1995) observed 15% less cholesterol in muscles and less C18:2 in all tissues of free-range pigs, while protein, zinc, copper and iron contents were elevated in these pigs.

Figure 7 highlights the statistically significant ($P < 0.001$) differences between pigs originating from the 17 different suppliers within the specific classification groups. The reason why a graph with the combined values of the P, O and R groups was not constructed is that there was too much of a difference between the numbers of pigs supplied by each producer to be meaningful. Again only graphs from the P, O and R groups were constructed, as these groups represent the majority of pigs sampled in this experiment.

The O group depicts a typical example of this variation between producers (Figure 7). In the O group, supplier 11 (producing pigs with an average IV of 68.34) was below the cut-off point of 70, specified for good fat quality, while supplier 8 (producing pigs with an average IV of 70.88) and supplier 16 (producing pigs with an average IV of 71.14) were just above the 70 cut-off point. In contrast to this, supplier 6 and 12 (producing pigs with average IV of 80.81 and 80.71, respectively had significantly higher ($P < 0.001$) IV than 70 or than suppliers 11 and 8 and 16. Basically the same trend was observed in the P and R groups. However, supplier 11 generally produced pigs with the most acceptable fat quality (IV below 70) in all 3 groups, while BF of pigs from all 3 groups, produced by supplier 12, was very unacceptable (with among the highest IV) in terms of technological quality. The main objective of this study was, however, to sample 45 pigs each from the P, O and R groups. There is also the possibility that some producers may concentrate on producing pigs in a specific group (e.g. the P group). Nevertheless, in the P group, supplier 16, 11 and 8 (producing pigs with average IV of 72.60, 72.79 and 73.50, respectively) approached the cut-off point of 70. Supplier 6 and 12 (producing pigs with average IV of 85.65 and 83.33, respectively) again had the most unacceptable fat in terms of quality. In the case of the R group, supplier 11, 1, 8 and 16 (supplying pigs with average IV of 66.03, 67.80, 68.55 and 69.27, respectively) produced pigs with acceptable BF quality. Supplier 12 and 9 (supplying pigs with average IV of 81.18 and 76.06) produced pigs with unacceptable BF quality. From a meat technological perspective these observations regarding the variation within the groups are very exciting. Pigs from certain suppliers approached the cut-off point of 70 in the P classification group, while in the case of the O and R groups, pigs originating from certain suppliers (e.g. supplier 11) had highly acceptable BF. This implies that it is possible to obtain good fat quality in pigs with relatively thin BF (less than 22 mm), by employing the right combination of feed and breeding in particular.







Means with different superscripts differ significantly.

Letter in right hand corner indicates classification group.

Value in bars represents the number of pigs in the specific group delivered by the specific supplier.

Figure 7: Variation in the backfat Iodine value of pigs in each of the P, O and R groups, originating from different producers.

APPLICABILITY OF INTERNATIONAL FAT QUALITY GUIDELINES REGARDING SOUTH AFRICAN PORK

From Tables 4, 6, 8, 10, 12 and 14 it was deduced that carcass characteristics, chemical properties and most FA (individual, combinations and ratios) were generally well correlated with IV at a $P < 0.001$. Hart, according to Houben & Krol (1983) proposed the limit for RI-value at 1.4598 based on a corresponding IV of less than 66, but most of the international guidelines do not specify what the corresponding IV has to be in order to conform to a specific requirement. In an attempt to find out which parameter values of South African

pigs corresponded to an IV of 60 and 70, respectively, individual scatterplots (utilizing all 2107 pigs sampled) were constructed for all of the parameters with available guidelines, as illustrated in Figures 8–21. As the limit for BF of good technological quality, in terms of IV, ranges between 60 (minimum) and 70 (maximum), only these two values will be discussed because the proposed limits of 65 and 66 fall within this range. Trendlines were then fitted to each individual scatterplot in order to determine the best fit, with regard to the R^2-value. The equations of the fitted trendlines are shown in Table 15. The highlighted equations indicate the best fit. This table indicates that logarithmic equations yielded the best fit between IV and %EFC, tetraenoic FA and UFA contents, while power equations best fitted the scatterplots of IV against C18:0 content, SFA content and the DBI as well as the C18:0/C18:2 ratio. Linear equations best represented the relationship between IV and RI, C18:2, dienoic FA and PUFA contents, while the exponential equations best expressed the association between IV and MUFA, trienoic FA and the combination of the penta- and hexaenoic FA contents. By substituting the x-value with IV of 60 and 70, respectively in the highlighted equation, (indicating the highest R^2-value) the corresponding value of each parameter at both IV were determined as indicated in Figures 8–21.

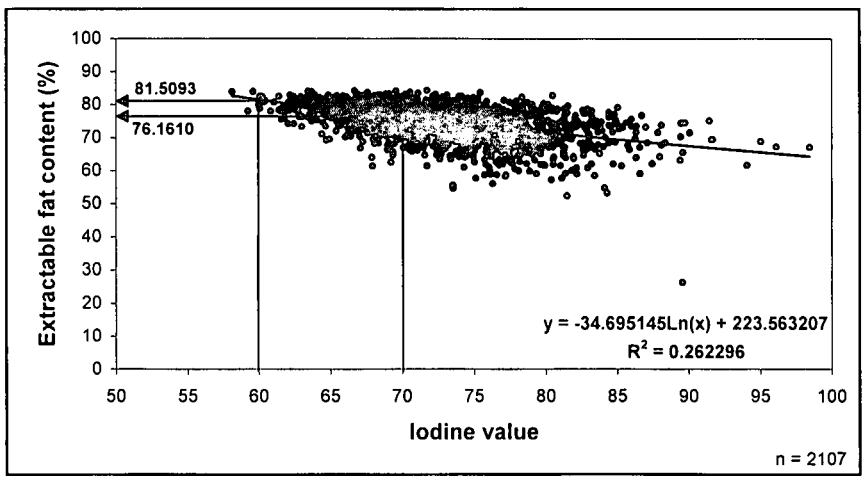


Figure 8: Scatterplot indicating the relationship between Extractable fat content and Iodine value.

The only graph that was not very meaningful was the graph of the penta- and hexaenoic FA combination with an R^2-value of 0.0047 (Figure 17). This was not surprising however, because this combination was not significantly correlated with IV, because the hexaenoic FA content was not significantly correlated with IV, as indicated in Table 9. The corresponding values of this combination, after substituting the x-value of equation with IV of 60 and 70 respectively, were 0.0099 and 0.0153. Neither of these values was near the proposed maximum of 1% proposed for this combination by Häuser & Prabucki (1990).

Closer inspection of these graphs (Figure 8–21) revealed that it seems as though an IV of 60 in South African pigs corresponds to most of the internationally specified cut-off points for most of the parameters. For instance in the case of RI, where Hart, according to Houben & Krol (1983) proposed a cut-off point of 1.4598, the RI-value was 1.4596 corresponding to an IV of 60 (Figure 9). The above-mentioned author proposed this cut-off point at an IV of 66 in Europe, but in South Africa an IV of 66 corresponds to a RI-value of 1.4603.

Table 15: Equations for constructing best fit trendlines between Iodine values and other fat quality parameters.

Parameter	Fit option	Equation	R^2
Chemical properties			
Extractable fat (%)	Linear	$y = -0.5548x + 114.0700$	0.2618
	Power	$y = 590.2662x^{-0.4824}$	0.2482
	Logarithmic	$y = -34.6951\ln(x) + 223.5632$	0.2623
	Exponential	$y = 120.5756e^{-0.0066x}$	0.2488
Refraction index	Linear	$y = 0.00010x + 1.45356$	0.7560
	Power	$y = 1.42926x^{0.00512}$	0.7527
	Logarithmic	$y = 0.00749\ln(x) + 1.42891$	0.7527
	Exponential	$y = 1.45358e^{0.00007x}$	0.7559
Fatty acid combination			
SFA (%)	Linear	$y = -0.4456x + 67.8511$	0.7910
	Power	$y = 1955.9426x^{-0.9369}$	0.7991
	Logarithmic	$y = -32.8590\ln(x) + 176.2110$	0.7975
	Exponential	$y = 89.2454e^{-0.0127x}$	0.7968
MUFA (%)	Linear	$y = -0.2295x + 61.5912$	0.2824
	Power	$y = 227.4685x^{-0.3791}$	0.2780
	Logarithmic	$y = -16.5884\ln(x) + 115.9617$	0.2734
	Exponential	$y = 65.6884e^{-0.0053x}$	0.2879
Dienoic (%)	Linear	$y = 0.6177x - 27.0398$	0.8361
	Power	$y = 0.0004x^{2.5164}$	0.8264
	Logarithmic	$y = 45.2584\ln(x) - 175.9986$	0.8321
	Exponential	$y = 1.4647e^{0.0341x}$	0.8192
Trienoic (%)	Linear	$y = 0.0291x - 1.3075$	0.4678
	Power	$y = 0.00002x^{2.48627}$	0.4747
	Logarithmic	$y = 2.1172\ln(x) - 8.2592$	0.4581
	Exponential	$y = 0.0664e^{0.0339x}$	0.4760
Tetraenoic (%)	Linear	$y = 0.0076x - 0.3267$	0.3977
	Power	$y = 0.000005x^{2.507812}$	0.3855
	Logarithmic	$y = 0.5598\ln(x) - 2.1720$	0.3996
	Exponential	$y = 0.0185e^{0.0339x}$	0.3793
Penta- + Hexaenoic (%)	Linear	$y = 0.0022x + 0.0654$	0.0016
	Power	$y = 0.00000004x^{3.03216599}$	0.0044
	Logarithmic	$y = 0.1586\ln(x) - 0.4564$	0.0016
	Exponential	$y = 0.0008e^{0.0430x}$	0.0047
PUFA (%)	Linear	$y = 0.6566x - 28.6087$	0.8543
	Power	$y = 0.0004x^{2.4911}$	0.8497
	Logarithmic	$y = 48.0941\ln(x) - 186.8862$	0.8497
	Exponential	$y = 1.6079e^{0.0338x}$	0.8428
UFA (%)	Linear	$y = 0.4271x + 32.9826$	0.7784
	Power	$y = 7.7821x^{0.4918}$	0.7824
	Logarithmic	$y = 31.5056\ln(x) - 70.9245$	0.7853
	Exponential	$y = 39.4295e^{0.0067x}$	0.7734

Table 15: Equations for constructing best fit trendlines between Iodine values and other fat quality parameters (continued).

Parameter	Fit option	Equation	R^2
Fatty acid composition			
C18:0 (%)	Linear	$y = -0.1904x + 25.6410$	0.5431
	Power	$y = 2058.1037x^{-1.2067}$	0.5589
	Logarithmic	$y = -14.0851\ln(x) + 72.1298$	0.5507
	Exponential	$y = 38.5043e^{-0.0164x}$	0.5549
C18:2 (%)	Linear	$y = 0.6008x - 26.4708$	0.8376
	Power	$y = 0.0003x^{2.5404}$	0.8279
	Logarithmic	$y = 44.0156\ln(x) - 171.3347$	0.8333
	Exponential	$y = 1.3770e^{0.0344x}$	0.8208
Fatty acid ratios			
C18:0/C18:2	Linear	$y = -0.0359x + 3.3385$	0.7925
	Power	$y = 6503769.8050x^{-3.7472}$	0.8695
	Logarithmic	$y = -2.6756\ln(x) + 12.1878$	0.8150
	Exponential	$y = 27.9625e^{-0.0508x}$	0.8624
DBI	Linear	$y = 1.1349x + 2.6845$	0.9124
	Power	$y = 1.3306x^{0.9703}$	0.9150
	Logarithmic	$y = 83.3452\ln(x) - 271.8158$	0.9121
	Exponential	$y = 32.5933e^{0.0132x}$	0.9102

The same trend was observed in %EFC (Figure 8), C18:0 content (Figure 10), SFA content (Figure 12), MUFA content (Figure 13), dienoic FA content (Figure 14), PUFA content (Figure 18), UFA content (Figure 19), the C18:0/C18:2 ratio (Figure 20) and DBI (Figure 21), where an IV of 60 substituted for the x-value in the respective equations corresponded better with the internationally proposed limits of these parameters.

All pigs conformed to the international requirement proposed by Häuser & Prabucki (1990) for MUFA content to be of less than 57%, but still the value of 47.9329%, corresponding to an IV of 60 in pigs, was closer to the proposed 57%. It is difficult to interpret the C18:2 content, as a variety of cut-off points are proposed for this FA. If the requirement of less than 9.2% C18:2 in bacon, set by Enser (1983) is to be met, then pigs with an IV of 60, which corresponds better to a C18:2 value of 9.5774% (Figure 11), would be suitable for bacon production. If however, the maximum C18:2 content has to be 15% (Ellis & Isbell, 1926; Houben & Krol, 1983; Enser, 1983; Wood, 1983; Whittington et al., 1986), pigs with an IV of 70, corresponding to a C18:2 value of 15.5854% (Figure 11), would be better suited for this purpose. Interestingly, if an IV of 65 were substituted into the equation, the corresponding C18:2 content is 12.5814%, which complies better with the 12% limit proposed by Girard, according to Lizardo et al. (2002). The average trienoic FA content of all classification groups were within the bounds of the less than 1% limit set by Häuser & Prabucki (1990) for BF of good quality. The same phenomenon observed in the C18:2 content was also found in the trienoic FA; a pig with an IV of 70, realizing a trienoic FA content of 0.7118% (Figure 15), was closer to the proposed limit of 1%. The same trend was also observed in the tetraenoic FA content (Figure 16).

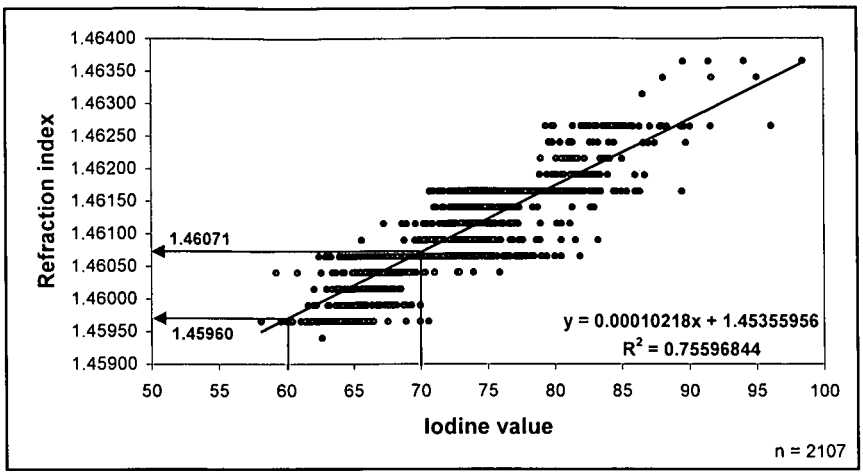


Figure 9: Scatterplot indicating the relationship between Refraction index and Iodine value.

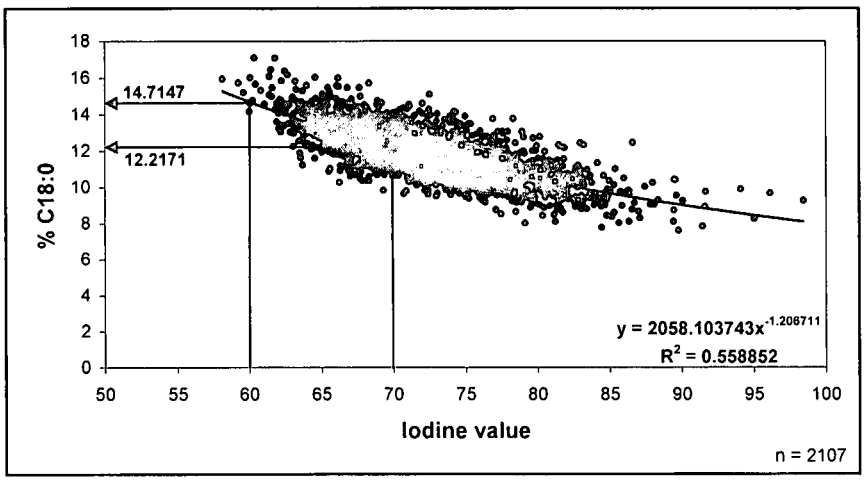


Figure 10: Scatterplot indicating the relationship between Stearic acid content and Iodine value.

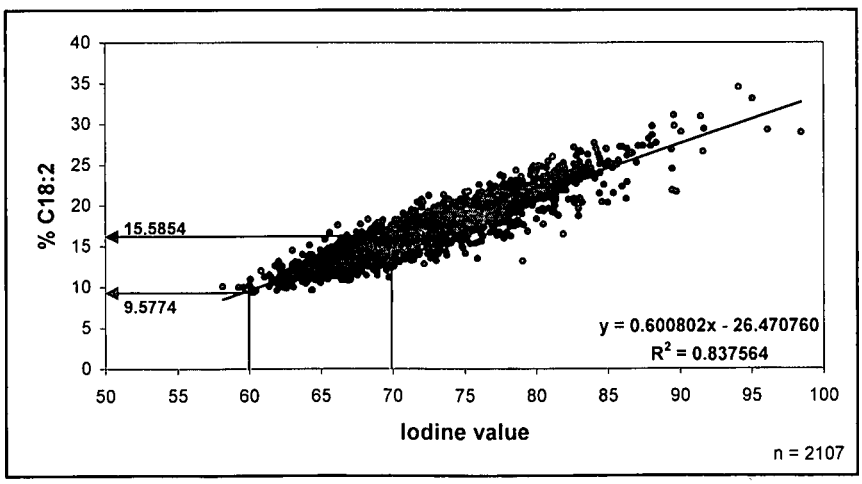


Figure 11: Scatterplot indicating the relationship between Linoleic acid content and Iodine value.

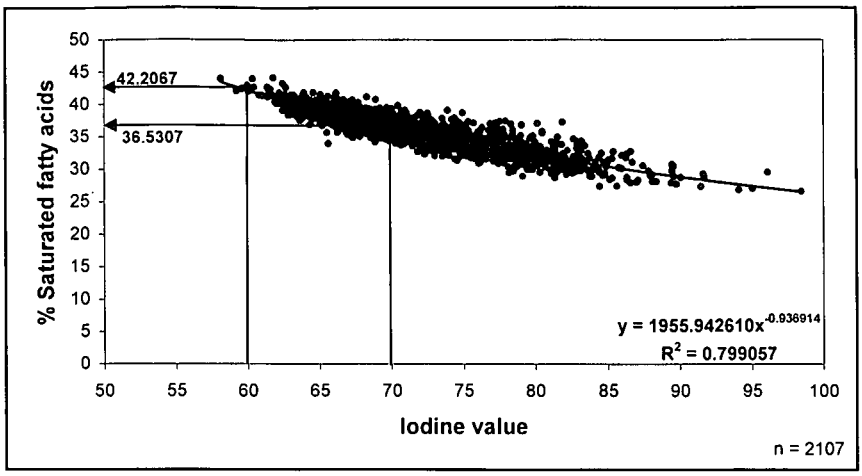


Figure 12: Scatterplot indicating the relationship between Saturated fatty acid content and Iodine value.

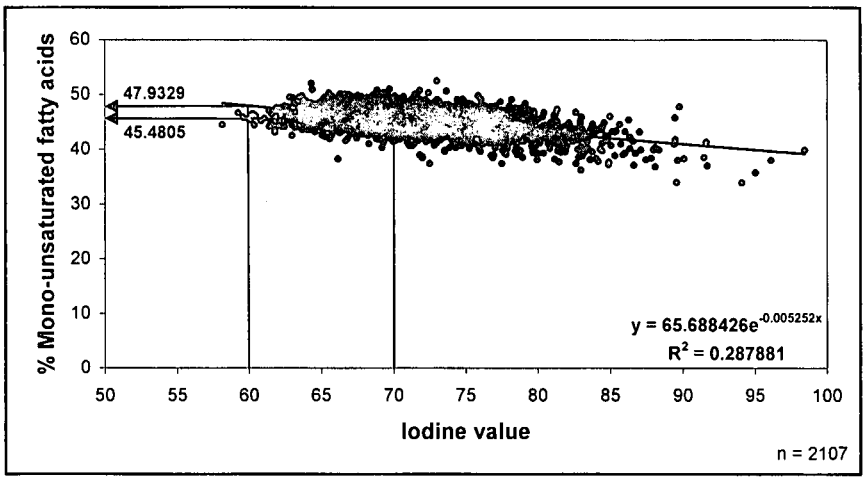


Figure 13: Scatterplot indicating the relationship between Mono-unsaturated fatty acid content and Iodine value.

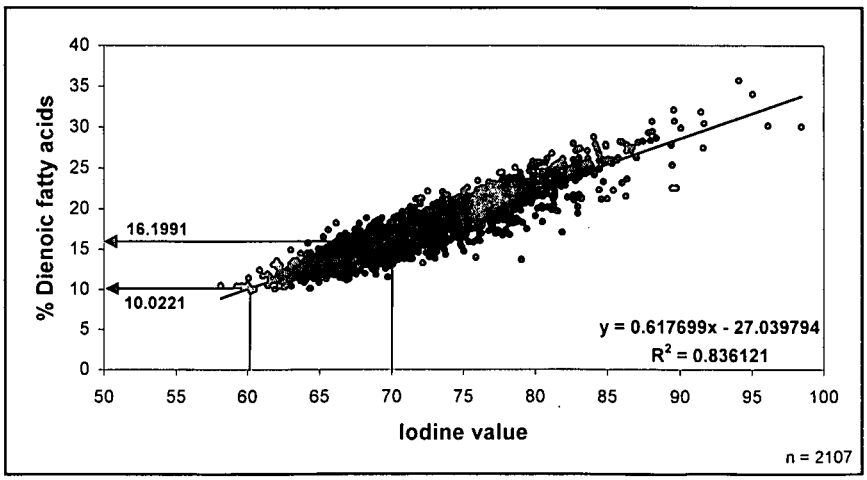


Figure 14: Scatterplot indicating the relationship between Dienoic fatty acid content and Iodine value.

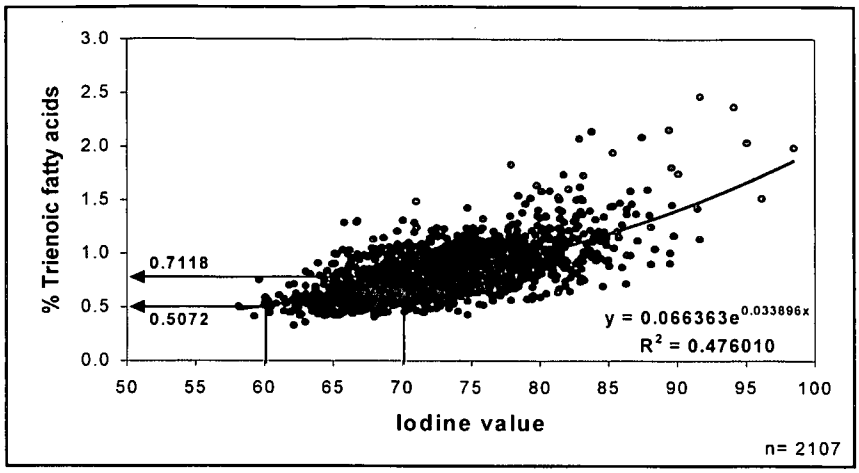


Figure 15: Scatterplot indicating the relationship between Trienoic fatty acid content and Iodine value.

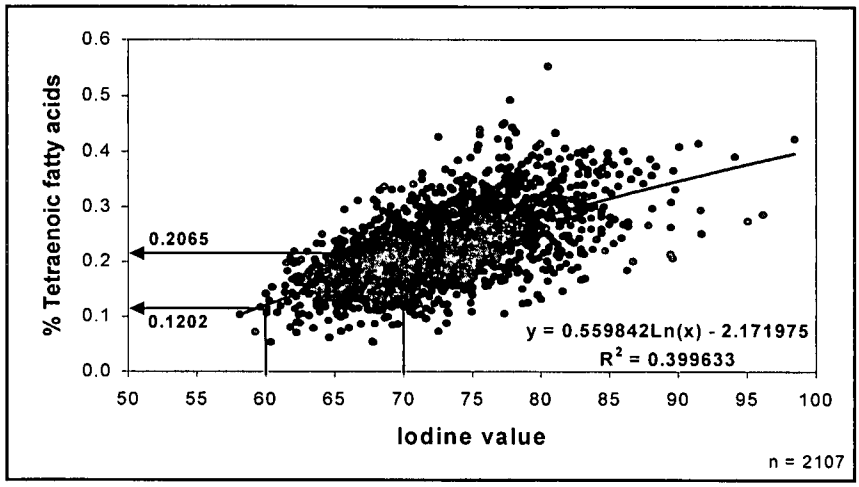


Figure 16: Scatterplot indicating the relationship between Tetraenoic fatty acid content and Iodine value.

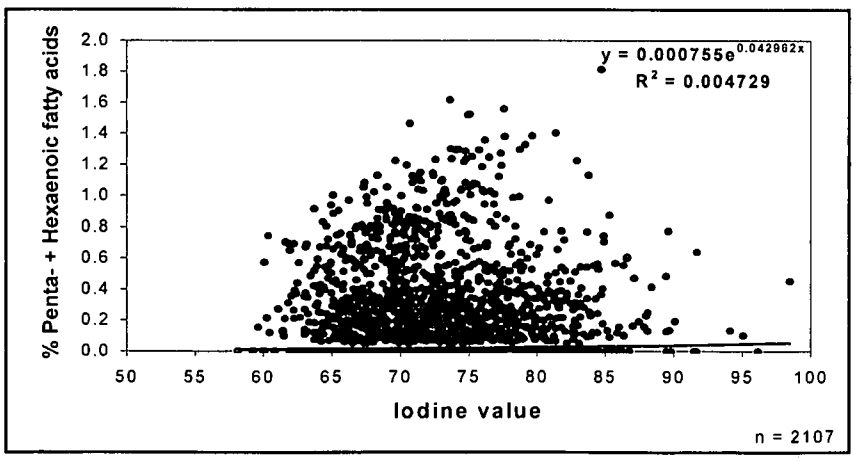


Figure 17: Scatterplot indicating the relationship between Penta- + Hexaenoic fatty acid content and Iodine value.

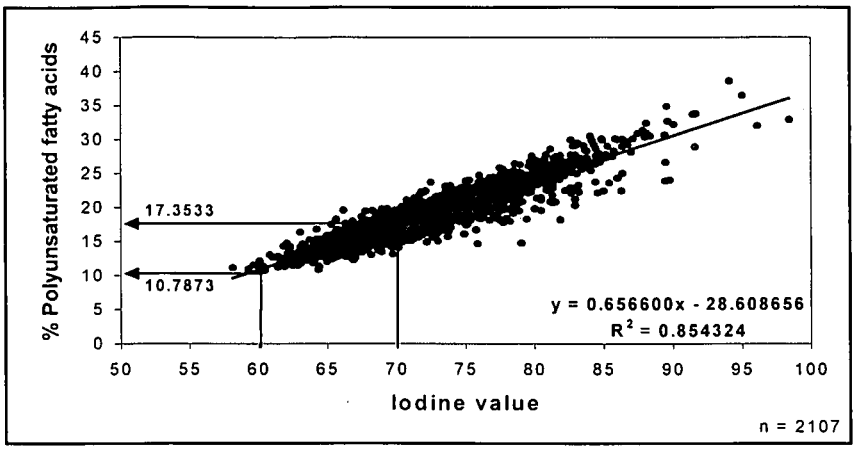


Figure 18: Scatterplot indicating the relationship between Polyunsaturated fatty acid content and Iodine value.

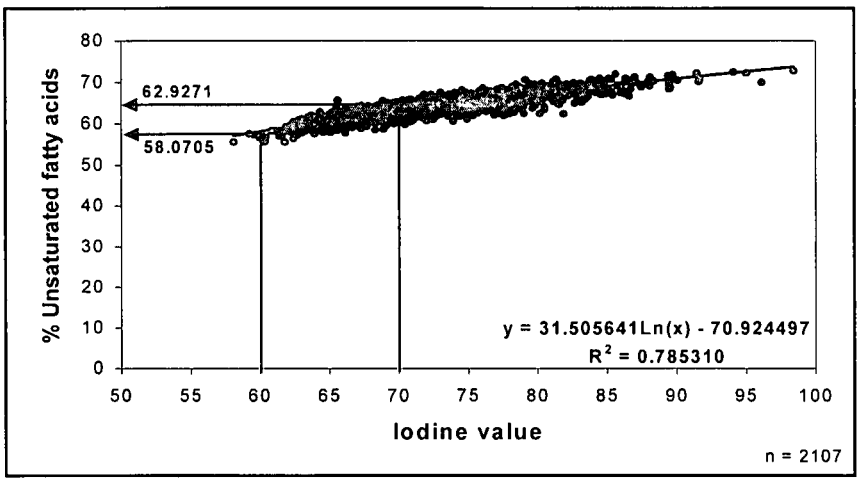


Figure 19: Scatterplot indicating the relationship between Unsaturated fatty acid content and Iodine value.

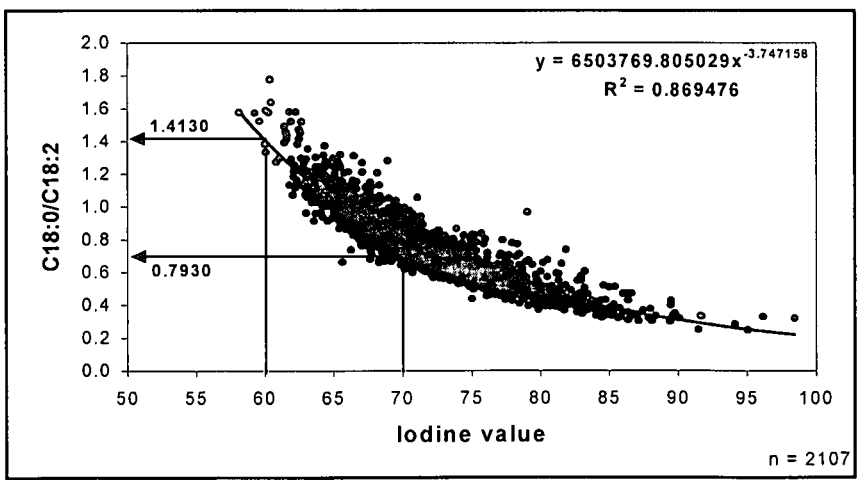


Figure 20: Scatterplot indicating the relationship between the Stearic to Linoleic acid ratio and Iodine value.

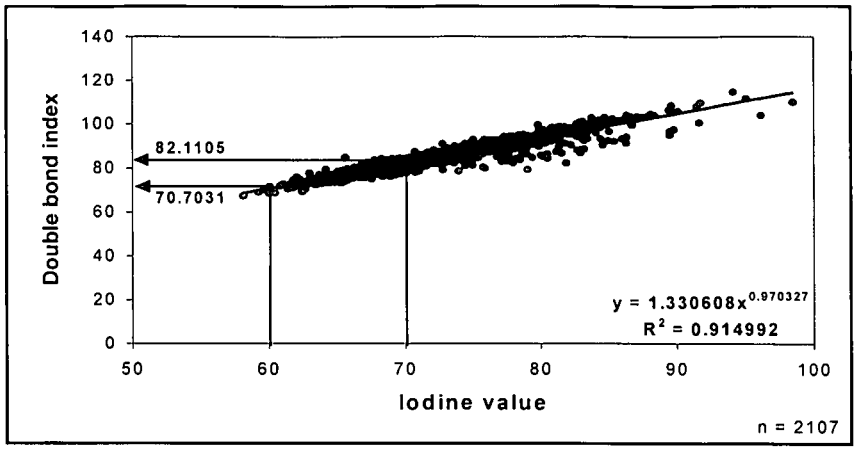


Figure 21: Scatterplot indicating the relationship between Double bond index and Iodine value.

The IV for pigs, corresponding to the different fat quality limits proposed by literature are summarized in Table 16. The x-value of the equations highlighted in Table 15 was calculated by substituting the y-value with the proposed limit. It was very interesting to see the variation in the IV to which the international limits conformed. These corresponding IV ranged between 27.0128, corresponding to a MUFA content of 57%, and 167.3291, corresponding to a Penta-+ Hexaenoic FA content of 1%. These two values were the extremes, but it must be noted that average pigs from all groups were within the bounds of the limits proposed for these FA.

The same trend can be seen with regard to the association between IV and the tri-and tetraenoic FA – the IV corresponding to the international limits were above the proposed IV for good fat quality. Within the PUFA content alone, there was a lot of variation. Limits ranged between 12% and 40%, with corresponding IV ranging between 61.8469 and 104.4908 respectively. The corresponding IV of a RI-value of 1.4598 was 61.0730 in this study, while Hart, according to Houben & Krol (1983) proposed that this RI-value corresponded to an IV of 66. This confirms the findings of the above mentioned Figures 8–21, where it seems that by comparison, the international limits corresponds to an IV of approximately 60.

Another good example of variation in the international limits is the C18:2 content, which may cause problems in the oxidative stability and firmness of certain meat products. Enser (1983) indicated that for bacon to have good consistency, C18:2 content had to be 9.2%. This would mean that pigs would have to have IV of 59.3719. Ten Cate, according to Fischer (1989b) proposed that fat with a PUFA content of more than 11% would cause problems in raw fermented sausages. A pig has to have a BF IV of 62.3679 to comply with the 11% PUFA content limit (Table 16). Houben & Krol (1980) stated that 30% C18:2 in BF did not present any problems in meat products, except in cervelat type sausage. This would imply that BF with IV of 93.7923 would not cause problems in meat products, which is not true. To have an EFC of 90%, constituting no "empty fat" tissue as proposed by Prabucki (1991), the corresponding IV in BF would have to be 46.9753. Consequently, Table 16 highlights the fact that some of the limits proposed for good quality fat by international standards are not totally realistic when applied to South African conditions.

Table 16: Calculation of corresponding Iodine values for fat quality cut-off points proposed by literature.

Parameter	Cut-off point	Reference	Corresponding IV
Chemical properties			
Extractable fat (%)	84	Prabucki (1991)	55.8437
	90	Prabucki (1991)	46.9753
Refraction index	1.4598	Hart, according to Houben & Krol (1983)	61.0730
Fatty acid composition			
C18:0 (%)	12	Houben & Krol (1983); Girard et al., according to Lizardo et al. (2002)	71.0477
C18:2 (%)	9.2	Enser (1983)	59.3719
	11	Ten Cate, according to Fischer (1989b)	62.3679
	12	Girard et al., according to Lizardo et al. (2002)	64.0323
	15	Ellis & Isbell (1926); Enser (1983); Wood (1983); Whittington et al. (1986)	69.0257
	30	Houben & Krol (1980)	93.7923
Fatty acid combinations			
SFA (%)	41	Häuser & Prabucki (1990)	61.8866
MUFA (%)	57	Häuser & Prabucki (1990)	27.0128
Dienoic (%)	10	Häuser & Prabucki (1990)	59.9641
Trienoic (%)	1	Häuser & Prabucki (1990)	80.0276
Tetraenoic (%)	0.5	Häuser & Prabucki (1990)	118.2417
Penta- + Hexaenoic (%)	1	Häuser & Prabucki (1990)	167.3291
PUFA (%)	12	Prabucki, according to Houben & Krol (1983)	61.8469
	13	Wenk et al., according to Warnants et al. (1996)	63.3699
	14	Stiebing et al., 1993; Warnants et al. (1998)	64.8929
	15	Houben & Krol (1983); Fischer et al., according to Warnants et al. (1996)	66.4159
	20	Warnants et al. (1998)	74.0308
	21	Stiebing et al. (1993)	75.5538
	22	Warnants et al. (1996)	77.0768
	23	Warnants et al. (1996); Bryhni et al. (2002)	78.5998
	40	Houben & Krol (1983)	104.4908
UFA(%)	59	Prabucki (1991)	61.7966
Fatty acid ratios			
C18:0/C18:2	1.20	Honkavaara (1989)	62.6745
	1.47	Enser (1983); Enser et al. (1984)	59.3704
Double bond index	80	Prabucki (1991)	68.1465

MODIFICATION OF THE FRENCH SYSTEM OF FAT QUALITY PREDICTION TO BE APPLICABLE TO SOUTH AFRICA

From the above discussion it is evident that closer investigation into the international limits set for the carcass characteristics (BFT and LMC) used in the South African pig classification system, to which the French system of on-line fat quality prediction might be applicable, was justified. It could be possible that, with the necessary modifications, because of the different measurements and formulas employed, the French system could be modified to predict fat quality in the South African classification system, thereby increasing the detection of pigs with poor fat quality. As previously mentioned, the Pearson correlation

coefficients in Tables 3, 5, 7, 9 and 11 suggested that, in general, more fat quality parameters, were better correlated with the BFT (45 mm) measurement than with the BFT (midline) measurement even though the samples were removed from midline position. It seems as though it is sufficient to use only the BFT (45 mm) measurement taken by the HGP to predict fat quality, as this measurement is a more accurate predictor of fat quality than midline BFT. Consequently, an additional midline BFT measurement seems not to be necessary to predict fat quality from grading information. The other method of carcass grading employed in South Africa is the measurement of BFT (45 mm) by the Intrascope. Not all abattoirs in South Africa use the HGP, as it is an expensive piece of equipment and the use of the BFT (45 mm) measurement to predict fat quality could be very practical for smaller abattoirs utilizing the Intrascope. The HGP measures both the BFT (45 mm) and LMC. Lean meat content and BFT (45 mm) were the carcass classification characteristics best correlated with the fat quality parameters. Iodine value, the internationally accepted measure of FA unsaturation, was one of the parameters best correlated with BFT (45 mm) with an r-value of –0.5610, followed by LMC with an r-value of 0.5531 (Table 3). As was evident from Table 2, only the P group did not conform to the proposed limits for BFT (45 mm) measurements, ranging between the minimum value of 15 mm, proposed by Davenel et al. (1999) and the maximum value of 20 mm, proposed by Cannon et al. (1996) to result in good quality BF. Pigs from the C, U and S groups conformed to the IV cut-off point of 70 proposed for good quality BF by Houben & Krol (1983), Barton-Gade (1983, 1987) and Girard et al., according to Davenel et al. (1999). No classification group could comply with the limit of less than 57% LMC set by Davenel et al. (1999) for good quality BF. As LMC is one of the two criteria used to grade carcasses with the HGP, it is evident that recalculation of the French classification system is necessary if it is to be used to predict the fat quality of South African pigs.

Striving to find the alternative cut-off points for BFT (45 mm) and LMC for South African conditions, the relationships between IV, BFT (45 mm) and LMC of all 2107 pigs were expressed on scatterplots. As in the previous section, trendlines were fitted to each scatterplot to determine the equation which best defined the particular relationship (with respect to the R^2-value). Table 17 indicates that the power equation best described the relationship between IV and BFT (45 mm), while a logarithmic equation yielded the best fitted trendline on the scatterplot of IV against LMC.

Table 17: Equations for constructing best fit trendlines for predicting Iodine values from backfat thickness and lean meat content.

Parameter	Fit option	Equation	R^2
Backfat thickness	Linear	$y = -0.5151x + 54.5898$	0.3147
	Power	$y = 281337.6572x^{-2.2754}$	0.3475
	Logarithmic	$y = -38.0685\ln(x) + 180.2106$	0.3187
	Exponential	$y = 155.4251e^{-0.0309x}$	0.3455
Lean meat content	Linear	$y = 0.2431x - 49.7536$	0.3060
	Power	$y = 21.3678x^{0.2681}$	0.3049
	Logarithmic	$y = 17.9745\ln(x) - 9.5648$	0.3100
	Exponential	$y = 51.7732e^{0.0336x}$	0.3007

The y-value of the respective highlighted equations was substituted with the various international cut-off points in order to find out what the corresponding IV (the x-value) of South African pigs was. These values are tabulated in Table 18. It was found that a BFT (45 mm) of more than 17.5 mm, proposed by Cannon et

al. (1996) corresponded to an IV of 70.5526 in pigs, which is within close range to the IV of 70, proposed by various authors, to result in good quality BF. It was confirmed that the cut-off point for LMC of less 57%, set by Davenel et al. (1999) was totally unrealistic, as it would result in pigs having a corresponding IV of 40.5807 (Table 18).

Table 18: Calculation of corresponding Iodine values for backfat thickness and lean meat content cut-off points proposed by literature.

Parameter	Cut-off point	Reference	Corresponding IV
Backfat thickness (mm)	15	Davenel et al. (1999)	75.4978
	17.5	Cannon et al. (1996)	70.5526
	18	Prabucki (1991)	69.6845
	20	Cannon et al. (1996)	66.5315
Lean meat content (%)	57	Davenel et al. (1999)	40.5807

By substituting the x-value with IV of 60 and 70, respectively, in each of the two above equations, alternative BFT (45 mm) and LMC measurements, which could be used to predict the fat quality of South African pork, were determined (Figures 22 and 23). Consequently, it can be deduced that an IV of less than 60 will be obtained at a BFT (45 mm) measurement of more than 25.3 mm (Figure 22) and a LMC of less than 64.0% (Figure 23). The meat industry measures BFT and LMC rounded off to one decimal, that is why these values were rounded off. The cut-off point for an IV of 60 was originally proposed by Fischer (1989b) as a requirement for fat utilized in firm-cutting sausages like salami. Fat quality requirements are very strict for these products as soft fat can cause a lot of problems, like fat exudation, smearing on cutting, insufficient drying and an oily appearance, which may lead to downgrading of the product, as discussed earlier. It is therefore not surprizing that pigs from only the U and S groups could comply with these strict requirements. This implies that technically BF from only U and S pigs should be used for the manufacture of firm-cutting sausages like salami.

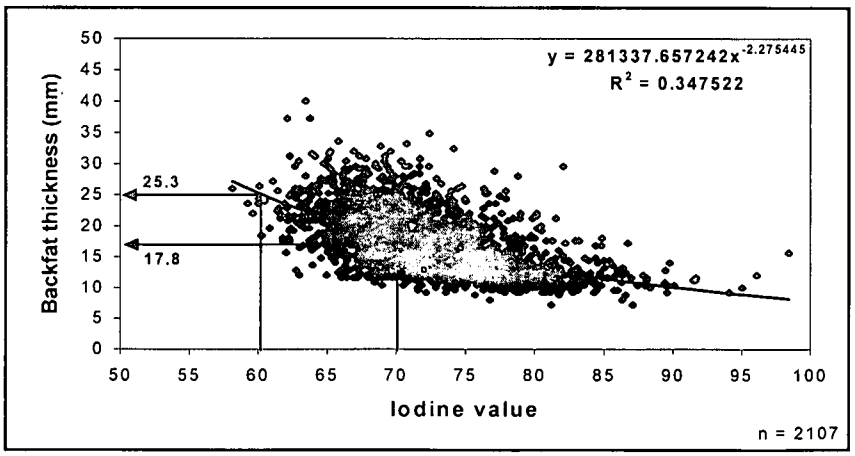


Figure 22: Scatterplot indicating the relationship between Backfat thickness and Iodine value.

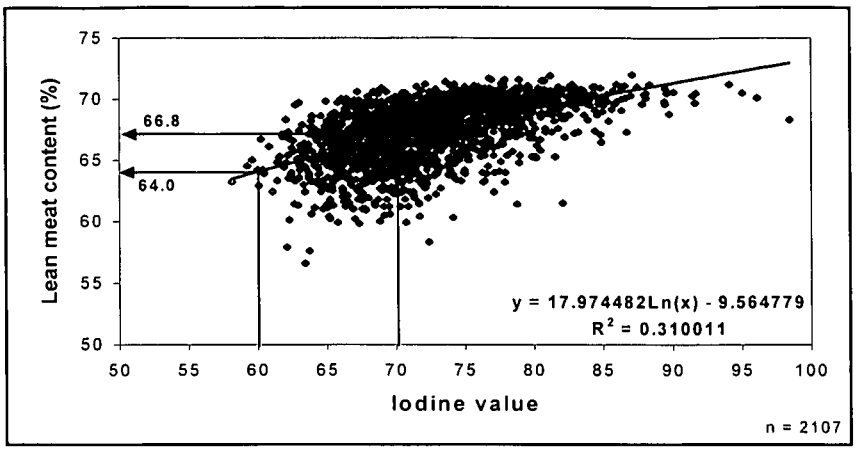


Figure 23: Scatterplot indicating the relationship between Lean meat content and Iodine value.

However, in literature the most common cut-off point for good quality BF, in terms of IV, is 70, as proposed by various authors (Houben & Krol, 1983; Barton-Gade, 1983, 1987; Girard et al., according to Davenel et al., 1999). The added benefit of using the IV of 70 as a measure of good quality is that it is not directed towards a specific product, but it is considered as a general requirement, covering the total spectrum of meat products. In addition, the French classification system utilizes the cut-off point of 70 as criterion for good quality fat as stated by Davenel et al. (1999). If the IV of 70 is substituted as the x-value in the respective equations, a BFT (45 mm) measurement of more than 17.8 mm (Figure 22), which is close to the limit of less than 17.5 mm proposed by Cannon et al. (1996), and a LMC of less than 66.8% (Figure 23) will result in BF of good technological quality in South African pigs. If the average of each group was taken into account, pigs from the R, C, U and S groups conformed to these new limits. It is proposed that South African pigs with a minimum BFT (45 mm) measurement of 17.8 mm and maximum LMC value of 66.8% will posses BF of good technological quality in terms of an IV of 70.

PROBABILITY ANALYSES

Table 19 was constructed in an attempt to determine the probability of selecting pigs from the whole population of 2107 pigs and within the individual classification groups that conformed to the various international requirements proposed for IV of good quality fat. This table highlights the fact that a maximum IV of 60 is too strict for South African pigs to comply with, as less than 1% of the pigs in the C and U groups and only 0.14% of all pigs sampled during this study could conform to this requirement. If the limit for the maximum IV to result in good quality fat was raised to 65 and 66, less than 11% of all pigs sampled could comply with these limits, although a definite increase in the number of pigs in each group conforming to these IV was observed (Table 19). In the R group, 6.62% pigs had IV less than 65 and this amount almost doubled to 12.68% when an IV of 66 was taken to be the cut-off point for good quality BF. Table 19 also indicates that 35.93% of all 2107 pigs sampled had IV lower than 70, which is a more acceptable percentage. The percentage of pigs from the P group complying with a maximum IV of 70 was 7.79%, in contrast with the 0.93% pigs from the same group conforming to a maximum IV of 66. The U group showed an enormous increase from 25.49% pigs conforming to the maximum IV of 66 to 70.59% pigs that conformed to the IV requirement of less than 70. Similar increases were found in the other groups.

Table 19: Probability of selecting pig carcasses within each classification group to conform to various Iodine value requirements.

	P	O	R	C	U	S	All pigs
Total number of carcasses	*539*	*539*	*544*	*347*	*102*	*36*	*2107*
%Carcasses in classification group with IV < 60	—	—	—	0.58	0.98	—	0.14
%Carcasses in classification group with IV < 65	0.56	1.67	6.62	15.85	17.65	25.00	6.17
%Carcasses in classification group with IV < 66	0.93	5.57	12.68	22.19	25.49	41.67	10.54
%Carcasses in classification group with IV < 70	7.79	26.16	47.61	61.96	70.59	77.78	35.93

The probability of selecting pigs with good fat quality from the C group was 62%, while there is a more than 70% chance that pigs in the U group will have an IV less than 70 (Table 19). The possibility to select a pig carcass with good BF quality (IV less than 70) from the S group was 77.78%. Consequently, it would be justified to propose that a maximum IV of 70 would be a more realistic cut-off point for South African pigs to conform to, in order to contain BF of good technological quality.

Table 20: Probability of selecting carcasses with an Iodine value < 70 from the different classification groups after employing the modified French system of selecting good quality backfat.

	P	O	R	C	U	S	All pigs
Utilizing only classification data							
Total number of carcasses	*539*	*539*	*544*	*347*	*102*	*36*	*2107*
%Carcasses with IV < 70	7.79	26.16	47.61	61.96	70.59	77.78	35.93
Utilizing only backfat thickness data							
Number of carcasses with BFT (45mm) > 17.8 mm	*0*	*4*	*400*	*347*	*102*	*36*	*889*
% Carcasses with BFT (45 mm) > 17.8 mm and IV < 70	0	25.00	53.00	61.69	70.59	77.78	59.39
Utilizing only lean meat content data							
Number of carcasses with LMC > 66.8%	*0*	*0*	*276*	*347*	*102*	*36*	*761*
%Carcasses with LMC > 66.8 and IV < 70	—	—	56.16	61.96	70.59	77.78	61.76
Utilizing backfat thickness and lean meat content data							
Number of carcasses with BFT (45 mm) > 17.8 mm and LMC < 66.8%	*0*	*0*	*272*	*347*	*102*	*36*	*757*
%Carcasses with BFT (45 mm) > 17.8 mm and LMC < 66.8% and IV < 70	—	—	56.25	61.69	70.59	77.78	61.82

IV = Iodine value; BFT (45 mm) = Backfat thickness measured 45 mm from the midline position; LMC = Lean meat content.

The effect of employing the modified French system to South African pigs is illustrated in Table 20. If only BFT (45 mm) data is utilized, no pigs with a minimum BFT (45 mm) of 17.8 mm and maximum IV of 70 would be selected from the P group, while 25.00% of the pigs in the O group could comply with these requirements

(Table 20). The probability of selecting pigs from the R group meeting these requirements is 53.00% (Table 20). As only BFT is measured by the Intrascope, abattoirs using this instrument for carcass grading can use this data to select pig carcasses with good fat quality. If LMC of less than 66.8% and IV of less than 70 are the only criteria to be met, the P and O groups are totally excluded from having good quality BF (Table 20). The probability of selecting a pig with good fat quality from the R group if these limits for LMC and IV are to be complied with is 56.16%, while 61.76% of the total amount of pigs would probably meet these requirements. There was no difference in the percentage of pigs in the C, U and S groups complying with these requirements when only BFT or only LMC data were utilized (Table 20).

Simultaneous employment of the modified French system (BFT (45 mm) > 17.8 mm and LMC < 66.8%) as well as the maximum IV of 70 resulted in totally eliminating the P and O groups from having good fat quality. As previously mentioned, the HGP utilizes both the BFT (45 mm) and LMC measurements in the classification process. Employing the modified French system in South Africa, therefore increases the probability of selecting pig carcasses with good fat quality (IV < 70) from the R group from 47.61% (if the Intrascope is employed) to 56.25% (if the HGP is employed). If the modified French system is employed, the probability of selecting pigs from all classification groups with good fat quality (IV < 70) using the Intrascope measured fat quality (utilizing only BFT measurements) is 35.93%. If the HGP is employed (utilizing BFT and LMC measurements) the probability of selecting pigs with good fat quality (IV < 70) increases to 61.82%. The overall picture is therefore also improved.

CHAPTER 5

CONCLUSIONS

Globally, consumers became more aware of a healthy lifestyle over the last three decades (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). The meat industry responded to these consumer demands by producing leaner pigs, with a more than 50 % reduction in BFT and a simultaneous increase in LMC in certain European countries over the last 20 years (Andersen; 2000). In the introduction to this study it was illustrated that South Africa is currently following this international trend towards leaner pork. The percentage of pigs in the P classification group (BFT less than 12 mm), expressed as a percentage of the total annual slaughter, increased from 17.5% in 1993 to 51.2% in 2002 (SAMIC, 2003). A factor contributing to the low BFT of South African pigs may be the low SLW of pigs (SAMIC, 2003).

The decrease in overall fatness has caused the FA profile of pigs to change to a more unsaturated one, beneficial to the consumer, but that leads to many problems during the manufacture of processed meat products (Bailey et al., 1973). Too much UFA leads to an inferior consistency, economical losses, processing, quality, storage and taste disadvantages (Affentranger et al., 1996). The unsaturation of pork backfat is further increased by the addition of large amounts of PUFA in feed. The high PUFA content causes BF to be soft and difficult to cut and handle during processing (Madsen et al., 1992; Verbeke et al., 1999). Fish meal, maize, soyabean oilcake, sunflower oilcake and wheaten bran are feed ingredients rich in PUFA and commonly used in pig diets in South Africa (Viljoen & Ras, 1991).

Several factors, including the absence of an in depth study on the BF quality of pigs and the indifference of the South African meat processing industry regarding fat quality, indicated that it was timely and relevant to do a survey on the BF quality of South African pigs. The other factors are: the very thin BF layers and low SLW of these pigs as well as the possible aggravating effect of locally available feedstuffs. The interest in the utilization of young boars and employment of increased SLW also necessitated an investigation of the fat quality of South African pigs.

This study was the first survey ever to be performed on the BF quality of South African pigs. It provided an overview of the current BF quality status of these pigs. The findings indicated that there were statistically significant differences in the BF quality of the different classification groups (PORCUS). In general, from a technological perspective, the P and O classification groups could not comply with the international standards proposed for good quality BF. This is very alarming, because most of the pigs produced in South Africa are graded as P and O carcasses. Higher prices per kg lean meat are paid for pigs in the P and O classification groups, making it more profitable to produce pigs in these classification groups. Increased BFT and decreased LMC can therefore be associated with increased fat quality. The reason for this is that thicker BF has a higher saturation level than thinner BF. This was reflected in the BF quality of the pigs. With

increased BFT, the SFA, MUFA and C18:0/C18:2 increased, while the UFA, PUFA, DBI and PI decreased. The main problem of highly unsaturated BF originates in the C18:2 content, leading to problems in the dienoic FA content, which in turn influences the PUFA levels in the BF. Leaner pigs naturally have higher proportions of C18:2 (Wood & Enser, 1982). If attention could be paid to the C18:2 content of feed, the problem of soft consistency could eliminated to a large extent, as C18:2 and C18:3 cannot be synthesized by the animal itself, but has to be supplied in the feed (Okuyama & Ikemoto, 1999).

The fat quality parameter most commonly used is IV, with an IV of 70 proposed as the cut-off point for good fat quality (Lea et al., 1970; Houben & Krol, 1983; Barton-Gade, 1983,1987; Girard et al., according to Davenel et al., 1999). In terms of IV the P to R groups had unacceptable IV, while the C to S groups had acceptable IV with good technological properties. The R group was found to be on the borderline in terms of fat quality. From the above findings, the assumption could be made that BFT and LMC can indeed be used to predict fat quality.

The chemical, carcass and FA characteristics were all well correlated with IV. In an attempt to determine the corresponding IV of the different fat quality parameters internationally proposed for good fat quality, correlation analyses and scatterplots with best fit trendlines and equations were utilized. This can be considered as one the most important contributions of this study. Previously, various fat quality parameters (individual FA, FA combinations and FA ratios) were available, but corresponding IV were not available. This work enabled the researcher to assign corresponding IV to various other fat quality parameters. On closer investigation it became evident that South African pigs did not conform to most of the internationally proposed fat quality criteria. It would imply that South African pigs must have an IV of ± 60 to have BF with good technological quality.

It was found that, if only the average IV of each group was taken into account, pigs from the R, C, U and S groups had the highest probability of having good fat quality. The French system of fat quality prediction was modified to conform to South African conditions. It was therefore proposed that South African pigs with a minimum BFT (45 mm) measurement of 17.8 mm and maximum LMC of 66.8%, will have a high probability of possessing BF of good technological quality, in terms of an IV of 70. By utilizing these new limits, the P and O classification groups are totally eliminated from possessing the potential of producing BF of good technological quality. An added benefit is that these values are applicable to either method of carcass evaluation (HGP or Intrascope) employed in South Africa. The probability of selecting pigs with good fat quality from the R group would, however, be higher if the HGP (employing backfat thickness and lean meat content measurements) were to be used, confirming that the HGP is a better measurement instrument than the Intrascope. It must be stressed that employing these criteria does not guarantee BF of good quality, but it will decrease the risk of selecting a pig carcass with soft fat as stated by Rampon et al., according to Davenel et al. (1999).

Boars were not significantly leaner than the other pigs (barrows and gilts combined). They had much better n-6/n-3 ratios, lower average SLW and %EFC than the rest of the pigs. A statistically significant seasonal trend in BF quality (IV) was also observed and can be considered as very positive. The results showed that during mid-summer BF from pigs were firmer and more saturated, leading to better technological quality,

while the opposite was true for fat quality in mid-winter. However, the seasonal differences in the fat quality were so large that a significant improvement in the winter BF quality would cause an improvement of the overall fat quality. This could possibly be achieved by including feed ingredients rich in SFA in pig rations during winter months.

The large variation observed in fat quality between pigs within the same group originating from different suppliers can also be regarded as very positive. Even within the P and O classification group, pigs from certain producers had acceptable fat quality. These observations could be ascribed to differences in breed, feeding regime, environmental conditions, growth promoters and/or possibly rearing system.

It is highly unlikely that suppliers will start to produce more pigs in the C to S groups (BFT 23 mm to more than 32 mm) to improve the fat quality of their pigs. The South African payment system discriminates against fat pigs because it has a lean meat rewarding strategy (a higher price per kg lean). It is also more economical for suppliers to produce pigs in the P and O groups with a high LMC and low BFT (ranging between less than 12 to 17 mm). Fat is deposited towards the end of the growth cycle when the feed/gain ratio decreases, making it less profitable for the pig farmer. Dietary manipulation of the pig feeds seems to be an option to change the FA composition of pigs. Wood (1984) observed that dietary FA are incorporated unchanged into the body fat because they are absorbed intact from the small intestine and directly deposited in the fat tissue of pigs. Van Schalkwyk (2002) showed that it was possible to produce pigs in the low BFT groups, namely P and O, with acceptable fat quality in terms of IV (more saturated profile) by including barley, feed wheat, hominy chop and poultry by-product as feed ingredients.

As the processing industry plays such an immense role in the pig industry, it will become more important to fulfil the needs of this industry (Bruwer, 1992). There is however, a conflict of interests regarding fat quality as the saturated fat required by the meat processor for good quality products, is the direct opposite of the unsaturated, healthier quality fat demanded by the consumer. Rearing pigs with a predetermined purpose and the production of so-called designer foods, is possible (Warnants et al., 1998). This may prove to be the only solution. Some producers could produce pigs intended for the processing industry, while others could produce pigs for the fresh meat market. The feed of pigs intended for processing would have to possess a more saturated profile, leading to pigs containing BF with a more SFA that will lead to better fat quality in meat products. Feed of pigs intended for the fresh meat market, could be enriched with n-3 PUFA which would satisfy the need of the consumer. It is however important that the whole pork chain participates. This means that if a producer supplies fatter pigs, with better fat quality, intended for the processing market, they be paid according to the quality they supply. According to the payment system, not only LMC, but also meat and fat quality traits will have to be taken into consideration to assure maximum carcass prices. Constant monitoring of the fat quality at abattoirs are also recommended to ensure that quality does not deteriorate.

The idea of using food for health purposes rather than for nutrition opens up a whole new field for the meat industry (Jiménez-Colmenero et al., 2001). According to Swan et al. (1997) the meat processing industry should exploit the fact that consumers are more receptive to the idea of nutraceuticals. Processed meat products should also target meeting the various needs and lifestyles of specific groups in the population e.g.

the elderly as well as toddlers (food that is not calorie or additive laden) and active people (e.g. processed meats that enhance performance) (Swan et al., 1997).

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

Cannon et al. (1996) surveyed pork manufacturing companies as part of a Pork Chain Quality Audit in America. A similar survey could be undertaken in South Africa with a smaller amount of pigs, but which encompasses studying the breed as well as the feeding regime. As traceability of meat is becoming increasingly important in other countries, according to Andersen (2000), the possibility of it being employed in South Africa can not be excluded. It would therefore be justified to study South African pigs from producers of which feed ingredients and strategies (restricted or *ad lib*) are known in order to establish exactly what causes problems and which factors could result in good quality fat in South Africa. As differences between the FA composition of the different sites in the pig body has been observed, it would be interesting to assess the magnitude of these differences and also to compare it to data from other countries in the world. It is suggested that IMF as well as fat from the primal cuts are sampled. Intramuscular fat is strongly influenced by genetics (Madsen et al., 1992) and may affect the juiciness (Wood et al., 1986b), flavour (Cameron et al., 1990), aroma (Mottram & Edwards, 1983) and tenderness of pork (DeVol et al., 1988). Consequently it has a major impact on eating quality. As consumers are becoming more health conscious (Rhee et al., 1988b) it would be wise to include health and nutritional properties of pork fat in such a survey.

A survey similar to this study and the one done by Enser et al. (1996) could be undertaken where FA compositions of the different red meats (Beef, Lamb and Pork) available in South African retail could be compared. This would provide the consumer with hard evidence as to which species is the most beneficial healthwise. It could make life easier for meat processors and retailers as well. The effects of packaging, oxidation and microbiological stability should also be included in this study.

CHAPTER 6

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CHAPTER 7

SUMMARY

Fat quality of backfat from 2107 baconer pig carcasses, sampled at a major South African pig abattoir, were evaluated to obtain an overview of the backfat quality of South African pigs. Extracted fat was used to determine iodine and refraction index values as well as fatty acid profiles of these samples. Significant differences ($P < 0.001$) in terms of backfat quality were observed between the different classification groups. Improved fat quality was associated with increased backfat thickness and decreased lean meat content, caused by an increase in the total saturated and mono-unsaturated fatty acid contents and a decrease in the total unsaturated and polyunsaturated fatty acid contents as well as double bond and peroxidizability indexes. The P and O classification groups (with backfat thickness measurements less than 17 mm) could not conform to the international standards proposed for backfat of good technological quality. The C, U and S groups (with backfat measurements of 23 to more than 32 mm) possessed backfat with good technological qualities. The R group had borderline fat quality. A high linoleic acid content, leading to a high dienoic fatty acid content, in turn influencing the total polyunsaturated fatty acid content, is the main cause of soft fat with poor technological quality.

Correlation analyses and statistical techniques were employed to acquire equations to describe the relationships between iodine value and international fat quality parameters. By substituting the international fat quality criteria into the equations it became clear that pigs had to have an iodine value of 60 to comply with most of these criteria, which was unrealistic. The French system predicts fat quality by utilizing backfat thickness and lean meat content. It was proposed, through modification of this system, that South African pig carcasses with a backfat thickness of more than 17.8 mm and a lean meat content of less than 66.8% would have the potential to deliver backfat with good technological properties in terms of iodine value. If these new criteria were applied, the P and O classification groups did not possess good quality fat. The probability of selecting a pig with an iodine value < 70 (indicating good fat quality) from the R group would then be > 55%. In the S group, > 77% of the pigs conformed to these new criteria. Pigs with poor fat quality may escape detection, but the risk of selecting a pig with poor fat quality from these groups is reduced. These values are applicable to either method of carcass evaluation (HGP or Intrascope) employed in South Africa. The method developed in this study therefore provides the South African meat industry with a cost-effective method to improve the probability of selecting pig carcasses with good fat quality.

Boars had much better omega-6 to omega-3 ratios, lower slaughter weights and extractable fat contents compared to barrows and gilts combined. A significant seasonal trend in the backfat iodine values was observed. Better fat quality was detected in mid-summer than in mid-winter. This seasonal effect was so large that improvement of winter backfat quality would cause the overall fat quality to improve. This could possibly be achieved by including feed ingredients rich in saturated fatty acids in the winter rations of pigs because fatty acid composition of the feed is reflected in the backfat of pigs.

Large variation in fat quality existed between pigs within the same group originating from different suppliers. Within the P classification group, pigs with both highly acceptable and highly unacceptable iodine values were observed. Feeding, breeding, environmental and/or management differences between the suppliers could account for this. Fat quality influences the consumer, supplier as well as the meat technologist.

Key words: pigs, backfat, fat quality, South Africa, survey, meat processing, fatty acid, season, supplier, boar

CHAPTER 8

OPSOMMING

Die rugvet van 2107 spekvarke is by een van die grootste vark abattoirs in Suid-Afrika bemonster. Die kwaliteit van hierdie monsters is geëvalueer ten einde 'n oorsig van Suid-Afrikaanse varke, in terme van rugvetkwaliteit, te verkry. Geëkstraheerde vet is gebruik om die jodium- sowel as refraksie-indeks waardes asook die vetsuurprofiele van hierdie varke te bepaal. Die rugvetkwaliteit van die verskillende klassifikasiegroepe het betekenisvol ($P < 0.001$) van mekaar verskil. Namate rugvetdikte toegeneem en maervleis inhoud afgeneem het, het die vetkwaliteit verbeter. Hierdie verbeterde vetkwaliteit kan toegeskryf word aan die toename in die totale versadigde en mono-onversadigde vetsuurinhoude, maar ook die afname in die totale onversadigde, poli-onversadigde vetsuurinhoude, sowel as die dubbelbindings- en peroksideerbaarheids indekse. Die P en O klassifikasiegroepe (met rugvetdiktes onder 17 mm) kon nie aan die internasionaal gespesifiseerde standaarde, wat vereis word vir rugvet met goeie tegnologiese kwaliteit, voldoen nie. Daarenteen het die C, U en S groepe (met rugvetdiktes vanaf 23 tot meer as 32 mm) vet van goeie tegnologiese waarde besit. Die R groep was 'n grensgeval. Die hoofoorsaak van sagte vet van swak tegnologiese waarde is 'n hoë linoleïensuur inhoud wat 'n hoë dienoësuur inhoud veroorsaak, wat op sy beurt weer lei tot 'n verhoogde konsentrasie poli-onversadige vetsure.

Korrelasie analises en statistiese tegnieke is gebruik om vergelykings te verkry wat die verhoudings tussen jodiumwaarde en die internasionale vetkwaliteitsparameters kon beskryf. Internasionale vetkwaliteitskriteria is in hierdie vergelykings ingestel en daar is bevind dat Suid-Afrikaanse varke oor 'n jodiumwaarde van 60 sou moes beskik om aan hierdie vereistes te voldoen, wat totaal onrealisties sou wees. Rugvetdikte asook maervleis inhoud word in die Franse klassifikasiesisteem van vetkwaliteitsvoorspelling gebruik. Met die nodige aanpassing van hierdie sisteem, is gevind dat Suid-Afrikaanse varkkarkasse met 'n rugvetdikte van meer as 17.8 mm en maervleis inhoud van minder as 66.8% oor die potensiaal beskik om rugvet van goeie gehalte, in terme van 'n jodiumwaarde, te lewer. Indien hierdie nuwe kriteria toegepas word, sou dit beteken dat varke in die P en O klassifikasiegroepe nie oor rugvet met goeie tegnologiese kwaliteit beskik nie. Die waarskynlikheid om 'n vark met 'n jodiumwaarde < 70 (wat dui op goeie vetkwaliteit) uit die R groep te kies was > 55%. In die S groep het > 77% van die karkasse voldoen aan die nuwe vetkwaltieitskriteria. Hoewel die moontlikheid steeds bestaan dat 'n varkkarkas met swak vetkwaliteit sou kon deurglip, verlaag dit die risiko om 'n varkkarkas met swak vetkwaliteit te selekteer. Hierdie nuwe kriteria kan toegepas word op metings van beide die Intraskoop en Hennesey graderings sondeerder. Die metode wat ontwikkel is gedurende hierdie studie verskaf dus aan die Suid-Afrikaanse vleisindustrie 'n koste-effeketiewe metode om die waarskynlikheid te verhoog om varke met goeie vetkwaliteit vanuit verskillende klassifikasiegroepe te selekteer.

Bere het aansienlik beter omega-6 tot omega-3 vetsuurverhoudings, laer slaggewigte en ekstraheerbare vetinhoude, in vergelyking met burge en sôe gekombineerd, gehad. Jodiumwaardes van die rugvet het 'n

betekenisvolle seisoenale neiging getoon. Gedurende die middel-somermaande was die vetkwaliteit beter as gedurende die middel-wintermaande. Indien 'n verbetering in die vetkwaliteit gedurende die winter bewerkstellig kon word, sou dit 'n verbetering in die totale vetkwaliteit teweeg bring. Die vetsuursamestelling van die rugvet van varke weerspieël die vetsuursamestelling van die voer. Rugvetkwaliteit sou verbeter kon word indien meer versadigde vette gedurende die wintermaande by voere gevoeg word.

Daar was groot variasie in vetkwaliteit tussen varke binne dieselfde groep wat van verskillende leweransiers afkomstig was. Varke met beide hoogs aanvaarbare en hoogs onaanvaarbare jodiumwaardes is binne die P klassifikasiegroep gevind. Voedings-, ras, omgewings- en/of bestuursverskille tussen die leweransiers kan hiervoor aanspreeklik wees. Vetkwaliteit beïnvloed dus die verbruiker, leweransier asook die vleistegnoloog.

Sleutelwoorde: varke, rugvet, vetkwaliteit, Suid-Afrika, opname, vleisverwerking, vetsuur, seisoen, leweransier, bere.

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