SIMPÓSIO SOBRE RENDIMENTO E QUALIDADE DA CARNE SUÍNA

15 e 16/09/98 – Concórdia, SC

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SUMÁRIO

FATORES PRODUTIVOS QUE AFETAM A QUALIDADE DA CARNE SUÍNA

Sergio Nicolaiewsky

Professor do Depto. de Zootecnia da Faculdade de Agronomia da Universidade Federal do Rio Grande do Sul (UFRGS) - Núcleo de Pesquisa sobre Qualidade da Carne Suína

Introdução

O plantel de suínos em algumas áreas do Brasil, em termos de qualidade, alcança níveis próximos aos dos melhores rebanhos do mundo. Países desenvolvidos tais como Dinamarca, França e Estados Unidos consideram importante critério de seleção a qualidade da carne suína.

A preocupação com a qualidade de carne como critério para seleção iniciou-se a partir de observações em que era verificado que determinados suínos eram susceptíveis ao estresse e que essa característica passava dos pais à progênie.

Animais acometidos dessa síndrome produziam carcaças cujas carnes apresentavam-se com problemas de cor, estrutura e de perda de líquidos, resultado de uma queda de pH muito rápida (em que o pH de 7,2 caia a valores inferiores a 6,0 em menos de uma hora, quando em processo de rigor mortis normal esse pH é atingido a partir de 8 horas após o abate) associado a temperaturas elevadas de carcaça. Neste caso, o glicogênio muscular é convertido rapidamente em ácido lático, ocasionando uma desnaturação das proteínas responsáveis pela capacidade de fixação de água e pela coloração da carne. Esse tipo de anomalia é conhecida como PSE (do inglês: pale, soft and exudative), que é uma carne pálida, flácida e com forte tendência a perder líquidos.

Existem casos em que devido a uma deficiência de glicogênio por estímulos prolongados como grandes distâncias de transporte, tempo de descanso e jejum prolongado, temperatura ambiente baixa, brigas entre os animais etc., ocorre somente uma leve diminuição de pH na carne, e após 24 horas do abate, o pH encontra-se acima de 6,2. Neste caso, estamos frente a carcaças DFD (do inglês: dark, firm and dry) que é uma carne com coloração escura, seca e firme e que, ao contrário da PSE, se caracteriza pela elevada capacidade de fixação de água e pouca conservabilidade.

Fatores que afetam a qualidade da carne de suínos

Na produção da carne de suínos os objetivos principais são obter um produto que seja, do ponto de vista do consumidor: seguro; atenda consistentemente suas necessidades; um bom negócio; tenha sido criado e abatido sob condições humanitárias aceitáveis.

Fatores de produção que afetam a qualidade da carne suína

Carcaça magra e com carne de qualidade - marmoreio - maciez; promotores de crescimento; susceptibilidade ao stress; exercícios, estado atlético e metabolismo muscular.

O transporte e o manejo pré-abate afetando a qualidade da carne

Tempo de jejum; densidade no transporte; temperatura corporal; mortes durante o transporte; desidratação; manuseio pré-abate (descanso).

Efeitos do processamento na qualidade da carne

Insensibilização - fraturas ósseas e hematomas; congelamento e perda de líquido - coloração - maciez.

Panorama no mundo e no sul do Brasil

Em observações feitas nos Estados Unidos, Canadá, Austrália, Dinamarca e Alemanha foi verificado que durante os últimos quatro anos houve um crescente aumento do número de suínos extremamente excitáveis. São animais muito difíceis de serem manejados nos abatedouros e geralmente resultam em carcaças PSE após o abate.

A incidência de carcaças suínas com anomalias de qualidade de carne em nosso meio pode estar aumentando à medida que esforços estão sendo feitos para aumentar a quantidade de carne em detrimento da gordura. Há um consenso de que a seleção de suínos para a produção de carcaças com mais carne e menos gordura provocou um efeito negativo sobre a qualidade da carne resultando em perdas importantes.

Enquanto a qualidade de carne suína vem sendo intensamente pesquisada na Europa e Estados Unidos desde a década de 60, no Brasil, e mais especificamente no Rio Grande do Sul, estes estudos iniciaram-se em 1988, na UFRGS, com trabalho da professora Jane M.R. Ourique da Faculdade de Veterinária que avaliou as correlações das características de qualidade da carne medidas através do pH, coloração e perdas por gotejamento. O trabalho seguinte foi o da professora Paulete V. Culau do Instituto de Biociências (1990) que verificou o efeito da distância de transporte e tempo de descanso dos animais antes do abate sobre a qualidade da carne. Em 1991, a professora Maria Cristina Bressan, da Universidade Federal de Lavras - MG, estudou o efeito do intervalo de tempo entre a sangria e a entrada das carcaças na câmara fria e diferentes velocidades de resfriamento sobre as características de qualidade da carne suína. Os trabalhos foram orientados pelo autor, professor da Faculdade de Agronomia, e apresentados como dissertações para o grau de mestre.

O quarto trabalho da seqüência foi de autoria do Médico Veterinário Remy Andrade Jr., serviu de base para seu curso de especialização na UFPR e tratava de diferentes fatores que poderiam afetar a qualidade da carne suína, bem como o efeito das carnes PSE e DFD sobre a perda de líquido no processo de resfriamento.

Em 1992 e 1993 realizamos, com a participação de todos os autores, previamente citados um levantamento da ocorrência de carcaças PSE no Estado do Rio Grande do Sul.

Finalmente, em 1997 o Engenheiro Agrônomo Ricardo Monghilhott de Brito, também no Curso de Mestrado da Faculdade de Agronomia da UFRGS, verificou o efeito do uso adicional das vitaminas E e C na qualidade da carne suína.

Deste conjunto de trabalhos é possível concluir que a incidência de carcaças com PSE, no Rio Grande do Sul, ou no Sul do Brasil, varia de 20 a 40%, o que não é muito diferente dos dados publicados relativos a outros países como Noruega (1981) 20%, Alemanha Ocidental (1982) 41,2%, Inglaterra (1978 e 1983) 12,8 a 15,5%, Espanha (1986) 31%, Estados Unidos da América do Norte (1992) 16%, Checoslováquia (1992) 22 a 31,5% e Austrália (1992) 32%.

Conclusões

Para atender as exigências da indústria de produzir um suíno em condições de bem-estar animal, com qualidade de carne e em níveis compatíveis de produtividade, é preciso: melhoria das qualidades sensoriais da carne sem comprometer a muscularidade; resolver as questões éticas e de segurança do uso do hormônio de crescimento - Somatotropina (PST); desenvolvimento de um Kit de diagnóstico do gen receptor do ryanodine para facilitar a eliminação dos aspectos negativos do gen halotano; melhoria das condições de transporte, pré-abate e insensibilização conhecendo melhor o comportamento animal e sua tolerância ao stress; controle da desidratação no transporte e rehidratação antes do abate e formas de manter os suínos calmos e frios antes do abate.

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COMO MEDIR A QUALIDADE DA CARNE NA LINHA DE ABATE DE SUÍNOS

Jose Vicente Peloso

Med. Veterinário – M.Agr.Sc.
SADIA S.A., Concórdia – SC

Introdução

Uma considerável e significativa variação na qualidade da carne do suíno é verificada nos frigoríficos brasileiros, europeus e norte-americanos pesquisados até o momento[3,12,24,39]. É sabido que os desvios de qualidade que ocorrem na carne suína são causados ao mesmo tempo por fatores genéticos e ambientais[1,28,31,33,38]. As relações de causa e efeito mais evidentes ocorrem entre a *Porcine Stress Syndrome* (PSS) e a carne *Pálida, Mole e Esxudativa* (PSE)[6,15,17,29,31] e entre o gene RN (*Rendimento Napoli*) e a carne ácida[18]. A tarefa de medir objetivamente a qualidade da carne contida nas carcaças na linha de abate de suínos exige a definição da utilidade e da precisão da medida, aliadas obviamente ao custo-benefício da mesma[7,8]. Medir a qualidade para o aproveitamento industrial das carcaças tem no mínimo três utilidades: "tipificar" carcaças de acordo com a qualidade da carne, permitindo a identificação de carcaças portadoras de defeitos que comprometem o rendimento e as características sensoriais durante o processamento dos produtos a que elas se destinam. Criar critérios que permitem bonificar ou penalizar as carcaças de acordo com os valores obtidos dentro destes valores pré-definidos. A terceira utilidade é o controle pela fábrica, permitindo conhecer a freqüência de carcaças e ou cortes que não possuem a qualidade desejada e o conseqüente gerenciamento deste problema.

Todas as avaliações objetivas e subjetivas possíveis dentro do frigorífico são baseadas nas transformações bioquímicas, físico-químicas e visuais que acontecem na musculatura estriada esquelética contida nas carcaças[30]. Após o abate do animal, esta musculatura passa a ser regulada, por um certo período de tempo, através do metabolismo anaeróbico (ausência de oxigênio nas células musculares) após o fim do metabolismo aeróbico (sangria e morte do animal)[5]. Durante este período, o músculo deixa de ser músculo e transforma-se em carne. Neste espaço de tempo, ocorrem modificações no músculo e em suas estruturas básicas (fibra muscular, mioplasma e suas proteínas constituintes), que vão definir a qualidade final deste músculo que virou carne[26,27].

Variações na qualidade da matéria-prima

Este conjunto de transformações que ocorre no músculo pode alterar de maneira irreversível as propriedades funcionais e as características tecnológicas e sensoriais da carne[10]. Estas transformações estão, de uma maneira ampla, condicionadas aos efeitos da quebra ou consumo do glicogênio muscular,

levando a uma maior ou menor concentração de ácido lático, determinando consequentemente o valor final do pH da carne[10,19,22]. Em outras palavras, a glicólise muscular em toda a sua cadeia de reações bioquímicas é o fator determinante da qualidade final do músculo suíno[26,27]. Para os frigoríficos, isto se traduz no mais freqüente problema tanto para produtos *in natura* quanto para processados, principalmente os embutidos e cozidos: a carne PSE[35]. Entretanto, na avaliação individual das características físicas, ou seja, capacidade de retenção de água, consistência (maciez, dureza, firmeza) e cor, definem-se outras categorias de qualidade da carne suína: RFN (normal ou ideal); RSE (cor normal, porém exsudativa e mole) e DFD (escura, dura e seca)[12,36].

Medindo a qualidade da carne nas carcaças

Dentro do frigorífico podemos dividir os momentos de avaliação da qualidade da carne em dois: antes e após o resfriamento das carcaças. Mais ainda, antes do resfriamento só é possível fazer qualquer medição quando os músculos escolhidos ficam expostos, do contrário a tarefa se torna pouco prática e de certa maneira irrelevante. Entretanto, já foi demonstrado que certas avaliações feitas no suíno vivo, possuem moderada correlação com as medidas tomadas nas carcaças correspondentes[16,17]. Valores de qualidade de carne obtidos de suínos vivos podem ter importância como critério de seleção em programas de melhoramento genético, mas seus métodos os tornam inviáveis em avaliações de grande escala, como as necessárias dentro de um frigorífico.

A primeira, e provavelmente uma das mais importantes medidas possíveis logo após o abate, é o valor do pH inicial ou pH_{40} (40 minutos pós-sangria, dependendo da disponibilidade prática). É uma medida utilizada quase como um padrão Mundial[23,39], possui moderada correlação com a qualidade final da carne e geralmente é feita no lombo (*m. Longissimus lumborum*) e/ou no pernil (*m. semimembranosus*)[8,21,22,32]. Serve como razoável estimador da carne PSE neste instante, porém sua precisão para detecção de PSE e/ou DFD aumenta quanto aliado a uma medida de cor e outra de capacidade de retenção de água (CRA)[7,8,13,21,32,34]. O pH inicial possui alta correlação com o genótipo de sensibilidade ao stress ("gene do halotano") e é possível diferenciar os animais sensíveis ao stress dos não sensíveis, pelos valores do pH_{40}[6,15,16,20,31]. A melhor aplicação do pH_{40} é quando se consegue utilizá-lo como potente estimador da CRA final da carcaça, numa velocidade de nórea de mais de 300 suínos/hora.

Além do pH_{40}, outras avaliações são utilizadas, porém com menor freqüência, ainda na carcaça quente, como valores de dispersão de luz ou cor, condutividade e/ou resistência elétrica[21,25]. O primeiro pode ser obtido dos equipamentos de tipificação de carcaças (relação carne:gordura) que utilizam a dispersão de luz como princípio de leitura da espessura do toucinho e do lombo (ex.: HGP4™, FOM™). Infelizmente, os valores de cor obtidos pelas pistolas de tipificação, são fracos estimadores da qualidade final do lombo[8,13,32]. As avaliações elétricas necessitam de equipamentos especialmente projetados para tanto (ver Tabela 1), que são mais resistentes ao ambiente industrial do que os pHmêtros. Desta forma, ambos podem ser empregados como substitutos do pH_{40}, porém com menor precisão[21,25,37].

A situação ideal é aquela na qual a qualidade final da carne contida na carcaça fria, pode ser estimada com suficiente precisão ainda na carcaça quente[13,32]. Assim sendo, é a qualidade final, ou seja, aquela presente na carne quando a carcaça é cortada (pernil, costado, barriga e paleta) que é mais relevante para a indústria[7,13]. Como já visto, valores de pH, cor e condutividade, utilizados em conjunto possibilitam com maior ou menor precisão, a detecção de carcaças com carne PSE antes do resfriamento. Após o resfriamento, quando as reações bioquímicas cessam por completo na carne e sua qualidade final é atingida, a utilização de valores de pH_u ou pH último, cor final associadas as medidas de CRA, permitem definir com maior precisão a real freqüência de lombos ou pernis RFN, RSE, PSE e DFD no frigorífico[4,5,11,36]. Neste sentido, as avaliações mais relevantes são as de cor de superfície, geralmente obtidas através do valor L* (*lightness*), o pH_u, e a dispersão da luz através de fibra ótica[8,21,33,34]. No ambiente comercial, o método mais prático para se determinar a CRA da carne é o *Drip Loss* ou Gotejamento, embora métodos alternativos tenham sido descritos[14]. Quando bem empregado, o gotejamento serve como valor de referência, e seu valor poder ser estimado com precisão suficiente usando-se por exemplo o pH_u ou cor final do músculo[7,13,20,21,22,30,32,37].

Tabela 1. Métodos de avaliação da carne suína freqüentemente utilizados na prática e na pesquisa.

Método	Preci-são	Tipo de Equipamento	Custo inicial	Tempo de Medição	Aplica-ção	Vantagem	Desvantagem	Outras Considerações
Avaliação Visual da Cor e Firmeza	Mode-rada	Padrões Fotográficos/ "Pastilhas" Japonesas	Baixo	Rápido	Simples	Rápido e Simples	Músculo tem que ser exposto e padronizado	Intensidade da luz no ambiente pode influenciar julgamento do observador
Métodos Físicos:								
% Gotejamento	Alta	Balança com precisão de 1 grama	Mode-rado	Lento	Simples	Medida objetiva da CRA[#]	Vagaroso, propenso a erro, destrutivo	Necessária padronização das amostras de músculo (dimensões e peso)
Filtro de Papel	Mode-rada	Balança de miligrama, filtro especial	Mode-rado	Moderado	Simples	Medida relacionada a CRA[#]	Músculo tem que ser exposto	Usado nas 24 horas *post mortem*
Centrifugação:								
Para CRA[#]	Alta	Centrífuga de alta velocidade	Alto	Lento	Simples	Medida relacionada a CRA[#]	Vagaroso, propenso a erro, destrutivo	Pouco prático
Para absorção de água	Alta	Centrífuga de baixa Velocidade	Mode-rado	Lento	Complexa	Relacionada a absorção de água	Vagarosa e destrutiva	Momento *post mortem* não é crítico
pH:								
Eletrodo de vidro/epoxi	Alta	pHmêtro e eletrodo (Correção p/ T°)	Mode-rado	Rápido	Simples	Fácil manuseio	Calibração e quebra do eletrodo	pHmêtro sensível a baixas temperaturas
Óticos/Elétricos:								
Reflectância da Luz	Mode-rada	Colorímetro (Ex.: Minolta™)	Alto	Rápido	Simples	Mede cor da superfície	Músculo tem que ser exposto	Descreve variação de cor Padrão CIE L* a b
Dispersão da Luz	Mode-rada	Fibra Ótica (Ex.: FOP™)	Mode-rado	Rápido	Simples	Mede cor profunda	Precisão	Descreve CRA do músculo
Condutividade Elétrica	Mode-rada	PQM™ LT-K*21™	Mode-rado	Rápido	Simples	Velocidade da medida	Precisão	Mais utilizado experimentalmente
Resistência Elétrica	Mode-rada	MS-Tester™ LF Digi 550™	Mode-rado	Rápido	Simples	Fácil manuseio	Invasivo	Mais utilizado experimentalmente
Químicos:								
Extração de Lipídios	Alta	Laboratorial	Alto	Rápido	Complexa	Precisão	Custo	Considerado padrão para gordura intra-muscular
Solubilidade de proteínas	Mode-rada	Centrífuga/ Espectrofotômetro	Alto	Lento	Complexa	Medida direta da CRA	Destrutiva/ Velocidade	Mais utilizado na pesquisa/ experimentalmente

Adaptado de Kauffman & Warner (1993) e Cross & Belk (1994) + opinião pessoal do autor. #Capacidade de Retenção de Água.

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CARACTERÍSTICAS FÍSICAS E ORGANOLÉPTICAS DA CARNE E GORDURA QUE AFETAM A QUALIDADE DOS PRODUTOS INDUSTRIALIZADOS

Massami Shimokomaki[1] & Rubison Olivo[2]

[1]Programa de Mestrado e Doutorado em Ciência dos Alimentos, Depto. de Tecnologia de Alimentos e Medicamentos, CCA-Universidade Estadual de Londrina, Caixa Postal, 6001, CEP 86051-970-Londrina, PR, Email mshimo@npd.uel.br
[2]Rezende Alimentos, Uberlândia, MG

O consumo de carnes industrializadas vem aumentando significativamente devido aos diversos fatores: estabilidade da moeda, mudança de comportamento como a da entrada das mulheres do mercado de trabalho, etc. Estimou-se pela Instituto Nielsen de que no período de 92 a 93, o consumo atingiu a 263 mil toneladas de embutidos emulsionados no Brasil. Baseando-se nestes fatos, pode-se projetar um consumo per capita de aproximadamente 2 kg indicando a importância destes produtos na nossa economia. Por estes fatos, abordaremos nesse artigo, os cuidados necessários para a obtenção de produtos emulsionados cárneos com qualidade.

Emulsão cárnea

As emulsões cárneas são consideradas por muito autores como sendo uma emulsão óleo em água porem, não são emulsões verdadeiras. E uma suspensão coloidal complexa não totalmente homogênea e suas partículas dispersas possuem tamanho de 10 a 50u. A fase dispersa é constituída por partículas de gordura, fibras musculares, aditivos, farináceos, e a fase continua é constituída pela água, sal, proteínas hidrossolúveis, e outros elementos solúveis. Muitos autores consideram, dessa forma quando não estão finamente triturados, os embutidos como sendo uma massa cárnea.

Como são formadas as massas cárneas?

A mistura dos ingredientes realizada pelo cutter confere uniformidade ao produto em relação ao tamanho das partículas. Nesta fase, ocorre a fragmentação da estrutura fibrosa dos músculos o que aumenta a exposição da superfície das proteínas. As proteínas miofibrilares nesta fase encontram-se no estado insolúvel. Posteriormente, na presença dos sais e água inicia-se a solubilização e o subsequente entumescimento das proteínas devido a absorção da água produzindo uma matriz viscosa (SOL). Essas proteínas solubilizadas funcionarão como agentes emulsificantes sendo a miosina considerada o principal componente emulsionante. A estabilidade desse sistema é o principal fator para a qualidade da massa e depende da propriedade de agentes emulsificantes em reter a água e gordura produzindo o efeito denominado coesividade proporcionada pela inter-relação destes componentes. A coesividade é afetada principalmente durante a fase de cozimento quando a gordura não se separa do sistema.

Modelos tem sido propostos para explicar a estabilidade da emulsão da carne. e dois deles são preponderantes: teoria da emulsão e teoria de aprisionamento físico. A teoria da emulsão apresentada por Mandigo e seu grupo (1) descrevem a formação de um Filme Protéico Interfacial (FPI) que é elaborada durante o batimento no cutter circundando a gotícula de gordura. através da sua porção hidrofóbica enquanto que a porção hidrofílica

localizada externamente à gotícula retém a água o que ocorre freqüentemente nas emulsões verdadeiras (Fig. 1).

A teoria do aprisionamento físico defende a hipótese de que as gotículas de gorduras são retidas devido ao desenvolvimento das forças iônicas presentes na matriz protéica. As proteínas geleificam-se durante o cozimento formando uma malha retendo as gotículas de gordura e a água (2).

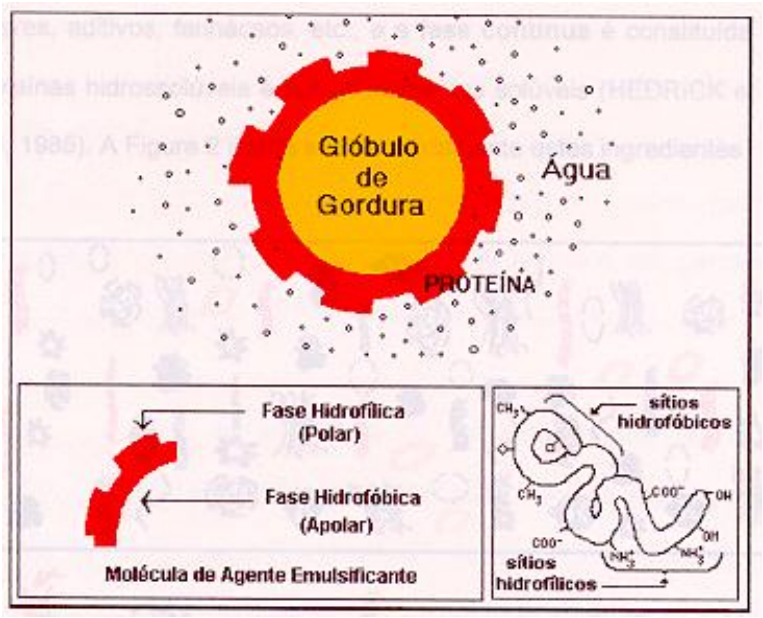

FIG. 1 - Formação de uma emulsão em que a proteína atua como agente estabilizador formando um filme que une gordura e água (Ref. 4).

Quebra da Emulsão

Apesar das discussões levantadas a respeito, ha o consenso de que os dois fenômenos podem ocorrer durante o processamento sendo que na massa ainda crua ocorre a formação da emulsão e ao provocar o tratamento térmico, o fenômeno do aprisionamento físico pelo gel protéico seria preponderante (3). E possível, portanto, afirmar que o produto cru apresenta uma textura tipo pasta em um estagio de fragilidade (SOL) e nessa fase ha a necessidade dos cuidados de manuseio para que não suceda a separação da gordura evitando o fenômeno da quebra da emulsão. Este fato traz como conseqüência inconformidade na qualidade do produto podendo provocar problemas de ordem econômica aos Frigoríficos. A máxima estabilidade do sistema [e conseguida através do equilíbrio entre a espessura do FPI e densidade e integridade da matriz protéica da emulsão durante o cozimento.

Fatores que afetam a estabilidade da emulsão

A estabilidade da emulsão é afetada por diversos fatores dos quais podemos destacar? tempo e temperatura utilizados durante o processo da emulsificação, tipo e tamanho dos seus constituintes. Durante a cominutação, a temperatura da massa aumenta provocada pela fricção pelo cutter. A temperatura máxima limite depende do ponto de fusão das gorduras como 10-12°C para frango, 15-18°C para suínos e 21-22°C para bovinos. A temperatura deverá ser mantida inerente ao tipo de gordura utilizada sem o qual ocorrera a sua fusão provocando o fat out durante o cozimento. Jones e Mandigo (1) observaram que durante a preparação da massa, a temperatura deveria ser mantida a 16°C. À essa temperatura, formam-se poros ao redor da gotícula de gordura que funcionam como válvulas de escape como o descrito na Fig. 2 (fase 1) por onde saem as gotículas menores de gordura {a medida que se eleva a temperatura. Ao mesmo tempo, ocorre a desnaturação protéica que envolve a gotícula aumentando o espessamento do FPI dificultando gradativamente o mecanismo da liberação da pressão interna (fase 2) ate que a gotícula e circundada pelo filme (fase 3). Em conseqüência, com o continuar do aumento dessa pressão interna com o aquecimento da massa, ha a ruptura da membrana interfacial (fase 4) provocando a quebra da emulsão.

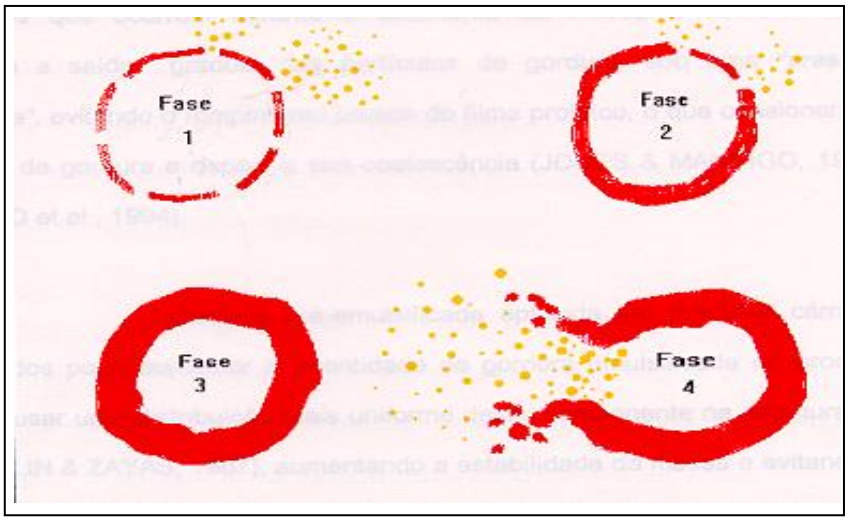

FIG. 2 - Ilustração esquemática dos prováveis acontecimentos durante a formação (1), estabilização (2,3) e quebra (4) da emulsão provocadas pela elevação da temperatura (Ref. 1).

Comportamento do colágeno durante a emulsificação

Outras proteínas podem ser utilizadas como agente emulsificante. Destaca-se o colágeno presente em diversos tecidos e órgãos que representam uma grande quantidade desprezada em frigoríficos como a pele, pulmão. Em determinadas condições, colágeno co-distribue com as proteínas miofibrilares podendo auxiliar na

estabilidade da emulsão. O grau de polimerização das suas moléculas afeta as propriedades de solubilidade que por sua vez afeta a funcionalidade da matriz protéica da massa cárnea. Nos nossos laboratórios, demostramos por métodos histológicos a distribuição do colágeno com as proteínas miofibrilares, ie., ao redor das gotículas de gorduras auxiliando na estabilização das gorduras. Durante o cozimento a 68-72°C, o colágeno se desnatura e nesse estado, solubilizado e gelatinizado, faz parte do filme protéico interfacial conforme pode ser verificado na Fig. 3. A atuação destas proteínas depende das pontes cruzadas que a estabilizam e que aumentam com a idade dos animais. Essa propriedade esta fundamentada na sua constituição contendo cerca de 60% de resíduos de aminoácidos de natureza hidrofóbica o que facilita a sua associação com a gordura. Entretanto, o seu uso terá que ser restrito a 1,2 a 1.5% para 18-24% de gordura para prevenir a quebra da emulsão (Fig. 4) (4).

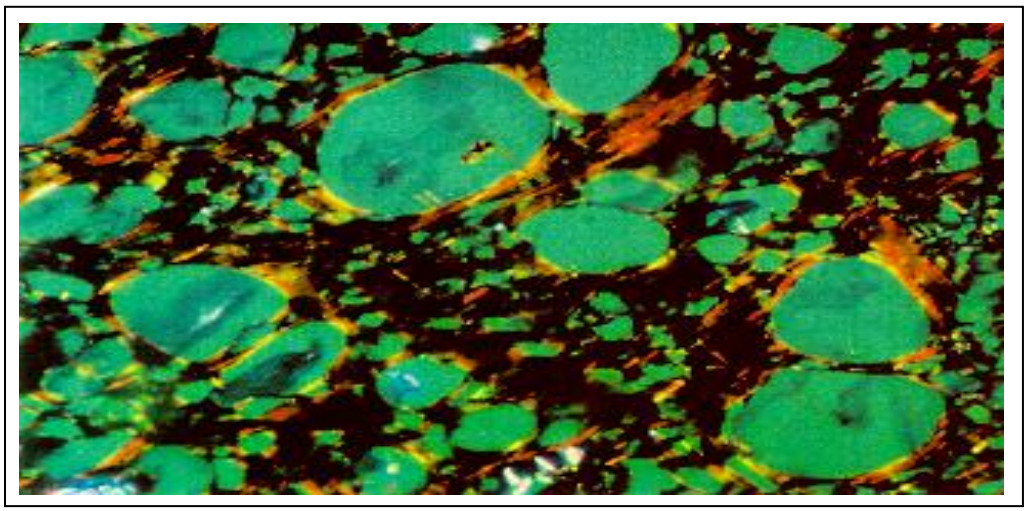

FIG. 3 - Microfotografia de amostra de salsichão mostrando a encapsulação dos glóbulos de gordura pelo colágeno, pelo método Picrosírius, (Ref. 4).

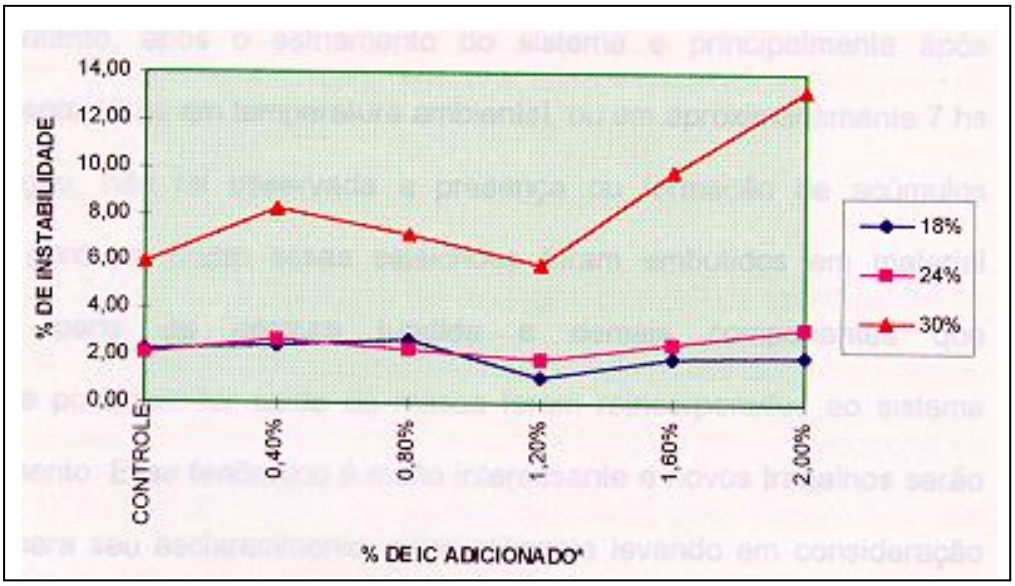

FIG.4 - Medida da estabilidade de salsichões com diferentes níveis de gordura e

colágeno adicionado (Ref. 4).

Pontes cruzadas em colágeno

Obviamente, a solubilidade do colágeno e uma propriedade a ser levada em consideração para essa função. Ser solúvel depende da idade dos animais desde que quanto mais idoso mais ligações cruzadas térmicamente estáveis estão presentes na sua molécula. A solubilidade depende da idade dos animais desde que quanto mais idoso mais ligações cruzadas térmicamente estáveis estão presentes na sua molécula. A origem destas pontes cruzadas esta na intermediação da atividade das enzimas lisiloxidase que atuam nos resíduos específicos da lisina formado aldeídos deste aminoácido para posterior formação das di-hidroxilisinooxilisinonorleucina (Fig. 5) (5). Estas apresentam natureza biológica intermediária e que durante o avanço em idade formam as pontes cruzadas maduras denominas piridinolinas que tornam a molécula mais estáveis emprestando uma maior textura à carne (6). O fenômeno poderá também na qualidade das emulsões.

FIG. 5 - Biossíntese das ligações cruzadas de colágeno intermediadas pela lisil-oxidase (Ref. 5).

PSE e propriedades funcionais da carne

A síndrome PSE tem sido intensamente abordado em carnes suínas. Recentemente, o assunto tem sido novamente focalizado e desta vez em aves (7,8). Reportamos, embora preliminarmente, a utilização da suplementação de vitamina E na dieta para minimizar a sua ocorrência e melhorar a funcionalidade em produtos simulados derivados de carnes de frango (9). O pH atingiu seu valor final em um período de 15 min. em carnes PSE e o controle necessitou de 40-45 min. Ao mesmo tempo foi observada que a perda de gotejamento foi em torno de 28% em peito de frango com PSE quando comparado com amostras suplementadas enquanto que a sua coloração foi protegida nas mesmas durante um certo período em refrigeração (Fig. 6). Finalmente, a Fig. 7 mostra a proteção que a vitamina E suplementada oferece também na prevenção da oxidação lipídica após um período de 6 dias de armazenamento tanto na carne crua como na cozida, medida pelo TBARS (9).

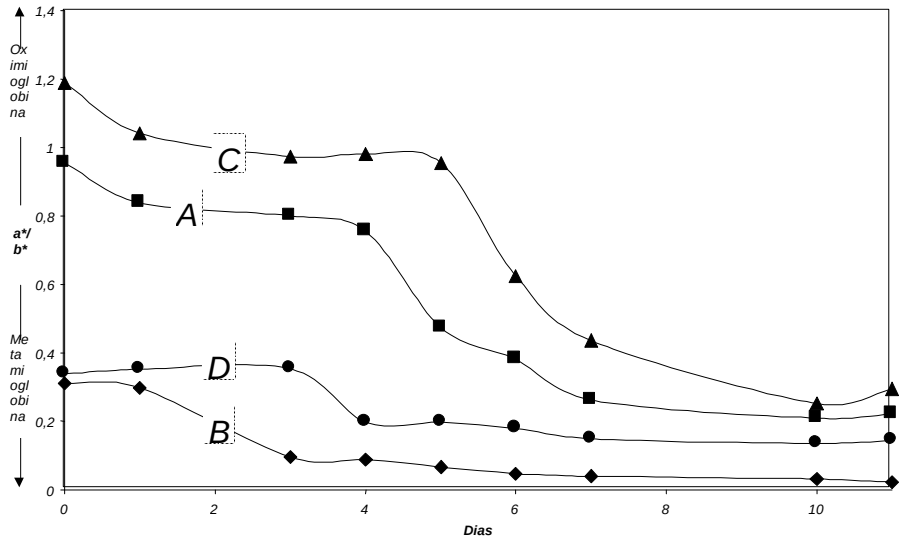

FIG. 6 – Formação de metamioglobina em CMS medida pela relação Razão a*/b* durante a vida-de-prateleira, onde: A – Controle/Crua, B – Controle/Cozida, C – Suplementado/Crua, D – Suplementado/Cozido.

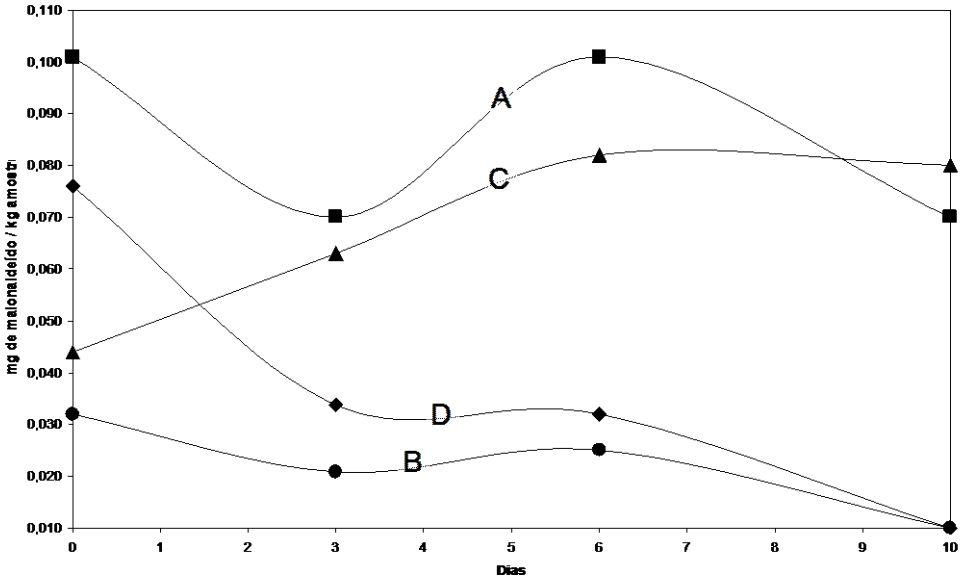

FIG. 7 – Formação de substâncias reativas ao ácido 2 – tiobarbitúrico (TBA) em CMS com o decorrer da vida-de-prateleira, onde: A – Controle/Crua, B – Controle/Cozida, C – Suplementado/Crua, D – Suplementado/Cozido.

EXIGÊNCIAS NUTRICIONAIS PARA MÁXIMO RENDIMENTO DE CARNE EM SUÍNOS

Alexandre de Mello Kessler

Departamento de Zootecnia da Universidade Federal do Rio Grande do Sul

Introdução

Quando são estabelecidas exigências nutricionais para suínos, e em especial para maximizar o crescimento muscular, convém conhecer a capacidade genética de crescimento diário dos componentes do ganho de peso. Esta capacidade pode ser estimada pelo peso e idade dos animais ao abate e por medições do rendimento de carne magra e espessura de toucinho (NRC, 1998). Destes componentes, os mais representativos são as deposições diárias de proteína e gordura corporais. A deposição de proteína, associada ao conteúdo de água, no chamado tecido magro, representa o principal objetivo da criação de animais para o abate, de forma que a adequação nutricional e minimização dos custos de produção devem estar associados a ela. O rendimento máximo de tecido magro é basicamente determinado pelo perfil genético/hormonal e pela adequação nutricional. O ganho diário de gordura corporal, por outro lado, deve ser o mínimo necessário à qualidade da carne no pós-abate e parece estar inversamente relacionado à taxa de deposição de proteína e diretamente relacionado à capacidade de ingestão voluntária de alimento.

A deposição de proteína corporal total pelos suínos é um parâmetro cuja variação no período de crescimento/terminação não alcança grande amplitude, ficando em torno de 100g/d dos 30 aos 90 kg de peso vivo (PV), para machos castrados e fêmeas, desde os primeiros estudos com animais das raças modernas (ex. OSLAGE & FLIEGEL, 1965). O NRC (1998) apresenta como padrão a deposição de 127,5 g/d (Fig. 1).

As linhagens modernas de alto rendimento de carne magra devem apresentar deposições próximas ou superiores a esta estimativa. Esta relativa constância do crescimento de tecido magro possibilita o estabelecimento das exigências nutricionais em modelo fatorial, sendo este o principal referencial do modelo, seguido das demandas para manutenção e da deposição mínima obrigatória de gordura corporal.

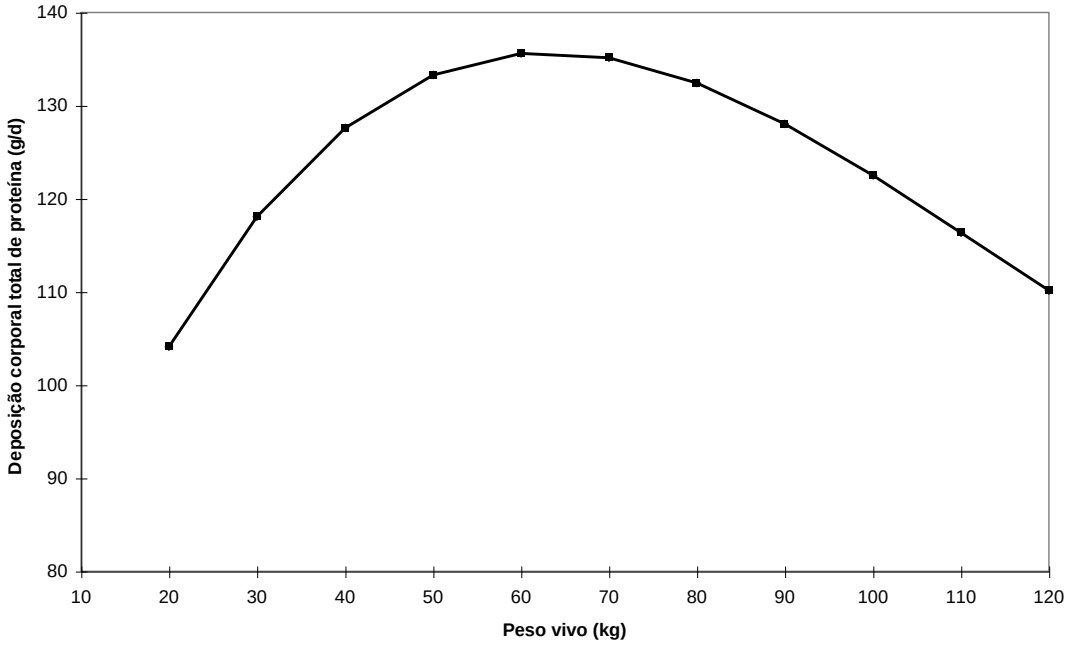

FIG. 1. Deposição diária corporal total potencial de suínos conforme a faixa de peso, pela equação Y = (0,47666 + 0,02147*PV - 0,00023758*PV^2 + 0,000000713*PV^3) * 127,5; para animais com ganho médio de carne magra de 325 g/d, ou 127,5 g/d de proteína total (NRC, 1998).

O Poder da Lisina

A lisina dietética é a longo tempo considerada como o nutriente que mais influencia a deposição de proteína pelos suínos em crescimento, sendo portanto tomada como base das exigências nutricionais para os demais aminoácidos e proteína dietética total (KESSLER, 1992; FULLER, 1996; BIKKER & BOSCH, 1996). Isto se deve à sua constância na proteína corporal, à relativa limitação nos alimentos práticos e uma destinação metabólica preferencial para a deposição de tecido magro. Além disto, como a deposição de proteína, no suíno em crescimento, representa a maior parte da demanda por este aminoácido, as estimativas das exigências diárias devem recair sobre este parâmetro, que por sua vez é a base das exigências dos demais aminoácidos, conforme as relações dentro da proteína ideal, já sedimentadas em inúmeros estudos. Na tabela 1 podem ser observadas estas relações dentro das exigências líquidas para manutenção e crescimento e na composição das dietas. As exigências diária de lisina devem ser estabelecidas com base no ganho diário de proteína ou tecido magro, pois existe uma dissociação importante entre o consumo de lisina e energia e seus efeitos sobre as deposições de proteína e gordura (KESSLER, 1992; KESSLER et al., 1995), e as exigências para manutenção são pequenas. Estimativas obtidas a partir dados de experimentos empíricos indicam, por sua vez, uma relação de lisina dietética total consumida para proteína corporal retida de 0,15-0,17: 1,0 (g/g)(ARC, 1981; KESSLER, 1992). Estimativas fatoriais estão entre 0,10 e 0,12:1,0 (g de lisina digestível para cada g de proteína corporal retida).

Tabela 1. Estimativas de composição ideal de aminoácidos (% em relação à lisina) para crescimento da proteína corporal, manutenção, e para dietas de suínos em crescimento e terminação (fonte: FULLER, 1996).

	Deposição de proteína corporal	Manutenção	Exigência 30-50 kg PV	Exigência 50-110 kg PV
Treonina	69	148	72	70
Valina	78	56	75	68
Metionina + cist.	53	135	63	65
Isoleucina	63	43	60	60
Leucina	115	65	110	100
Fenilalan. + tiros.	124	104	120	95
Lisina	100	100	100	100
Triptofano	18	30	18	19

Energia

A mencionada dissociação entre o consumo diário de lisina (ou proteína ideal) e de energia digestível (ou metabolizável) é evidente em animais com menor taxa diária de crescimento de tecido magro. Animais com platô para retenção protéica em torno das 100 g/d usualmente têm capacidade de ingestão de alimento (e de energia) superior às demandas para o tecido magro de forma que no pós-platô o consumo energético é muito mais direcionado para a retenção de gordura corporal. Isto é mais evidente em machos castrados, que apresentam taxas de retenção protéica similares às das fêmeas mas um maior consumo energético. As Figs. 2 e 3 mostram curvas de deposição de proteína e gordura, segundo o consumo de energia digestível, do trabalho esclarecedor de CAMPBELL & TAVERNER (1988). A linhagem B de baixa capacidade de deposição de proteína, atinge o máximo de crescimento protéico muito antes do limite de ingestão voluntária de ED. Para serem produzidas carcaças mais magras, estes animais estes animais devem receber oferta restrita de ED (em torno de 8 Mcal/d, conforme os dados). Por outro lado, a resposta linear crescente da deposição de proteína nos cachaços da linhagem A, indica que animais de alta deposição de tecido magro, têm demandas energéticas associadas a esta deposição que são superiores à capacidade de ingestão energética, e neste caso nenhuma restrição é necessária, mesmo no período de terminação. É conhecido que a deposição de gordura (DG) no crescimento de suínos é linear com o aumento na ingestão calórica, apresentando uma deposição que pode ser chamada de mínima obrigatória mesmo quando a deposição de proteína (DP) está limitada pela restrição no consumo. Na realidade, a deposição de gordura é mais afetada por esta restrição, e esta DG mínima pode ser estudada pela relação com a proteína depositada (relação DG/DP, em g/g por dia). Esta relação é variável de acordo com a capacidade de DP e do consumo voluntário dos suínos, variando, por exemplo, de 1,0 a 1,5, aos 50 e 100 kg PV, respectivamente, em cachaços de alta DP, e baixo consumo voluntário

(QUINIOU et al., 1995), em torno de 2,0, em cachaços de alta DP, e médio consumo voluntário (CAMPBELL & TAVERNER, 1988), em torno de 3,0, em cachaços de baixa DP, e médio consumo voluntário (CAMPBELL & TAVERNER, 1988), e de 3,5 a mais de 5,0, nos castrados de baixa/média DP, recebendo alimentação restrita ou à vontade, respectivamente (CAMPBELL & TAVERNER, 1988; KESSLER, 1992). O conhecimento da relação DG/DP mínima é essencial para o estabelecimento de um programa de restrição alimentar para animais em terminação com alto consumo voluntário, como forma de reduzir a gordura na carcaça e não prejudicar o crescimento de tecido magro. Algumas linhagens modernas, com participação importantes de raças como a Pietrain, apresentam alta DP e baixo consumo voluntário, de forma que não é necessário o estabelecimento de programas de restrição alimentar.

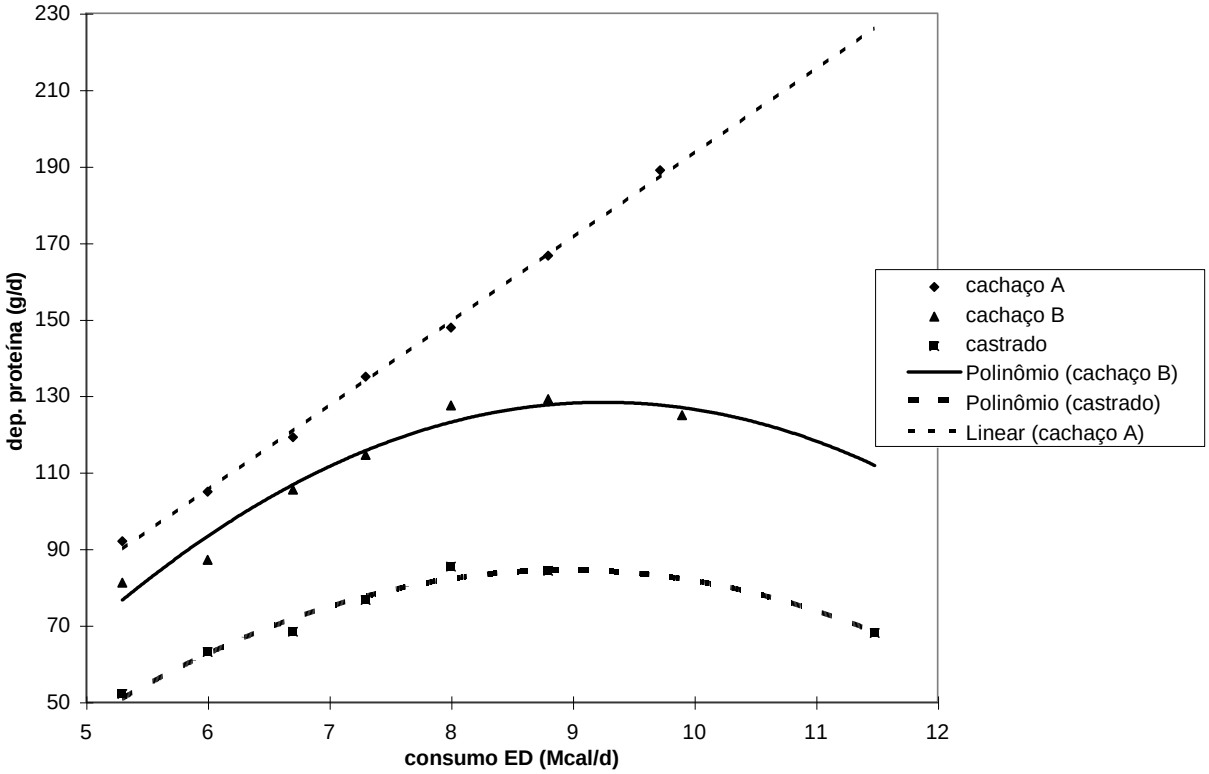

FIG. 2. Curvas de deposição de proteína corporal, de acordo com o consumo de ED, de cachaço de linhagem de alta deposição de tecido magro (A), e cachaços e castrados de linhagem de baixa deposição de tecido magro (B) (fonte: CAMPBELL & TAVERNER, 1988)

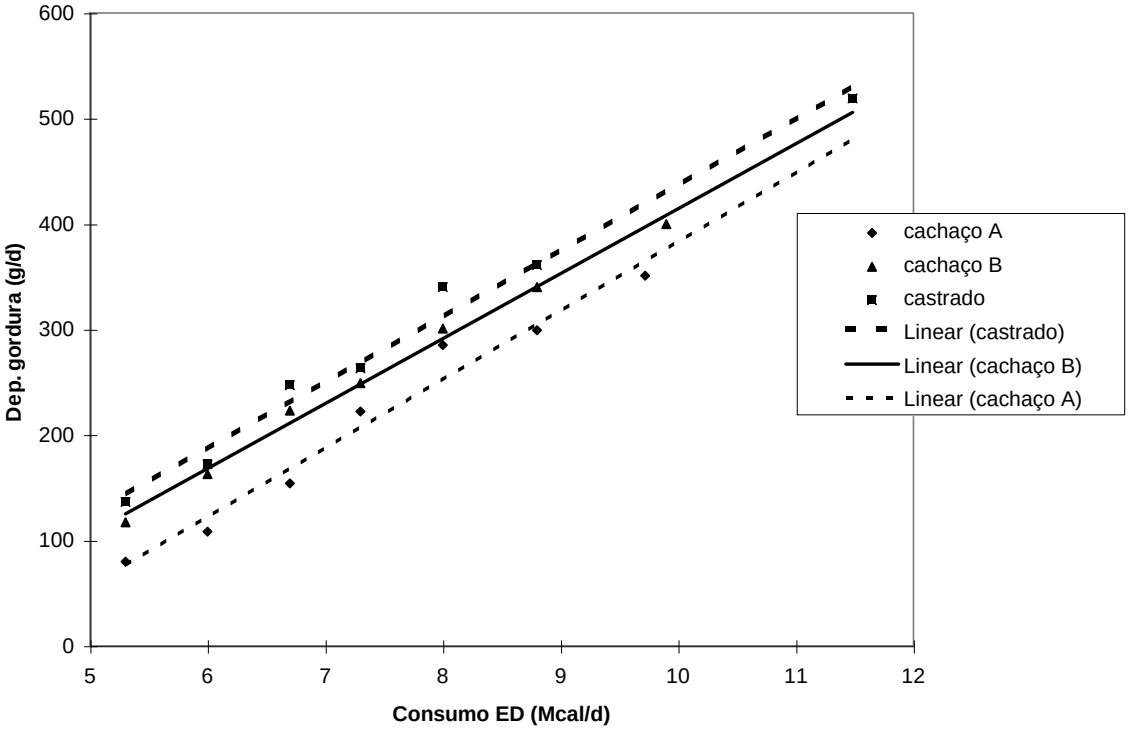

FIG. 3. Curvas de deposição de gordura corporal, de acordo com o consumo de ED, de cachaço de linhagem de alta deposição de tecido magro (A), e cachaços e castrados de linhagem de baixa deposição de tecido magro (B) (fonte: CAMPBELL & TAVERNER, 1988).

Modelos Fatoriais

O estabelecimento de modelos fatoriais é bastante útil pelo seu poder de predição das exigências nutricionais nas mais diversas categorias de animais e/ou situações de produção. Por outro lado, o ajuste destas predições é dependente do conhecimento de variáveis que não são de fácil medição ou domínio geral. Estas variáveis basicamente são: fatores que influenciam as exigências de manutenção dos animais (temperatura ambiental, instalações, desafio de patógenos, etc..); e os níveis e respectivas eficiências de deposição de proteína e gordura corporais; e a capacidade de consumo voluntário de alimento. De qualquer forma, os modelos baseados nestas variáveis têm apresentado resultados positivos, e o modelo do NRC (1998) vem para popularizar esta proposta. Para o crescimento/terminação de suínos, os referenciais são as estimativas das exigências de energia e lisina, sendo os demais nutrientes definidos a partir de relações com estes primeiros. As predições para as exigências de EM e lisina podem ser obtidas pelas equações que seguem (NRC, 1998):

$$EM_c \text{ (kcal/d)} = 106 * PV^{0,75} + 10,6 * DP + 12,5 * DG \quad (1)$$

sendo PV em kg e DP e DG em g/d;

$$\text{e} \quad \text{Lisina digestível (g/d)} = 0,036 * PV^{0,75} + 0,12 * DP \quad (2)$$

De acordo com a equação (1), a EM exigida, se usarmos o princípio da relação DG/DP, será tanto mais particionada para o crescimento de tecido magro quanto maior for a DP da população suína a que se aplica. Na Tabela 2 pode ser visualizado um quadro teórico onde, nos extremos, é verificada uma partição mais homogênea da EM consumida entre EM para manutenção, DP e DG quando os suínos apresentam alta capacidade de DP. Nos animais de baixa DP, a energia consumida é essencialmente direcionada para a síntese de gordura corporal.

Tabela 2. Partição da estimativa de exigência diária de energia metabolizável (EMc), segundo equação do NRC (1998), nas frações EM para manutenção (EMmanut.), EM para deposição de proteína (EM DP) e gordura (EM DG), conforme o nível de DP e as relações DG/DP, para suínos de 70 kg PV. Dados em %.

DP (g/d)	Fração Emc	Rel. DG/DP = 1	Rel. DG/DP = 2	Rel. DG/DP = 3	Rel. DG/DP = 4
Emmanut.		---	---	37	32
90	EM DP			14	12
	EM DG			49	56
Emmanut.		---	38	31	26
120	EM DP		19	15	13
	EM DG		44	54	61
Emmanut.		43	32	26	---
150	EM DP	26	20	16	
	EM DG	31	47	58	
Emmanut.		38	29	---	---
180	EM DP	28	21		
	EM DG	33	50		

As equações (1) e (2) assumem eficiências (acima da manutenção) de uso de energia de 0,53 de DP (k_P), de 0,75 para DG (k_G) e de uso da lisina digestível de 0,58. Estes são valores razoavelmente conservativos e que conferem alguma segurança à formulação de dietas. Valores medidos por KESSLER (1992) e revisados por FOWLER et al. (1980) situam-se nas seguintes amplitudes: k_P = 0,37-0,63 e k_G = 0,70-0,91. Para a conversão da lisina digestível, acima da mantença, têm sido sugeridos valores de eficiência iguais ou superiores a 0,70 (BIKKER & BOSCH, 1996; KYRIAZAKIS & EMMANS, 1995). Por outro lado, experimentos em condições de granja comercial têm verificado eficiências de retenção da lisina total consumida não superiores a 0,47 (ARC, 1981; KESSLER, 1992), o que determina exigência diária consideravelmente superior. Esta eficiência não parece ser influenciada pelo genótipo (KYRIAZAKIS & EMMANS, 1995), mas parece diminuir linearmente com o aumento no nível de DP e na ingestão protéica (KESSLER, 1992). Quanto ao gasto energético de manutenção (106 kcal*$PV^{0,75}$/d), deve ser considerados os efeitos ambientais que, especialmente para os animais mais jovens, podem gerar incrementos neste componente da ordem de 50 a 100% (NOBLET et al., 1985; KESSLER,1992).

Novas Perspectivas e Conclusões

O futuro da nutrição de suínos está obviamente ligado ao progresso no melhoramento genético destes animais. Se mantida a direção de produção de animais com alta taxa de crescimento de tecido magro, o ajuste nutricional será, como mencionado, realizado a partir da correta estimativa das deposições diárias de proteína e gordura corporais. Por outro lado, os efeitos dos níveis de proteína total consumida e seus efeitos sobre a gordura da carcaça e a partição da do crescimento proteico na carcaça e vísceras precisa ser melhor estudado. As linhagens modernas apresentam maior proporção corporal como músculos e com aumento considerável de fibras glicolíticas. Isto pode levar a uma revisão das fontes de energia da dieta bem como dos níveis de nutrientes associados ao metabolismo energético deste novo padrão de composição corporal.

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GENETIC AND NUTRITIONAL INFLUENCES ON PORK QUALITY

M. Ellis

Department of Animal Sciences, University of Illinois
Urbana Il 61801, USA

Introduction

Discussion of the issue of pork quality is complicated by two factors. Firstly, there are many different components to quality, a number of which are not clearly defined and are difficult to measure objectively. In addition, genetics and nutrition are only two of a multitude of factors, many of which are outside of the producer's control, that impact the ultimate quality of pork and in many situations their effects relative to other factors will be small. Nevertheless, both genetics and nutrition can have a significant influence on pork quality, both positive and negative, and an understanding of these impacts is the first step to developing production programs to optimize quality.

There have been a number of attempts to define quality, with perhaps the most extensive being that of Hoffmann (1994) who suggested that meat quality could be considered in terms of sensory properties, technological factors, nutritive value and hygienic and toxicological or food safety aspects. This review will focus on water holding capacity, a major factor that affects processing and saleable product yields, and pork color and palatability, factors that have a major bearing on the consumer acceptability of pork. In addition, nutritional influences on fat quality will be considered.

1. Genetic Influences on Quality

1.1 Variation Among Breeds and Genetic Lines

One of the most rapid and easiest methods to improve any trait is to import a breed or genetic line with superior characteristics and, consequently, there has been great interest in variation between breeds for quality aspects. A breed that has received considerable attention in this respect is the Duroc. This breed has a number of positive production attributes, including high feed intake, fast growth and hardiness, and it has been used extensively as a part of commercial sire and dam lines. In addition, the Duroc has high intramuscular fat (IMF) relative to other breeds and there is evidence of a positive association between IMF and eating quality.

Recent studies in North America and Europe have confirmed the advantages of the Duroc relative to other breeds and lines. The National Pork Producers Council has carried out two comparisons, one involving purebreds (NPPC, 1994) and the other terminal sire lines (NPPC, 1995) and these studies are summarized in Tables I and 2,

respectively. These results illustrate the higher growth rates and intramuscular fat levels for the Duroc. Differences among breeds and lines for eating quality and shear force were, however, modest and did not always favor the Duroc (Tables I and 2). A threshold model has been proposed for the association between IMF and eating quality (Bejerholm and Barton-Gade, 1986; DeVol et al., 1988) with the proposed minimum IMF level for optimum eating quality being between 2 to 3%. A possible explanation for the relatively small differences in eating quality between the Duroc and other breeds in the NPPC studies is that all of the breeds and lines investigated had IMF levels close to or above the proposed threshold (Tables I and 2).

A study carried out in the United Kingdom (MLC, 1991) compared slaughter pigs with increasing proportions of Duroc and showed an increase in growth rate, backfat thickness and IMF and an improvement in eating quality with increasing Duroc inclusion (Table 3). However, the incidence of the Pale, Soft, Exudative (PSE) pig meat condition also decreased with increasing Duroc inclusion and a number of authors have shown a negative relationship between PSE and palatability traits (e.g. Topel et al., 1976) which suggests that any eating quality advantage for the Duroc may be due, in part, to the lower incidence of PSE associated with this breed.

The genetic line comparisons carried out by the NPPC (Tables I and 2) focused attention on the Berkshire, with this breed producing the best eating quality and lowest shear force of all those evaluated. The Berkshire is being used in programs to produce a "high quality" product for specific markets, including for export to Japan. However, the growth performance and, particularly, the carcass lean contents of the Berkshire are relatively poor (Tables 1 and 2) and, therefore, the costs of producing Berkshires will be relatively high. This illustrates the dilemma faced by the swine industry in terms of trade-offs between growth and carcass characteristics and, thus, the costs of production, and quality attributes.

1.2. Single Genes Associated with Quality

Although there are likely to be a large number of individual genes that impact pork quality, at the present time only two genes with major effects on quality traits have been identified; these are the Halothane and Rendement Napole (RN) genes. Interestingly both these genes exert their influence through effects on post-mortem glycolysis and, consequently, either the rate or the extent of the decline in pH after slaughter. The Halothane gene can produce a very rapid decline in muscle pH immediately post mortem when muscle temperatures are still high and this combination results in the PSE condition. The RN gene produces a normal rate of but a more extensive pH decline, producing a low ultimate pH in the muscle i.e. the acid-meat condition.

Table 1. Breed differences in growth, carcass and meat quality (from National Pork Producers Council, 1994).

	Av.daily gain, g	Backfat depth 10th rib (mm)	Loin eye area (cm^2)	Ultimate pH	Intra-muscular fat (%)	Shear force (kg)	Taste Panel[1]	
							Juiciness	Tenderness
Berkshire	754	29.5	32.8	5.90	3.24	5.79	3.1	3.5
Chester White	735	30.5	34.5	5.86	3.13	5.92	3.3	3.4
Duroc	804	27.2	34.2	5.73	4.29	5.90	3.3	3.4
Hampshire	735	23.4	39.7	5.57	2.63	6.19	3.3	3.3
Landrace	754	26.2	36.7	5.67	2.49	6.38	3.1	3.1
Poland China	758	28.7	34.7	5.74	3.22	6.54	3.1	3.0
Spot	740	28.7	34.9	5.72	3.09	6.51	3.0	3.0
Yorkshire	745	26.7	35.4	5.72	2.48	6.39	3.0	3.1

[1] higher values = more tender and juicier.

Table 2. Breed and genetic line differences in growth, carcass and meat quality. (from National Pork Producers Council, 1995)

	Av.daily gain, g	Backfat depth 10th rib (mm)	Loin eye area (cm^2)	Ultimate pH	Intra-muscular fat (%)	Shear force (kg)	Taste Panel[1]	
							Juiciness	Tenderness
Berkshire	840^{c}	31.8^{d}	37.0^{c}	5.91^{a}	2.41^{bc}	5.74^{ab}	3.50^{a}	3.4
Danbred HD	831^{c}	24.9^{a}	43.5^{a}	5.75^{cd}	2.33^{c}	5.81^{ab}	3.45^{ab}	3.4
Duroc	885^{a}	28.7^{c}	39.6^{b}	5.85^{ab}	3.03^{a}	5.65^{a}	3.38^{ab}	3.3
Hampshire	849^{bc}	25.7^{a}	42.5^{a}	5.70^{d}	2.57^{b}	5.86^{ab}	3.36^{ab}	3.4
NGT Large White	849^{bc}	29.7^{cd}	36.3^{c}	5.84^{ab}	2.15^{c}	6.09^{c}	3.16^{c}	3.4
NE SPF Duroc	894^{a}	28.2^{bc}	41.0^{ab}	5.88^{ab}	2.71^{ab}	5.78^{ab}	3.36^{ab}	3.4
Newsham Hybrid	863^{ab}	24.9^{a}	41.6^{a}	5.82^{bc}	2.25^{c}	6.12^{c}	3.25^{bc}	3.3
Spot	835^{c}	31.5^{d}	37.6^{c}	5.83^{bc}	2.35^{c}	5.91^{bc}	3.16^{c}	3.3
Yorkshire	835^{c}	26.7^{ab}	39.8^{b}	5.84^{ab}	2.33^{c}	6.13^{c}	3.26^{bc}	3.4

Means in the same column with different superscripts differ (P<.05)

[1] Higher values = more tender and juicier.

Table 3. Influence of proportion of Duroc genes on carcass and eating quality. (from Meat and Livestock Commission, 1991)

Percentage Duroc	0	25	50	75	Approx. LSD[a]
P2 backfat depth (mm)	10.2	11.2	11.7	12.8	.59
Intramuscular fat, (%)	.70	.86	1.08	1.27	.10
Carcasses judged PSE (%)	8.3	5.4	1.6	0.1	4.20
Taste panel[b]:					
Tenderness	4.96	5.03	5.32	5.38	.25
Juiciness	4.09	4.11	4.18	4.38	.17
Pork flavor	3.88	3.99	3.96	3.98	.12

[a] Least significant difference between means, $P<.05$
[b] Evaluated using an 8-point scale; lower values = poorer quality.

1.2.1. The Halothane Gene

This is so-called because animals homozygous for the recessive form of the gene show a distinctive response when exposed to the anaesthetic gas halothane which is characterized by muscle rigidity and hyperthermia. The halothane gene is of interest because it influences all aspects of the production and marketing chain with both beneficial and deleterious effects. The gene is being exploited in commercial programs with, most commonly, heterozygous carrier animals being produced as the slaughter generation.

The benefits and disadvantages of producing Halothane carrier progeny can be illustrated by the results of a recent study carried out at the University of Illinois (Leach et al., 1996). In this trial, a Halothane carrier sire line was mated to a negative female line resulting in both Halothane carrier and negative progeny being produced within the same litter. This allows the effects of the gene to be evaluated against the same genetic background. Halothane carriers had a number of advantages over negative animals, including better feed efficiency, improved carcass yield, and increased carcass lean content (Table 4). However, carriers had poorer muscle color and water holding capacity (Table 4) which would offset any growth and carcass advantage. Interestingly, the eating quality of the carrier and negative

animals in the study of Leach et al. (1996) was similar (Table 4). However, other studies have shown a negative effect of the Halothane gene on palatability traits (Boles et al., 1991). The economic advantages and disadvantages of the Halothane gene will, to a certain extent, balance and its net effect on the overall economics of pork production may be negligible. In addition, because of the increasing importance of quality to the swine sector, a number of national industries and breeding programs have decided to eliminate the gene.

Table 4. Within-litter comparison of Halothane carrier and negative pigs. (from Leach et al, 1996)

	Carrier	Negative	Av.SE	Sig[a]
Average daily gain, g	974	964	16.9	NS
Gain:Feed	.36	.33	.005	**
Dressing percentage	75.3	74.4	.29	***
Weight of fat-free lean in the side, kg	24.7	23.9	.35	*
Longissimus:				
pH (45 min)	6.4	6.6	.05	***
Minolta L*	45.7	42.0	1.03	***
Drip loss, %	5.2	3.4	.43	***
Shear force, kg	3.4	3.4	.17	NS
Juiciness[b]	7.3	7.6	.27	NS
Tenderness[b]	9.1	9.2	.30	NS

[a] NS, *, **, *** = not significant, P<.05, P<.01, P<.001, respectively.
[b] Taste panel scores from 0 = extremely dry and tough to 15 = extremely moist and tender.

1.2.2. The Rendement Napole Gene

Another single gene that has been shown to affect meat quality is the Rendement Napole (RN) gene, which is also referred to as the Napole or Acid Meat gene or the Hampshire effect, because its effects have only been observed in purebred and crossbred Hampshire pigs, or commercial lines with Hampshire ancestry. Historically, breed comparison involving the Hampshire have generally shown low ultimate pH values for this breed in comparison with others (Sayre et al., 1963). More recently, a comparison of terminal sire breeds and lines carried out by NPPC also showed this phenomenon in US Hampshire populations (Table 2; NPPC, 1995). Monin and Sellier (1985), working with Hampshire populations in France, were the first to show that the low ultimate pH or acid meat was the result of elevated glycogen and glycolytic potential levels in the muscle. Glycolytic potential (GP) is an index of the potential of the muscle for glycolysis and it is calculated from the concentrations of glycogen, glucose-6-phosphate, glucose, and lactate within the muscle.

The GP of Hampshires is elevated compared to other breeds (Monin and Sellier, 1985) resulting in an extended decline in pH post mortem, producing an abnormally low ultimate pH and the so-called acid-meat condition. At these low pH levels, the muscle approaches its isoelectric point at which there are no electric charges on the muscle proteins and, consequently, the water holding capacity of the muscle is dramatically reduced. Evidence suggests that the high GP levels are the result of a single dominant gene. The dominant allele, which produces the acid-meat condition, is designated RN^- and the recessive allele is designated rn^+.

The net effect of the RN^- allele is to increase drip, purge, and cooking losses and reduce curing and processing yields. In addition, muscle color is generally paler for high GP compared to low GP animals. However, the RN^- allele also has positive effects on quality with a number of studies showing a reduction in shear force and improvements in tenderness and juiciness for animals with high GP (genotypes RN^-RN^- and/or RN^-rn^+) compared to low GP pigs (genotype rn^+rn^+). High GP animals also seem to have small advantages in growth rate, backfat thickness, loin eye area, and carcass lean content compared to those with low GP. Thus, the RN gene has both positive and negative effects with the major trade-off being between reduced water holding capacity and improved eating quality. In practice, this gene may be exploited in situations where a high eating quality product is desired but eliminated from populations where the meat is principally used for cured and processed products.

Estimates of the frequency of the dominant allele (RN^-), which have largely been derived in European populations, have generally been high (between 0.5 and 0.7). A recent study involving samples of pigs from US Hampshire breeders, produced an estimate of the frequency of the RN^- allele of 0.64 (Miller, 1998), which is within the range found in European populations.

Because this is a dominant gene, the RN^- allele can be eliminated by using only homozygous recessive animals (rn^+rn^+) as replacement breeding stock. However,

the only method currently available to identify these animals is using glycolytic potential values determined on a biopsy muscle sample taken in the live animal. Several research groups are trying to identify the specific gene involved and eventually develop a DNA-based test to genotype animals. The RN gene has been localized to an area of chromosome 15 and a number of markers linked to the RN locus have been reported (Mariani et al., 1996), but to date the specific gene has not been located.

1.3. Association Between Pork Quality and Carcass Leanness

The swine industry has been remarkably successful at reducing backfat levels and increasing carcass lean content. For example, in the United Kingdom average backfat thickness levels, measured at the P2 position, have been halved over the last 20 years, being reduced from above 20 mm to current levels of approximately 11 mm (MLC, 1997). Similar trends have been observed in other countries although the extent of the decline has often been less extreme. Improvements in carcass leanness have been achieved through a combination of genetic selection, improved nutrition and, in the case of the UK, the use of entire males.

Programs to reduce carcass fat levels have been so successful that the question "Are pigs too lean" has frequently been asked, and there are major concerns within the meat sector that the quality of pork from lean carcasses is inferior, particularly in terms of palatability attributes. Intramuscular fat levels (IMF) decline with increasing carcass leanness and can be very low in lean carcasses (less than 1%) and there is a general belief that eating quality and IMF are positively related.

What evidence is there that eating quality is negatively associated with carcass leanness? As previously discussed, circumstantial evidence available to suggest that breeds and lines with low carcass and intramuscular fat levels produce tougher, drier meat (Tables 1 and 2). However, as already pointed out, there are other aspects that affect meat quality that also differ between breeds and thus confound any evaluation of the association between IMF and quality. Wood et al. (1986) compared lean (8 mm P2 backfat) and fat (16 mm P2 backfat) pigs and showed a small difference in taste panel juiciness scores in favor of the fatter animals but little difference in tenderness or other palatability traits (Table 5). However, the IMF content of pigs in this study was low, being under 1% even for the fatter carcasses. The threshold model for the effect of IMF on eating quality that has previously been discussed (Bejerholm and Barton-Gade, 1986; DeVol et al., 1988) suggests that a minimum of 2 to 3% IMF is required for optimum palatability. However, the study of Bejerhom and Barton-Gade (1986) used different genotypes to create the range of IMF levels to investigate associations with eating quality and DeVol et al. (1988) selected pigs of different IMF levels from the slaughter line. Therefore, in both of these studies the level of IMF was confounded with other factors, particularly genotype, and it is not certain if this same threshold level for IMF exists within a breed or genetic line.

Relatively few studies have investigated the genetic correlations between carcass lean and eating quality. However, estimates of the genetic correlations between backfat thickness and IMF on the one hand and palatability traits on the other have generally been unfavorable suggesting that genetic selection for improved carcass lean content will produce a correlated reduction in pork tenderness and juiciness.

The relationship between IMF and pork palatability is, therefore, not clearly established. There is some interest in selecting for higher levels of IMF; however, there are no techniques currently available to do this in the live animal. There are reports that suggest that there may be single genes that have a large effect on IMF levels and ultimately it may be feasible to select for these using a DNA-based test. However, todate none of these genes have been identified.

Table 5. Influence of backfat thickness on eating quality of pork loin chops. (from Wood et al., 1986).

	Backfat thickness (P2, mm)		
	Lean (8)	Fat (16)	SED[a]
Intramuscular fat (%)	.55	.96	0.37***
Tenderness[b]	1.0	1.1	.37
Juiciness[b]	1.0	1.3	0.7**
Flavor liking[b]	1.5	1.7	.15
Pork flavor[b]	.6	.9	.14
Overall acceptability[b]	.7	1.0	.23

[a] Standard error of the difference (SED); *, **, *** = P<.05, P<.01; P<.001 respectively.
[b] Evaluated using a 15 point scale; -7 to +7; lower values = poorer quality.

2. Nutritional Influences on Quality

2.1. Vitamin and Minerals

2.1.1. Vitamin E and Selenium

A major cause of deterioration in the quality of meat during storage is lipid

oxidation which can result in a number of undesirable changes and reduce the shelf-life of pork. These changes include the development of oxidative rancidity and an associated increase in unpleasant odors and flavors. In addition, the deterioration of fresh pork color during aerobic storage has been attributed to oxidative changes in the chemical form of muscle pigments; myoglobin can be converted into metmyoglobin producing a dull brown muscle color which is less attractive to the consumer. This color change is particularly important for ground products, such as sausage, where a greater surface area is generally available for oxidation to take place. It has also been proposed that oxidation of the phospholipids in the cell membranes disrupts cell wall integrity and can reduce water holding capacity. The unsaturated fatty acid content of body fat, including the phospholipids in membranes, is very closely related to the composition of the dietary fat and can therefore be readily manipulated by altering the dietary fat source (see section 2.2). One approach to reducing the impact of oxidation on product appearance is to use vacuum or modified atmosphere packaging and storage, which exclude or displace oxygen and limit oxidation.

Another potential approach to reducing oxidation in pork and improving shelf-life and quality is to use antioxidants and the feeding of high levels of vitamin E to pigs and other species has been widely investigated. In growing-finishing pigs, the NRC (1998) recommended that the dietary requirements for vitamin E to prevent deficiency symptoms is 11 mg/kg of feed of DL-a-tocopherol; however, increased levels of 30 mg/kg or higher are recommended in situations where relatively high levels of unsaturated fatty acids are fed (Ullrey, 198l). However, there has been considerable interest in pigs, as well as in cattle and sheep, in feeding much higher levels of supplementary vitamin E to prevent deterioration in meat quality during storage associated with lipid oxidation discussed above.

Jensen et al. (1998) summarized the results of 14 studies that investigated the impact of feeding high levels of vitamin E (within the range of 100 to 800 mg/kg of feed of DL-a-tocopherol) to growing-finishing pigs. These studies used chops, steaks and/or ground pork products and employed a range of storage times and conditions post mortem. All of the studies that measured muscle vitamin E levels showed a dose-dependent increase and a significant reduction in lipid oxidation from feeding high vitamin E levels. The effects of vitamin E feeding on pork color and water holding capacity were, however, more variable. For example, Jensen et al. (1997) found no effect of feeding vitamin E at levels up to 700 mg/kg on muscle color and drip loss despite the fact that muscle vitamin E levels were increased and lipid oxidation was decreased by the elevated dietary vitamin E treatments. Asghar et al. (1991) found that the surface redness of the muscle (measured by Hunter a* values) was increased and the drip loss from frozen pork chops upon thawing was decreased by feeding 200 mg of a-tocopherol acetate per kg of feed compared to the controls (10 mg/kg); the color and drip loss of muscle from pigs fed 100 mg/kg feed was intermediate between the other two treatments but not statistically different from the controls.

Two recent studies that have investigated the effect of vitamin E on water

holding capacity are summarized in Table 6. The study of Cheah et al. (1995) showed a significant reduction in drip loss from feeding 500 mg/kg of feed of supplementary vitamin E for 46 days prior to slaughter for both Halothane negative and carrier animals. In contrast, Cannon et al. (1996) fed 100 mg/kg of feed of supplementary vitamin E for an 84 day period prior to slaughter and showed no effect on muscle color or drip loss for storage periods of up to 56 days post mortem. An obvious explanation for the difference in response observed in these two studies is the lower level of vitamin E used by Cannon et al. (1996) and these authors suggested that the lack of response may have resulted from the low a-tocopherol concentrations found in the muscle of treated pigs. Obviously, the response to dietary vitamin E supplementation will depend on the level fed and the time of feeding and may actually vary depending on the response criterion used.

Another nutrient that is involved in reducing lipid oxidation in the cell membrane is selenium, which is a component of the enzyme glutathione peroxidase. This enzyme can remove peroxides from cell membranes and has, therefore, a shared role with vitamin E in reducing cell membrane oxidation. However, there is little experimental evidence to suggest that providing pigs with additional selenium above that required to prevent deficiency symptoms shows any benefit in terms of meat quality.

2.1.2. Vitamin D_3

Recently, there has been considerable interest in feeding high levels of vitamin D_3 to cattle to improve tenderness (Swanek et al., 1997). It has been suggested that such an approach results in an increase in muscle calcium levels which stimulate proteolytic enzyme activity post mortem and improve meat tenderness. A preliminary study was carried out at the University of Illinois to investigate the impact of feeding high levels of vitamin D_3 (331 vs 55,000 vs 175,000 IU/kg) to finishing pigs during the final 10 days prior to slaughter (Enright et al., 1998). This study failed to show any beneficial effects of feeding vitamin D_3 on palatability traits; however, drip loss was reduced and muscle color was darker for treated animals relative to controls (Table 7).

Table 6. Impact of dietary Vitamin E supplementation on drip loss from longissimus chops.

Study	Supplementary Vitamin E level (mg/kg)	Other Treatment	Drip Loss (%)	
			Control	Supplemented
Cheah et al., 1995	500	Halothane genotype:		
		Negative	6.9	3.2
		Carrier	9.1	5.0
Cannon et al., 1996	100	Days of storage:		
		0	5.01	4.76
		14	3.81	3.30
		28	2.96	2.68
		56	2.35	2.40

Table 7. Impact of feeding high levels of vitamin D_3 for 10 days prior to slaughter.

Vitamin D_3 level	Low	Moderate	High	SE mean	SIG [1]
Vitamin D_3 ('000 IU/kg)	.331	50.040	175.000		
Ultimate pH	5.50	5.53	5.47	.0386	NS
Subjective color	2.08[a]	2.72[ab]	3.08[b]	.198	**
Hunter L*	54.58	52.49	51.20	1.018	NS (P<.07)
Hunter a*	6.33	6.43	6.54	2.05	NS
Hunter b*	16.69[a]	15.99[ab]	15.64[b]	.209	**
Drip loss, %	4.39[a]	3.21[ab]	2.04[b]	.593	*

Enright et al., 1998
[1] NS, *,** = not statistically significant, P<.05, P<.0l, respectively.
[a,b] Means in some row with different superscripts differ (P<.05)

2.2. Fat Nutrition and Fat Quality

Fat quality is largely defined in terms of physical and nutritive characteristics, aspects which are both closely related to the fatty acid composition of the fat depots. In the pig, many of the fatty acids in the diet are absorbed across the gut intact and are deposited directly into the fat. Thus, the composition of the fat depots, in terms of fatty acid profile, is closely related to the fatty acid composition of the dietary fat. If pigs are fed a diet with no added fats or oils they synthesize and deposit saturated fatty acids (principally palmitic and stearic) and mono-unsaturated oleic acid (Metz and Dekker, 198l). Deposition of polyunsaturated fatty acids (principally C18:2 and C18:3) occurs only if they are included in the diet.

The major issues relating to fat quality are soft fat, oxidative rancidity, and the impact of the composition of pork fat on human health. These issues are receiving increasing attention in the US industry because of the significant changes in production practices and consumer requirements that have occurred over recent years.

Soft fat is of major concern to the meat processor because it can cause significant problems during cutting, grinding and slicing operations and can result in lower processing yields and reduced value. For example, Shackleford et al. (1990) fed corn-soy diets with 0 (control) or 10% of either beef tallow, safflower oil, sunflower oil, or canola oil and showed a significant reduction in fat firmness for pigs fed the oil containing diets relative to controls. In addition, belly slicing yields and the bacon flavor and overall palatability ratings were lower for pigs fed canola oil.

The softness of fat is directly proportional to the amount of unsaturated fatty acids in the fat depot. This area is receiving increasing attention because of changes in the genetics of pigs and in feed ingredients used to formulate swine rations. Soft fat problems are relatively greater in leaner pigs which have a greater proportion of the fatty acids in the carcass fat derived from the diet and a smaller proportion from *de novo* synthesis of fatty acids by the animal. This is illustrated by the results of a UK study (Wood et al., 1989, Table 8) that compared the composition of the backfat in pigs with different carcass fat levels and showed that leaner pigs had a higher proportion of polyunsaturated fatty acids (C18:2 and C18:3).

Table 8. Influence of backfat thickness on composition of backfat.

Components	Average P2 fat thickness (mm)			SE of differences and overall significance	
	8	12	16		
Water	22.36	17.08	14.06	0.560	***
Lipid	69.25	77.00	81.59	0.726	***
Collagen	4.49	2.98	2.04	0.140	***
Myristic (C14:0)	1.49	1.51	1.49	0.021	ns
Palmitic (16:0)	24.55	25.41	25.87	0.181	***
Palmitoleic (C16:1)	2.78	2.66	2.69	0.065	NS
Stearic (C18:0)	13.15	13.83	13.91	0.215	***
Oleic (C18:1)	40.34	42.83	43.11	0.307	***
Linoleic (C18:2)	14.94	12.38	10.65	0.368	***
Linolenic (C18:3)	1.11	0.89	0.84	0.043	***

Wood et al., 1989
NS, *** = not statistically significant, P<0.00l, respectively.

The inclusion of fat supplements in corn-soy diets is increasing due to the economic competitiveness of certain fats relative to corn on a cost per unit of energy basis and also to suppress dust levels within swine buildings. Also, there is increased use of high-oil corn in swine rations and there is concern over the potential for this change to impact fat quality. All of these developments will result in an increase in the proportion of unsaturated fatty acids in the fat depots of the pig and increase the likelihood of soft fat problems.

The unsaturated fatty acid that is of major concern is linoleic acid (C18:2), which is at a relatively high concentration in conventional feedstuffs and fat sources used in pig diets. Linoleic acid is not synthesized by the pig or significantly modified before being deposited in the fat depot. This means that all of the C18:2 in pig fat is derived directly from the diet. The fatty acid profile of the fats and oils commonly used as feed ingredients for pigs is summarized in Table 9. Vegetable oils are generally higher in unsaturated fats than animals fats, particularly C18:2, and the inclusion of these in rations will obviously increase the degree of unsaturation in the fat depots and increase the likelihood of fat quality problems.

Table 9. Fatty acid composition of fats and oils

Type of Lipid	Selected fatty acids (% of total fatty acids)										Tot. Sat	Tot. Unsat	U:S[1] ratio	Iodine Value
	<C10	C12:0	C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	>C20				
Animal Fats:														
Beef tallow	0.1	0.9	2.7	24.9	4.2	18.9	3.1	0.6	0.6	0.3	52.1	47.9	0.92	44
Choice White Grease	0.2	0.2	1.9	21.5	5.7	14.9	11.6	0.4	0.4	1.8	40.8	59.2	1.45	60
Lard	0.1	0.2	1.3	23.8	2.7	13.5	10.2	1.0.	1.0	1.0	41.1	58.9	1.44	64
Poultry Fat	0.0	0.1	0.9	21.6	5.7	6.0	19.4	1.0	1.2	1.2	31.2	68.8	2.20	78
Restaurant Grease	-	-	1.9	16.2	2.5	10.5	17.5	1.9	1.0	1.0	29.9	70.1	2.34	75
Fish Oils:														
Anchovy	-	-	7.4	17.4	10.5	4.0	11.6	1.2	0.8	30.3	34.6	65.4	1.89	-
Herring	-	0.2	7.1	11.7	9.6	0.8	11.9	1.1	0.8	45.6	22.8	77.2	3.39	-
Menhaden	-	0	8.0	10.5	10.5	3.8	14.5	2.1	1.5	29.5	33.3	66.7	66.7	-
Vegetable Oils:														
Canola (Rapeseed)	0.0	0.0	0.0	4.0	0.2	1.8	56.1	20.3	9.3	3.6	7.4	92.6	12.4	117
Coconut	14.0	44.6	16.8	8.2	0.0	2.8	5.8	1.8	0.0	-	91.9	8.1	6	10
Corn	0.0	0.0	0.0	10.9	0.0	1.8	24.2	59.0	0.7	-	13.3	86.7	0.09	125
Cottonseed	0.0	0.0	0.8	22.7	0.8	2.3	17.0	51.5	0.2	0.1	27.1	72.9	6.53	105
Olive	0.0	0.0	0.0	11.0	0.8	2.2	72.5	7.9	0.6	0.3	14.1	85.9	2.69	86
Palm	0.0	0.1	1.0	43.5	0.3	4.3	36.6	9.1	0.2	0.1	51.6	48.4	6.08	50
Peanut	0.0	0.0	0.1	9.5	0.1	2.2	44.8	32.0	-	6.4	17.8	82.2	0.94	92
Safflower	0.0	0.0	0.4	6.2	0.4	2.3	11.7	74.1	0.4	-	9.5	90.5	4.63	140
Sesame	0.0	0.0	0.0	8.9	0.2	4.8	39.3	41.3	0.3	0.2	14.8	85.2	9.52	110
Soybean	0.0	0.0	0.1	10.3	0.2	3.8	22.8	51.0	6.8	0.2	15.1	84.2	5.73	130
Sunflower	0.0	0.0	0.0	5.4	0.2	3.5	45.3	39.8	0.2	-	10.6	89.4	5.64 8.47	133

NRC, 1998

[1] Unsaturated to saturated fatty acid ratio.

A measure of the degree of unsaturation of fats, both dietary and within the body, is the Iodine Value (IV), with higher values indicating a greater proportion of unsaturated fats. Boyd (1997) investigated the relationships between dietary fatty acid profile and the fatty acid profile and IV of backfat. The relationship between dietary linoleic (C18:2) content and the IV of the backfat was linear (Figure I- em anexo), with IVs increasing from approximately 65 to 76 for diets containing 1.3 and 3.5% of C18:2, respectively.

Threshold levels for body fat composition for soft fat problems have not been clearly established. The Danes have set a fairly rigid standard of a maximum body fat IV of 70 (Barton-Gade, 1987). Boyd (1997) suggested that some pigs fed a corn-soy diet with no added fat would exceed this threshold. To prevent problems occurring, dietary specifications in Europe generally include a maximum inclusion level for C18:2 which is commonly set at around 1.6% of the diet for finisher rations. Boyd (1997) has suggested a less stringent IV threshold of 74 for US conditions and a dietary linoleic acid maximum of 2.10% to meet this threshold.

An area that has received relatively little attention is the relationship between the composition of pig fat and the eating quality of pork, particularly in terms of odor and flavor. Historically, major problems in this respect were experienced with feeding fish oils or fish meals with a relatively high oil content and the associated development of fishy taints in the meat. Fish oils are generally high in polyunsaturated fatty acids such as C20:5 and C22:6 (Irie and Sakimoto, 1992) that are very susceptible to oxidative rancidity and the development of off-flavors.

The relationship between fatty acid composition of intramuscular fat and the palatability of pork was investigated by Cameron and Enser (1991) who showed that the correlations between the concentration of specific fatty acids and eating quality traits were generally weak (Table 10). However, correlations involving polyunsaturated fatty acids and palatability scores were generally negative and those for the saturated fatty acids were generally positive suggesting that the higher the degree of unsaturation in the IMF, the poorer the eating quality. A possible explanation for this is the increased level of oxidation and development of rancidity for fat that is high in unsaturated fatty acid.

One of the consequences of the close relationship between the composition of dietary and body fat is that it is relatively easy to manipulate fat composition by changing the fat source fed to the pig. In the human, the consumption of high levels of saturated fat has been associated with an increasing incidence of coronary heart disease and a number of studies have investigated the potential for increasing the concentrations of “healthier” fatty acids in pig fat by including them in the diet.

Table 10. Correlations between the fatty acid composition of the intramuscular fat and pork eating quality.

	Fatty Acid									
Traits	**14.0**	**16.0**	**16.l**	**18.0**	**18.1**	**18.2**	**18.3**	**20.4**	**22.5**	**22.1**
Tenderness	0.14	0.13	0.17	-0.04	0.19	-0.21	0.05	-0.20	-0.23	-0.17
Juiciness	0.15	0.05	0.08	0.04	0.09	-0.06	0.23	-0.20	-0.23	-0.16
Flavour	0.11	0.08	0.21	0.06	0.19	-0.19	-0.10	-0.19	-0.23	-0.21
Overall acceptability	0.19	0.12	0.17	0.01	0.19	-0.20	0.15	-0.26	-0.28	-0.21

Cameron and Enser, 1991
Positive correlations represent favorable relationships.
Negative correlations represent unfavorable relationships.

Of particular interest have been the so-called omega-3 fatty acids that have been associated with a beneficial effect on cardiovascular diseases. Feed sources that are rich in omega-3 fatty acids include fish oils and certain vegetable oils such as flaxseed and linseed. Including these feedstuffs in diets for pigs has led to an increase in omega-3 fatty acid concentrations in the fat depots of the animal but have also been associated with adverse effect on flavor in some studies probably as a result of lipid oxidation (Romans et al., 1995a, 1995b).

Another issue receiving increasing attention is that of the effects of dietary conjugated linoleic acid (CLA) on growth, carcass and meat quality characteristics. This fatty acid is found at a relatively high level in dairy products and has been shown to increased feed conversion efficiency and decrease carcass fat content in laboratory animals (Chin et al., 1994). There has been little published on the effects of CLA on growth and meat quality in pigs. Duggan et al. (1997) fed diets either 2% CLA or 2% sunflower oil from 61.5 to 106 kg liveweight and found a reduction in feed intake (-5.2%), improved feed efficiency (5.9%), reduced subcutaneous fat levels (-6.8%) and similar growth rates for pigs fed CLA compared to those fed sunflower oil. Thiel et al. (1998) showed improvements in daily gain, feed efficiency and carcass fat levels from feeding between 0.12 and 1.0% CLA to pigs between 26.3 and 116 kg liveweight. In addition, belly hardness increased linearly as the concentration of CLA in the diet increased, suggesting an improvement in fat quality due to CLA inclusion. Further research is required to validate the effect of CLA on fat quality, and investigate its effect on palatability traits.

2.3. Feeding Level and Dietary Protein:Energy Ratio Effects

A number of studies carried out in the United Kingdom have shown an eating quality advantage for pigs reared under ad libitum compared to restricted feeding. The results from two of these studies are presented in Table 11. The feeding regimes were imposed between approximately 30 to 85 kg live weight in the case of the Warkup et al. (1990) and from 30 kg to between 80 and 120 kg in the study of Ellis et al. (1996). The degree of feed restriction imposed was similar in both trials at approximately 82% of ad libitum intake. The results of these studies (Table 11) suggest a small but significant improvement in tenderness and juiciness from ad libitum feeding. The mechanism for any improvement in palatability resulting from ad libitum feeding has not been established but could result from the improved growth rate and/or increased intramuscular fat levels in ad libitum compared to restrict fed animals. Warkup and Kempster (1991) proposed a theoretical model in which increases in intramuscular fat levels and/or lean growth rates are associated with improvements in tenderness and juiciness. This model has not been validated but raises an issue over the extent to which eating quality can be improved by manipulating the growth curve of the animal.

There is concern that the low levels of IMF in some of the genetically lean lines of pigs result in reduced palatability of pork. In the short term, the easiest method to

increase IMF levels is via nutrition and a number of studies have shown substantial increases in intramuscular fat from feeding protein-deficient diets to pigs (Table 12). However, most of these trials were carried out during both growing and finishing phases and the protein-deficient diets also produced substantial increases in carcass fat levels and reductions in feed efficiencies and would be uneconomic in most situations. The impact of short-term feeding of protein-deficient diets on IMF levels is less well established. Cisneros et al. (1996) produced a 2 percentage units increase in IMF from feeding a protein-deficient diet for approximately 5 weeks prior to slaughter (Table 12). In a follow up study, Cisneros et al. (1998) investigated the interaction between the level of lysine deficiency and time of feeding of protein deficient diets on longissimus IMF. The results of this study suggested that a minimum feeding period of 5 weeks was required to elicit a consistent response in IMF and that there was an optimum level of lysine deficiency to produce the maximum response (Figure 2 – em anexo). Feeding protein levels above or below this optimum resulted in a reduction in the level of IMF within the muscle. In this study, pigs on the lowest level of protein (0.4%) had a reduced feed intake relative to the other treatments and this is the probable explanation for the relatively modest response in IMF for this treatment.

Table 11. Effect of ad libitum and restricted feeding regimens on eating quality.

	Advantage of ad libitum over restricted feeding [1]	
Trait	**Trial A[a]**	**Trial B[b]**
Tenderness	0.30***	0.47*
Juiciness	0.26***	0.19*
Flavor	.00	-0.05
Odor	0.12	0.02
Overall acceptability	0.19***	

[1] 8-point scale; lower values = poorer quality
*, *** = P<.05, P<.00l, respectively
[a] Source: Ellis et al., 1996
[b] Source: Warkup et al., 1990

Table 12. Influence of feeding protein deficient diets on intramuscular fat content of the longissimus.

Dietary protein/lysine level (%)		Intramuscular fat (%)		Weight range (kg)	Source
Adequate	Deficient	Adequate	Deficient		
18.5-0.96	13.l-0.64	l.5	2.5	to 103	Essen-Gustavsson et al., 1994
17.6-0.81	11.9-0.48	1.4	3.5	25 - 98	Castell et al., 1994
25.0	10.0	3.4	9.4	30 - 90	Goerl et al., 1995
16.0-0.82	12.0-0.55	5.5	11.2	10 - 100	Kerr et al., 1995
20.5-1.05	16.6-0.70	1.2	2.4	39 - 90	Blanchard et al., 1998
14.0-0.56	10.0-0.40	3.8	5.7	80 - 110	Cisneros et al., 1996

2.4. Feed Withdrawal Prior to Slaughter

Denying pigs access to feed for a period of time prior to slaughter has a number of potential advantages. The stomach is relatively empty at slaughter and consequently the incidence of stomach punctures during the evisceration process and, therefore, the potential for carcass contamination by gut contents should be reduced. In addition, it may be possible to lower the glycogen content of muscles at slaughter and increase ultimate pH values, which is likely to improve pork quality attributes.

The impact of feed withdrawal prior to slaughter has been investigated in a series of studies carried out at the University of Illinois which have used pigs with high and low glycolytic potential resulting from the Rendement Napole gene. Pigs that carry the dominant allele of this gene (RN^-RN^- or RN^-rn^+) have elevated muscle glycogen levels and might be expected to respond differently to feed withdrawal compared to animals that are homozygous recessive at this locus (rn^+rn^+) and have normal, lower muscle glycogen levels. In the first of these studies (Bidner, 1998; unpublished data), pigs with high (RN^-rn^+) and low (rn^+rn^+) glycolytic potential were held off feed for 12, 36 and 60 hours before slaughter. Pigs from the three feed withdrawal treatments were mixed during transport and in the lairage prior to slaughter. The results from this study are presented in Table 13. Withdrawing feed for 36 or 60 hours resulted in an increase in muscle pH and improvements in muscle color for animals with low (rn^+rn^+) but not with high (RN^-rn^+) glycolytic potential. There was a numerical improvement in purge and drip loss for pigs with low glycolytic potential on the 36 and 60 hour treatments (Table 13). Apparently, starving animals with high glycolytic potential did not reduce muscle glycogen to a level low enough to impact muscle pH.

Table 13. Influence of pre-slaughter feed withdrawal on longissimus muscle quality in pigs with low (rn^+rn^+) and high (RN^- rn^+) glycolytic potential - Study I.

Glycolytic potential	Low			High				
Time off-feed (hours)	12	36	60	12	36	60	SE	SIG
Ultimate pH	5.45[a]	5.59[b]	5.65[b]	5.36[a]	5.34[a]	5.36[a]	.02	*
Purge Loss, %	4.10	2.46	2.37	4.48	4.66	4.05	.33	NS
Drip Loss, %	4.17	3.11	3.50	5.49	6.22	5.25	.30	NS
Hunter L*	55.54[a]	53.08[b]	51.76[b]	55.33[a]	55.55[a]	55.48[a]	.45	*

(Bidner, 1998; unpublished data)
NS, * = not statistically significant, $P<.05$
[a, b] means within rows with different superscripts differ

In a further study (Bidner, 1998; unpublished data), pigs with high and low glycolytic potential were held off-feed for periods of 12 or 36 hours prior to slaughter. Pigs remained in their farm groups and were not mixed with unfamiliar pigs prior to slaughter. The longer period of feed withdrawal produced no change in muscle pH or any of the quality attributes for pigs with low and high glycolytic potential (Table 14). These results are in contrast to those described earlier (Table 13) where pigs were mixed with unfamiliar animals and suggest that some form of additional stress is required to reduce muscle glycogen and levels and improve meat quality. These two studies show that genotype and animal handling factors interact to determine the response in pork quality to feed withdrawal.

In addition, prolonged periods of feed withdrawal are associated with loss of carcass weight and a reduced return in situations where animals that are paid for on a dead weight basis. Dressing percentage (i.e. carcass weight expressed as a percentage of slaughter live weight) is actually increased by removing feed from pigs prior to slaughter as a result of losses of gut fill and offal weight, particularly a reduction in liver weight. This is illustrated by the results from the first study from the University of Illinois described above where dressing percentage was increased from 68.9 to 74.2 % for pigs held off feed for 12 and 60 hours, respectively (Table 15). However, European research has shown that carcass weights start to decline after about 9 to 18 hours of starvation and Warriss and Brown (1983) predicted that between 18 and 48 hours of starvation the rate of loss was to equivalent to 0.11 % of carcass weight per hour.

An interesting finding in relation to feed withdrawal prior to slaughter has emerged from recent research carried out at the University of Illinois that investigated eating behavior in growing-finishing pigs (Hyun et al., 1997). This study showed that in uncrowded situations, pigs consumed relatively little feed during the night time between 6.00 pm and 6.00 am. This suggests that if pigs are despatched for slaughter early in the morning then the majority will not have fed for approximately 12 hours. If, however, pigs are crowded or the environmental temperature is high then feeding is likely to continue during the night time.

Table 14. Influence of pre-slaughter feed withdrawal on longissimus muscle quality in pigs with low and high glycolytic potential - Study 2.

Glytolytic potential	Low (rn^+, rn^+)		High (RN^-, rn^+)			
Time off feed (hours)	12	36	12	36	SE	SIG
Ultimate pH	5.48	5.51	5.46	5.42	.01	NS
Drip loss, %	7.32	6.94	7.31	7.96	.33	NS
Hunter L*	55.3	54.4	52.5	53.2	.36	NS
Minolta L*	50.2	48.9	46.9	48.5	.41	NS

(Bidner, 1998; unpublished)
NS = not statistically significant.

Table 15. Influence of pre-slaughter feed withdrawal on dressing percentage and ulcer score - Study I

Time off feed (hours)	12	36	60	SE of means	SIG
Slaughter wt, kg	114.28^a	108.85^b	106.49^b	1.07	**
Carcass wt, kg	78.72^a	79.3^a	78.95^a	.93	NS
Dressing, %	68.94^a	72.85^b	74.22^b	.59	***
Live wt.loss, %	0^a	4.35^b	6.38^c	.30	***
Ulcer score*	0^a	0.96^b	1.44^c	.69	***

(Bidner, 1998; unpublished data).
[1] Three point scale: 0 = normal, 1 = Keratinized 2 = Eroded 3 = Ulcerated.

2.5. Other Compounds

A number of other dietary components have been reported to improve meat quality. Two recent studies have highlighted the potential to improve meat quality through nutritional approaches immediately prior to slaughter that modify post-mortem glycolysis. A study carried out in Australia has shown a large effect on pork quality of feeding magnesium aspartate to pigs for 5 days prior to slaughter (D'Souza et al., 1998) in terms of reduced drip loss, improved color and a lower incidence of the PSE condition for treated animals compared to controls (Table 16). Magnesium reduces plasma cortisol and catecholamine concentrations and may act to reduce the animal's glycolytic response to pre-slaughter stress. Similarly, Kremer et al. (1998) showed that feeding sodium oxalate to pigs for 4 hours immediately pre-slaughter slowed the decline in pH postmortem and decreased water loss from the muscle

during a 12-day storage period. Sodium oxalate inhibits the action of the enzyme pyruvate kinase and, consequently, reduces the rate of post-mortem glycolysis.

There has also been interest in the administration of oral electrolytes in the last few days prior to slaughter to alter the acid-base balance of the animal. In particular, the use of oral sodium bicarbonate, an alkaline salt, has been evaluated as a technique to reduce the incidence of PSE. One study (Ahn et al., 1992) showed a delayed post mortem pH decline in pigs given sodium bicarbonate orally immediately prior to slaughter. However, this study and that of Boles et al. (1994) failed to show any positive benefit of sodium bicarbonate treatment on pork color or drip loss.

Other reports have suggested that feeding high levels of L-carnitine (up to 300 mg/kg) and niacin (150 mg/kg) may positively impact meat quality (cited by Mordenti and Marchetti, 1996), although further research is required to confirm these findings.

Table 16. The effect of feeding magnesium aspartate and pre-slaughter handling (minimum or negative) on meat quality.

Diet (D)	Control		Magnesium Aspartate					
Handling (H)	Minimum	Negative	Minimum	Negative	SE of Diff	D	H	D*H
PH (40min)	6.60	6.59	6.79	6.69	.074	**	NS	NS
PH (24 hrs)	5.48	5.51	5.61	5.57	0.45	**	NS	NS
Drip loss	4.0	6.4	3.5	3.5	.82	**	*	*
Lightness-L*	48.7	49.1	45.2	47.4	1.11	**	NS	NS
% PSE carcasses	8	33	0	0	-	*	NS	NS

D'Souza et al., 1997.
NS, *, ** = not statistically significant, P<.05, P<.01, respectively.

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SWINE BREEDING, SEX, FEEDING REGIME, AND SLAUGHTER WEIGHT AND THEIR EFFECTS ON CARCASS LEAN YIELD

Mike Ellis

Professor Of Swine Genetics And Management
Department Of Animal Sciences,
University Of Illinois

Introduction

The pressure for producers to improve carcass lean content comes initially from consumers who in most areas of the world increasingly demand lean pig meat products. This has led to the introduction of carcass payment schemes based on lean content in many countries. In addition, the feed energy cost of depositing lean is significantly less than that for depositing fat and, consequently, producing lean carcasses results in an improvement in feed efficiency. This is a win-win situation - lean carcasses cost the producer less to produce and have a greater value because they meet market requirements.

Schemes to improve carcass lean content have been in place in some countries for several years. For example, pricing schemes based on carcass lean have been in operation in the UK for at least 30 years and the average backfat thickness of British pigs, measured at the P2 position, has been halved over the last 25 years from in excess of 20 mm to approaching 10 mm currently. However, carcass fat levels are often higher in other countries with, for example, levels in the US currently averaging approximately 25 mm and some sources in the meat sector has suggested that the optimum level for the US market may be around 18 mm. One point to consider is that even though the commercial optimum may be defined and achieved, there is considerable variation around the optimum in lean contents among carcases from the same population and that a significant proportion of carcasses will invariably be too fat for market requirements and some carcasses may actually be too lean. This is illustrated by UK data, where the current mean P2 fat depth is around 11 mm but the range is from approximately 4 mm to 20 mm. It is important to point out that these measurements of backfat thickness include the skin, and consequently, the extremely lean carcasses have very little subcutaneous fat.

Approaches to Increasing Lean Yield

Broadly speaking, there are three major areas that producers should consider when trying to improve carcass lean content, namely genetics, nutrition and carcass modifiers. The factors to consider each of these areas are outlined in Table I.

Table 1. Approaches to increase lean yield.

A. Genetic Factors
- Variation between breeds and genetic lines
- Single genes (e.g. Halothane gene)
- Sex differences (entire males vs castrates vs. gilts)
B. Nutritional Factors
- Feeding to requirements
- Low energy density diets
- Restrict feeding
C. Carcass Modifiers
- pST
- Beta-agonists
- Chromium picolinate
- Betaine
- Conjugated linoleic acid

A. Genetics Factors Influencing Lean Yield

i. Variation between breeds and genetic lines

There is huge variation both between and within breeds for all aspects of performance, including growth, carcass lean content, and meat quality. This is illustrated in Tables 2 and 3 which summarize recent genotype comparisons carried out in the US. Among US breeds, the Duroc has normally been found to be the fastest growing with the Hampshire generally producing the leanest carcasses (Tables 2 and 3). Over recent years, stock from European breeding companies have been imported into the US because of their high carcass lean content. Two such companies, Newsham Hybrids and Danbred HD, had stock included in the comparison summarized in Table 3.

Table 2. Breed differences in growth, carcass and meat quality (from National Pork Producers Council, 1994).

	Av.daily gain, g	Backfat depth 10th rib (mm)	Loin eye area (cm^2)	Ultimate pH	Intra-muscular fat (%)	Shear force (kg)	Taste Panel[1]	
							Juiciness	Tenderness
Berkshire	754	29.5	32.8	5.90	3.24	5.79	3.1	3.5
Chester White	735	30.5	34.5	5.86	3.13	5.92	3.3	3.4
Duroc	804	27.2	34.2	5.73	4.29	5.90	3.3	3.4
Hampshire	735	23.4	39.7	5.57	2.63	6.19	3.3	3.3
Landrace	754	26.2	36.7	5.67	2.49	6.38	3.1	3.1
Poland China	758	28.7	34.7	5.74	3.22	6.54	3.1	3.0
Spot	740	28.7	34.9	5.72	3.09	6.51	3.0	3.0
Yorkshire	745	26.7	35.4	5.72	2.48	6.39	3.0	3.1

[1] higher values = more tender and juicier.

Table 3. Breed and genetic line differences in growth, carcass and meat quality (from National Pork Producers Council, 1995).

	Av.daily gain, g	Backfat depth 10th rib (mm)	Loin eye area (cm^2)	Carcass lean (%)	Ultimate pH	Intra-muscular fat (%)	Shear force (kg)	Taste Panel[1]	
								Juiciness	Tenderness
Berkshire	840^{c}	31.8^{d}	37.0^{c}	47.0^{c}	5.91^{a}	2.41^{bc}	5.74^{ab}	3.50^{a}	3.4
Danbred HD	831^{c}	24.9^{a}	43.5^{a}	52.0^{a}	5.75^{cd}	2.33^{c}	5.81^{ab}	3.45^{ab}	3.4
Duroc	885^{a}	28.7^{c}	39.6^{b}	49.0^{b}	5.85^{ab}	3.03^{a}	5.65^{a}	3.38^{ab}	3.3
Hampshire	849^{bc}	25.7^{a}	42.5^{a}	51.2^{a}	5.70^{d}	2.57^{b}	5.86^{ab}	3.36^{ab}	3.4
NGT Large White	849^{bc}	29.7^{cd}	36.3^{c}	47.7^{c}	5.84^{ab}	2.15^{c}	6.09^{c}	3.16^{c}	3.4
NE SPF Duroc	894^{a}	28.2^{bc}	41.0^{ab}	49.8^{b}	5.88^{ab}	2.71^{ab}	5.78^{ab}	3.36^{ab}	3.4
Newsham Hybrid	863^{ab}	24.9^{a}	41.6^{a}	51.3^{a}	5.82^{bc}	2.25^{c}	6.12^{c}	3.25^{bc}	3.3
Spot	835^{c}	31.5^{d}	37.6^{c}	47.4^{c}	5.83^{bc}	2.35^{c}	5.91^{bc}	3.16^{c}	3.3
Yorkshire	835^{c}	26.7^{ab}	39.8^{b}	49.9^{b}	5.84^{ab}	2.33^{c}	6.13^{c}	3.26^{bc}	3.4

Means in the same column with different superscripts differ ($P<.05$).

[1] Higher values = more tender and juicier.

The Duroc is a breed that has become widely used throughout the world because it has a number of production advantages, including faster growth, improved stress resistance, hardiness, and good meat quality (Table 4). Although the Duroc has been shown to be moderately lean compared to other US breeds (Table 2 and 3), European studies have generally found that the Duroc is fatter than the white breeds and lines. This is illustrated in Table 4, where the results of a UK study that compared various proportion of Duroc in the slaughter generation from 0 (white line cross) to 75%, are presented.

Another breed that has received considerable attention because of its high carcass lean content is the Pietrain which has been shown to have a relatively low feed intake and, consequently, be slow growing when compared to breeds such as the Duroc, Hampshire and the white breeds. The high carcass lean content of the Pietrain, therefore, largely results from a reduced rate of fat deposition rather than any increase in lean growth rate.

As well as between-breed variation in lean yield, there is also substantial variation within a breed between the stocks from different breeders or breeding companies. This is illustrated in Table 5 where the results of a UK study carried out during the 1980's are summarized. The study compared white-line crossbreds from four of the leading UK breeding companies, three of which are currently major suppliers of breeding stock in the US and other industries worldwide. The variation in performance between genetics lines from the four sources that were based on similar breed composition was huge (Table 5) with, for example, lean growth rate varying by a staggering 27%. This highlights the importance of choosing a source of breeding stock with the highest genetic potential.

Table 4. Influence of proportion of Duroc genes on carcass and eating quality. (from Meat and Livestock Commission, 1991).

Percentage Duroc	0	25	50	75	Approx. LSD[a]
P2 backfat depth (mm)	10.2	11.2	11.7	12.8	.59
Intramuscular fat, (%)	.70	.86	1.08	1.27	.10
Carcasses judged PSE (%)	8.3	5.4	1.6	0.1	4.20
Taste panel[b]:					
Tenderness	4.96	5.03	5.32	5.38	.25
Juiciness	4.09	4.11	4.18	4.38	.17
Pork flavor	3.88	3.99	3.96	3.98	.12

[a] Least significant difference between means, $P<.05$

[b] Evaluated using an 8-point scale; lower values = poorer quality.

Table 5. Range in performance for four UK breeding companies (Meat and Livestock Commission, 1988).

	Mean	Company Range	% difference
Number of piglets born alive	10.2	9.8 - 10.8	10.2
Daily feed intake, kg	2.16	2.07 - 2.29	10.6
Daily gain, g	842	774 - 890	15.0
Feed conversion ratio	2.59	2.45 - 2.87	17.1
Dressing percentage	75.7	74.7 - 76.5	2.4
Carcass lean, %	55.2	51.6 - 58.2	12.8
Lean growth rate, g/day	365	31.5 - 40.0	27.0

ii. The Halothane Gene

The Halothane gene is of interest because of its positive effects on carcass lean content. However, it also has negative effects on stress susceptibility with associated deleterious effects on pig meat quality and stress related deaths. In the early 1990's, the gene responsible for this condition (the Ryanodine Receptor gene) was identified and a DNA based test that distinguishes between the three Halothane genotypes (negative [NN], carrier [Nn], and reactor [nn]) was developed. A number of breeding companies are offering Halothane carrier sire lines and negative dam lines in an attempt to exploit the advantages of the gene whilst minimizing the disadvantages. We carried out a within-litter comparison of Halothane carrier and negative animals in a recent study at the University of Illinois (Table 6). Halothane carriers had advantages in feed efficiency, dressing percentage, and carcass fat-free lean content. However, the carriers also had poorer meat quality in terms of paler color (higher Minolta L* values) and a higher drip loss. Thus, the advantages to the producer were largely offset by the losses to the meat sector and the results of this study suggest that the net economic benefit of this gene to the US industry may be close to zero. In addition, there is evidence from commercial situations that death losses may be higher in carrier compared to negative animals, particularly during transport to the slaughter plant.

Table 6. Within-litter comparison of Halothane carrier and negative pigs. (from Leach et al, 1996).

	Carrier	Negative	Av.SE	Sig[a]
Average daily gain, g	974	964	16.9	NS
Gain:Feed	.36	.33	.005	**
Dressing percentage	75.3	74.4	.29	***
Weight of fat-free lean in the side, kg	24.7	23.9	.35	*
Longissimus:				
pH (45 min)	6.4	6.6	.05	***
Minolta L*	45.7	42.0	1.03	***
Drip loss, %	5.2	3.4	.43	***
Shear force, kg	3.4	3.4	.17	NS
Juiciness[b]	7.3	7.6	.27	NS
Tenderness[b]	9.1	9.2	.30	NS

[a] NS, *, **, *** = not significant, P<.05, P<.01, P<.001, respectively.

[b] Taste panel scores from 0 = extremely dry and tough to 15 = extremely moist and tender.

iii. Sex differences in Growth and Carcass Traits

There are major differences in growth and carcass characteristics between the sexes. The major issue has been over the merits of producing entire males rather than castrates. Kempster and Lowe (1993) summarized published information on the relative differences between entire males and castrates and these results are presented in Table 7, which relates to studies where pigs were mainly slaughtered in the live weight range 85 to 100 kg liveweight (65 to 75 kg carcass weight). There are a number of advantages to producing entires rather than castrates including a major increase in the efficiency of lean meat production and a substantial improvement in carcass lean. It is estimated that producing entire males contributed approximately 10 to 15% the increase carcass lean in the UK industry over the past 20 years. In addition, the lower appetite of entires means that they can be fed ad libitum to slaughter weight without producing a fat carcass with consequent savings in building costs and labor for feeding.

The absolute difference between entires and castrates increases with weight and, therefore, the production benefits of producing entires increase with slaughter weight. The major disadvantage of producing entires is boar taint, which is the characteristic unpleasant odor given off from the meat from entires when cooked. Boar taint results largely from two compounds, androstenone and skatole, which are deposited at relatively high rates in the fat of entires compared to either castrates or gilts.

Table 7. Relative performance of entire males and castrates (castrate performance level = 100) (Kempster and Lowe, 1993).

	Relative performance	Range within which Most trial results fall
Daily feed intake	91	±5
Daily live weight gain	103	±2
Dressing percentage	99	±1
Gain:feed ratio	113	±5
P2 fat thickness	80	±5
Carcass lean percentage	106	±3
Carcass fat percentage (separable)	89	±4
Daily lean growth rate	116	±5
Lean gain:feed	125	±5

Research on meat quality in young boars has been centered largely in Europe with a considerable volume of work in this area being carried out in the UK. In general, the UK evidence would suggest little difference between the three sexes in terms of tenderness, juiciness, odor, or flavor. For example, a study by Wood et al. (1986) comparing entires and gilts showed similar scores for all aspects of eating quality, including abnormal odor intensity (Table 8). On the other hand, there are reports from other European countries of an adverse consumer reaction to the aroma from boar meat. Malmfors and Lundstrom (1983) summarized the data from a number of consumer studies (Table 9) and showed that there was evidence from a number of countries of an adverse consumer reaction to the aroma of boars. The most likely explanation of this variation in consumer reaction is the slaughter weight used for pigs in the

various countries. In the UK, for example, pigs are slaughtered at relatively light weights and young ages compared to most other countries. Under such circumstances, the likelihood of boars developing high levels of taint in the meat is limited.

Table 8. Influence of sex on eating quality[1] (From Wood et al. 1986)

Trait	Entire Male	Gilt
Tenderness	1.2	0.9
Juiciness	1.2	1.2
Flavor	1.5	1.7
Pork Odor	1.1	1.2
Abnormal odor	7.0	7.0
Overall acceptability	0.8	1.0

[1] Evaluated using a 15-point scale; lower values = poorer quality.

Table 9. Consumer reaction to boar meat. (From Malmfors and Lundstrom, 1983).

Country	No.Studies	Slaughter Live wt.	Type of product	Reaction to aroma of boar vs. castrate/gilt
UK	7	54-120	Fresh	Little difference
			Cured and processed	Little difference
France	1	95-105	Fresh	Boar less pleasant
			Cured and processed	Little difference
Holland	1	100	Fresh	Boar less pleasant
Sweden	1	105-110	Fresh	Boar less pleasant
			Cured and processed	Little difference

Differences between the performance of castrates and gilts observed in recent studies carried out at the University of Illinois are summarized in Table 10. There is obviously some variation between these studies in the relative differences between the two sexes. Data from US studies generally shows that the differences between castrates and gilts in growth rate and carcass lean content largely results from the higher feed intake of the castrate, there being little difference between these two sexes for lean growth rate. However, there is evidence that differences between barrows and gilts for growth and carcass traits may vary between genotypes.

Table 10. Difference in performance between castrates and gilts in studies carried out at the University of Illinois (castrate performance - gilt performance).

Study	I	2	3
Daily feed intake, kg	+0.33	+0.14	+0.35
Average daily intake, g	+57	+56	+83
Gain:feed	-0.02	-0.01	-0.03
Dressing percentage	+0.3	+0.3	+.2
10^{th} rib backfat thickness, cm	+0.8	+0.3	+0.58
Loin eye area, cm^2	-3.4	-2.8	-4.5
Fat-free lean, %	-4.2	-	-2.4

Study I: Leach et al., 1996; weight range 40 to 125 kg.
Study 2: Cisneros et al., 1996; weight range 60 to 130 kg.
Study 3: Miller, K.D. Unpublished, weight range 40 to 112 kg.

B. Nutritional Approaches to Improving Carcass Lean Yield

i. Feeding to Requirements

Feeding pigs to maximize their lean growth potential will generally result in high carcass lean yields. The two critical pieces of information required to formulate diets that maximize lean gain are estimates of the lean growth rate and the feed intake of the pigs being fed. The animal's lean growth rate will determine its requirements for protein and amino acids and its feed intake will determine the dietary concentration of nutrients required to meet requirements.

The animal's nutrient requirements are not fixed and vary with factors associated with both the animal and the environment in which it is reared. Central to determining animal requirements is the lean growth rate of the pig, which together with the growth of other tissues that contain protein, sets both the protein and individual amino acid requirements of the animal. However, lean growth rates are not fixed and vary with such factors as the genotype, sex and weight of the pig. In addition, there is increasing evidence that the environment in which the animal is reared, in terms of physical, social, climatic and disease components, will also affect lean growth. Obviously, lean growth rates are situation specific and ideally feeding programs should be tailored for each swine operation to account for this.

The effect of genotype on lean growth and feed intake is illustrated in Table 11 where a study carried out at Purdue University is summarized. In this study (Gu et al., 1991), five genotypes representing a broad sample of the genetics available to US pork producers were compared. The variation in growth performance was considerable; feed intakes varied by 0.22 kg (approximately 7%), live weight gain by in excess of 100 g/day (approximately 11%) and lean growth rates by over 60 g/day (approximately 19%). Obviously, the optimum diet to meet requirements would differ with genotype and this is illustrated in Table 12, where the dietary lysine levels necessary to maximize lean gain in two of these genotypes (i.e. genotypes 4 and 5 from Table I) are presented. Dietary lysine levels would need to be 25% higher to meet the requirements of genotype 5 compared to genotype 4 (Table 12). If one also considers that lean growth rates are likely to be depressed by a number of the common-stressors experienced by animals on commercial units, there is an obvious benefit from tailoring diet formulations to specific genotypes and farms.

Table 11. Genotype Effects on Lean Growth and Feed Intake.

Genotype	Feed Intake kg/d	Daily gain, g	Lean growth rate g/d
1	3.15	916	329
2	3.02	924	361
3	3.06	1010	390
4	3.24	1001	332
5	3.03	1017	393

Gu et al., 1992.

Table 12. Genotype Specific Feed Formulation.

Genotype	4	5
Lean growth rate, g/d	332	393
Feed intake, kg/d	3.24	3.03
Whole-body protein gain, g/d	133	157
Total lysine requirements, g/d	18.0	21.1
Dietary lysine, %	0.56	0.70
Dietary crude protein, %[a]	12.8	14.7

[a] Corn-soy diet.

The steps to estimate lysine requirements are outlined in Table 13. The starting point is to estimate lean growth rates. Whole body protein gain approximates to 40% of carcass lean gain and dietary lysine requirements are estimated from protein gain using three assumptions. Firstly that the lysine content of deposited protein is 6.9%, that 60% of lysine that is absorbed across the gut is deposited, and that the digestibility of dietary lysine is 85%. The requirements for other essential amino acids are calculated using an ideal protein ratio such as the one proposed by Baker (1997) which is presented in Table 14.

Table 13. Steps in estimating lysine requirements.

Estimate:

I. Carcass lean growth rate (LGR) = (Lean at End - Lean at Start)/Days on test

2. Whole-Body Protein Gain = 0.40 x LGR

3. Lysine Requirement
   Lysine content of protein gain = 6.9%
   60% of absorbed lysine is deposited
   Lysine digestibility = 85%

4. Requirements for other essential amino acids based on ideal protein (Baker, 1997)

The overall lean growth rate of pigs for the whole, or part, of the grow-finish period can be estimated simply by dividing the total weight of lean deposited (i.e. carcass lean at end - carcass lean at start) by the days on test. There are a number of equations in the literature to estimate carcass lean contents at the start and end of the growing-finishing period (Brannaman et al., 1984; NPPC, 1991) and these have been summarized in Table 15 and 16, respectively. Equations to predict carcass lean contents of the lighter pigs are based on live weight and a general approximation that can be used is that the weight of lean in the carcass is 40% of live weight (Table 15). For pigs at slaughter weight, a measure of backfat thickness (and possibly loin eye depth or area) is included in the equations to predict carcass lean (Table 16). Carcass measures can be obtained on the live animal using ultrasound scanning, but in practice are generally obtained from slaughter house measurements of backfat depths.

Table 14. Ideal pattern of essential amino acids for pigs (based on true digestible amino acid level).

Liveweight	10-20 kg	20-50 kg	50-110 kg
Amino acid			
Lysine	100	100	100
Arginine	42	30	18
Histidine	32	32	32
Tryptophan	17	18	19
Isoleucine	60	60	60
Leucine	100	100	100
Valine	68	68	68
Phe + Tyr	95	95	95
Met + Cys	60	62	63
Threonine	65	67	70

Baker, 1997.

Table 15. Prediction equations for estimation of Carcass Lean Content in pigs at start of growing period.

- Bannaman et al., 1984 (for pigs from 15 to 50 kg liveweight)
  Lean wt (kg) = l.59 + 0.44 (Live Wt)

- NPPC, 1991
  Lean wt (lb) = (0.418 x Live Wt) - 3.650

"Rule of Thumb"
Wt of lean _ 40% of live weight

Table 16. Generalized equations to predict carcass fat-free lean at slaughter (NPPC, 1991).

From fat-0-meater measurement

FFL = 51.537 + [0.035 x HCW (lb)] - [12.260 x FOM(in)]

From last-rib ruler backfat (midline) measurement:

FFL = 50.767 + [0.035 x HCW] - [8.979 x LR fat)

Estimation of overall lean growth rates obviously gives one value for the whole of the growth period and has the advantages of being simple to derive and if the carcass measurements are obtained from the slaughter plant, the data is easy and cheap to collect. In addition, slaughter plant data are collected by direct measurements on the carcass rather than indirect measurement on the live animal. However, there are a number of possible disadvantages to such an approach, including the potential for biases in predicting carcass lean content from generalized equations (discussed below). In addition, carcass weights and backfat measures are not taken in a standardized way across slaughter plants and this may introduce errors in prediction of carcass composition. Finally, and most importantly, such an approach assumes that lean and protein growth is linear across the whole of the growth period and this not the case. The rate of deposition of lean is curvilinear being relatively low at lighter weights, increasing to a maximum and then declining. Some typical protein growth curves are presented in Figure I, which is taken from Schinckel et al. (1994).

Theoretically, knowledge of the lean growth curve of pigs in a given situation will allow relatively frequent changes in diet formulation to be made in response to the animal's changing requirements for protein. This is particularly the case as animal approach slaughter weights, at which stage lean growth rates tend to decline relatively rapidly (Figure I). Adjusting dietary lysine and protein levels to take account of these reducing requirements can generally result in considerable savings in feed costs and also reduces nitrogen output in the excreta, an increasingly important consideration in situation where excess nitrogen outputs are a problem.

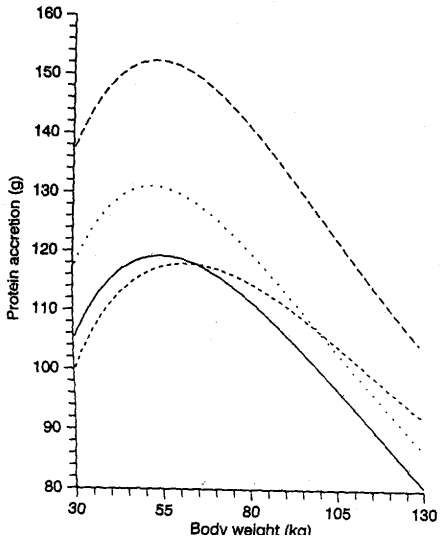

FIG. 1. Protein accretion curves for four genotypes.

The development of on-farm growth curves is being proposed by a number of sources. The concept is simple; a batch of pigs containing both sexes are grown on non-limiting diets and are weighed and ultrasonically scanned periodically during the growth period. The weight of lean and protein in the carcass at the start and end and at interim weights are predicted using equations. Regression analysis is carried out on these data to develop lean growth and protein accretion curves.

In practice, the regression procedures to develop the growth curves are relatively complex and require specialist knowledge of statistics (Whittemore et al., 1988; Schinckel, 1994). Once the data on live weights and ultrasonic carcass measurements are collected, the following steps are taken to develop the curves:

1. carcass lean and whole body protein contents at the various weights are predicted from prediction equations.

2. the regression equation for daily live weight growth rate is developed from live weight and days on test.

3. the regression equation describing the relationship between live weight and carcass lean or whole body protein is developed.

4. the equations from l and 2 are combined to estimate the protein or lean accretion rate.

Step 3 uses an allometric function (i.e. $Y = a X^b$, where Y is the weight of tissue and X is the live weight) which describes the relationship between the weight of a part (lean or protein) and the whole (body weight).

A number of general guidelines are suggested to ensure that the protein accretion curves that are developed are valid, these include:

- A minimum of 40 animals per sex should be used and the progeny from a number of sires should be represented.
- A diet that doesn't limit lean gain should be used.
- Pigs should be housed in a representative environment.
- Pig weights and ultrasound scans should be collected from lighter start eights to heavier weights than the normal slaughter weight to allow the shape of the accretion curve to be estimated accurately. Under US conditions, it is suggested that data be collected from approximately 20 kg to 140 kg live weight.
- Ultrasound scans are carried out on at least 5 occasions from approximately 40 kg live weight upwards. Prediction of carcass composition at lighter weights is based one equations that include live weight only (Table 15).
- Equations to predict body composition from live weight and ultrasonic carcass measurements should have been developed for the specific genotype being used. This is to minimize the problem of bias in the use of prediction equations discussed below.

In theory, the use of protein accretion curves has many potential advantages. In particular, the ability to precisely estimate protein gain across the growing period allows diet formulations to be regularly adjusted to meet changing requirements. This should improve performance and reduce diet costs. It has been estimated that under US conditions a reduction in dietary lysine level by 0.1% reduced the cost of the diet by between 0.2 and 0.3 cents/kg and that the potential savings per pig produced from using growth curves is in the range $0.45 to 1.20. Another advantage of developing protein accretion curves is that they can be used to predict the optimum weight at which to slaughter pigs in a given situation. Lean growth rate and feed efficiencies decline and carcass fatness increases as pigs approach slaughter weight. However, the rate of the decline is genotype specific, and knowledge of this for pigs on a particular farm will allow the optimum economic weight for slaughter to be calculated.

However, there are a number of potential disadvantages to developing growth curves using this approach including:

- The cost - it is estimated that the cost of collecting the scanning data under US conditions is approximately $2,000 (i.e. $5/scan x 80 pigs x 5 scans/pig).
- Suitable prediction equations may not be available for the genotype in question, particularly for the interim weights. Problems of bias (discussed below) are potentially large.
- Ensuring that both the diet fed is not limiting and the environment in which the pigs are reared is representative.

- Requires some basic knowledge of statistical procedures, particularly regression and also access to a computer and basic statistical software.

- The information is retrospective and if something changes on the unit that influences lean/protein growth then the information may not be accurate. For example, if the climate changes dramatically between the seasons, this may have a dramatic effect on lean growth and would invalidate growth curves developed under different climatic conditions.

- The initial improvements from applying growth curves can be large, particularly in situations where the diets currently fed on the farm are substantially out of line with animal requirements. However, the subsequent development of lean growth curves may only result in fine-tuning of the diets and may not justify the cost.

- Perhaps the major limitation is that this approach has not been fully evaluated in comparison with other simpler approaches and is, therefore, not a technology that has been proven under field conditions.

A potential problem with any approach that uses prediction equations is that of bias, which is defined as the difference between measured values and those predicted from equations. The use of prediction equations such as those presented in Table 15 and 16 can result in significant bias, particularly if they are used in populations that differ substantially from the one in which the equations were developed.

Schinckel (unpublished data) using the data of Gu et al. (1992), has shown that bias in predicting the carcass lean contents of different genotypes at approximately 20 kg can result in errors in calculating overall lean growth rates between 20 to 25 g/day. This is equivalent to an error of approximately 8% for overall lean growth rates averaging 300 g/day. Biases can be much larger when predicting carcass lean content at slaughter weights, particularly where equations from other sources are used and the lean content of the test group is outside the range of the population from which the prediction equations were developed. This is illustrated by the study of Wilson (1995) who estimated bias in a range of genotypes from predicting carcass lean content using the NPPC equation given in Table 17. The higher the lean content of the genotype, the greater was the bias (Table 17) with at the extreme, the equation under-predicting carcass lean content by almost 16 percentage units. This would result in lean growth rates being underestimated by over 100 g/day for the leaner genotypes. The best approach to minimizing bias in predicting carcass lean content is by using equations developed for the genotype that is used on the farm, although this is not always possible.

Table 17. Genotype bias in predicting carcass lean (Wilson, 1995).

Line	Measured Lean %	Bias[1]	Bias[2]
A	67.0	-15.8	-15.5
B	62.8	-11.0	-11.6
C	58.3	-8.4	-8.5
D	58.2	-7.2	-8.4
F	56.9	-6.3	-9.2
J	45.8	2.9	-2.3

[1] Bias I using NPPC (1991) equation based on Fat-o-meater measurements.
[2] Bias 2 using NPPC (1991) equation based on last rib fat thickness.

Perhaps the major utility of estimating lean and protein growth on specific farms is in establishing baseline information to use to set diet formulations, but the input and costs required has to be set against the value of this information. The major problems with using these curves, apart from the cost and effort involved, is that they measure the historical situation on a unit and may not be representative of what is currently happening. Ideally, real-time measures of current protein gains are needed to accurately adjust diets to requirements, but at present no such measures exist. However, in the future remote sensing technologies, including the ability to measure feed and water intakes and the animals live weight, body temperature and metabolic status as well as monitoring environmental conditions, may enable accurate estimation of tissue growth and, therefore, nutrient requirements.

ii. Low Energy Density Diets

One approach to reducing carcass fat levels is to reduce the energy intake of ad libitum fed animals by offering diets with reduced energy density. Within limits, pigs have the capacity to increase feed intake as the dietary energy concentration of the diet is reduced in an attempt to maintain total energy intake. However, there is a lower limit to dietary energy density beyond which pigs can't compensate by increasing intake further and the energy intake of the animal will be reduced. This is illustrated in the results of a study carried out a the University of Illinois (Table 18). In this trial, the energy concentration of a corn-soybean meal diet (Diet I) was diluted using a combination of wheat bran, corn gluten feed and alfalfa meal.

There was a general trend for decreasing dietary energy contents to be associated with reduced growth rates and improved carcass lean content. However, dressing percentage and lean growth rates were also reduced by diluting the energy density of the diet (Table 18).

One potential problem with this approach is that ingredients with low energy density are not necessarily cheap and there is an increased cost with transporting bulkier feedstuffs and with disposing of the extra manure production.

Table 18. Effect of dietary energy concentration on growth and carcass characteristics (Stein and Easter, 1996).

Diet #	**1**	**2**	**3**	**4**	**5**
Dietary energy concentration, kcal ME/kg	3,500	3,300	3,100	2,900	2,700
Initial weight, kg	53.9	54.7	54.4	53.6	54.1
Final weight, kg	113.8	113.9	111.8	112.9	111.2
Average daily gain, g	1017^{a}	1038^{a}	1006^{ab}	931^{bc}	872^{c}
Feed intake, kg/day	2.91^{a}	3.28^{b}	3.36^{b}	3.23^{b}	3.31^{b}
Feed intake, mcal/day	10.17^{ab}	10.83^{a}	10.41^{a}	9.36^{bc}	8.93^{c}
Gain:Feed, kg/kg	0.35^{a}	0.32^{b}	0.30^{bc}	0.29^{c}	0.26^{d}
Gain:Feed, g/Mcal	100	96	97	100	98
Dressing percentage	75.97^{a}	74.9^{ab}	74.56^{bc}	73.96^{c}	73.51^{c}
10th rib fat, in	0.85^{a}	0.86^{a}	0.78^{ab}	0.70^{b}	0.69^{b}
Loin eye area, in^{2}	5.71	5.57	5.68	5.62	5.34
Carcass lean, %	50.78^{ab}	50.42^{b}	51.72^{ab}	52.32^{a}	52.0^{ab}
Av.daily lean gain, g	392^{a}	383^{ab}	386^{ab}	358^{bc}	330^{c}

Means in the same row with different superscripts differ ($P<0.05$).

iii. Restrict Feeding

The simplest approach to increasing carcass lean contents is to restrict the amount of feed supplied to the animal, particularly in the later stages of the finishing period when fat deposition rates increase dramatically. As previously discussed, there are lines of pigs with low feed intake capacity and/or high lean growth rates that can be fed ad libitum to conventional slaughter weights without becoming excessively fat. However, a large number of genetic lines, particulary castrates, can produce excessively fat carcasses if allowed free access to cereal-based diets. An example of the effects of restricted feeding on growth and carcass traits is given in Table 19 which is taken from a study carried out by Cameron and Curran (1995).

If restrict feeding is applied then it is important that all pigs in a group can feed simultaneously. In practice, this is generally achieved by either floor feeding or via a continuous trough, and this has obvious implications for housing design compared to ad libitum feeding.

Table 19. Comparison of high and low lean growth rate lines on ad libitum and restricted (75% of ad libitum) feeding (Cameron and Curran, 1995).

Feeding regime:	**Ad libitum**		**Restricted**	
Lean growth potential:	**High**	**Low**	**High**	**Low**
Feed intake, g/day	1995	1999	1595	1595
Daily gain, g	845	770	699	651
Feed conversion ratio	2.36	2.39	2.30	2.45
Carcass lean, %	50.9	47.5	53.8	49.4
Lean growth rate, g/day	491	412	416	359

C. Effect of Carcass Modifiers on Growth Performance and Lean Yield

There has been considerable interest in a number of compounds that have a potential role in modifying growth and carcass composition. These include porcine somatotropin (pST) and beta-agonists such as Ractopamine both of which have been shown to have positive effects on growth rate, feed efficiency and carcass lean content (Tables 20 and 21). Research with other compounds such as chromium picolinate and betaine has produced variable responses. More recently, considerable attention is being focused in the US on the potential of conjugated linoleic acid to improve growth and carcass characteristics and fat quality (Table 22).

Table 20. Summary of results of the effects of pST administration on growth and carcass characteristics (Stahly, 1990).

	pST dose (ug/kg/day)	
	0	60-130
Daily feed intake, kg	3.04	2.60
Daily gain, kg	0.94	1.08
Feed:gain	3.26	2.47
Dressing percentage	74.6	73.0
Backfat - 10th rib, cm	2.34	2.03
Carcass muscle, %	50.1	62.4

Table 21. Effect of Ractopamine Hydrochloride on the carcass cutting yields of finishing swine. (Stites et al., 1991)

	Ractopamine (ppm)				Control vs Av. RAC effect
	0	5	10	20	
Daily feed intake, kg	2.70	2.46	2.67	2.67	NS
Daily gain, kg	0.78	0.83	0.84	0.85	*
Feed:gain	3.44	2.97	3.16	3.13	*
Dressing percentage	74.2	74.4	74.9	76.2	*
10th rib fat thickness, cm	3.0	2.7	2.8	2.8	NS
Loin eye area, cm^2	37.2	40.3	39.9	42.9	*
Predicted lean, %	50.6	52.9	52.4	53.6	*

Table 22. Impact of conjugated linoleic acid on growth and carcass characteristics (Thiel et al., 1998).

	Conjugated linoleic acid (%)				
	0	0.12	0.25	0.50	1.00
Daily gain, kg	0.942^{b}	0.30^{b}	0.953^{b}	0.974^{ab}	1.109^{a}
Gain:Feed	0.352^{bc}	0.367^{ac}	0.373^{a}	0.370^{ac}	0.384^{a}
10th rib backfat thickness, cm	2.9^{a}	2.3^{b}	2.3^{b}	2.6^{b}	2.6^{b}
Belly hardness, cm	52.0^{b}	55.3^{b}	56.3^{b}	67.4^{ab}	78.8^{a}

Potential Negative Effects of In creasing Carcass Lean Contents

Concerns have been expressed that increasing carcass lean contents can result in some undesirable correlated changes in other areas of economic importance to the swine producer. Particular concerns have been expressed in terms of the quality of the carcass and of the meat and over the reproductive performance of leaner lines of pigs. In terms of carcass and meat quality, the major concerns are over carcass handling and processing properties, and particularly the issue of tissue separation, and the eating quality of meat from lean pigs. There is a general belief in some quarters that the eating quality of lean pig meat is poor because of its low intramuscular fat or marbling content. However, the scientific evidence is not conclusive in this area and there is still some considerable debate over the role of intramuscular fat in determining eating quality. The major issue in terms of reproductive performance is whether lean lines of pigs have enough body fat reserves to sustain performance over a number of parities. The particular concern is with the gilt during the first lactation where if she is nursing a normal size litter the losses of body fat to maintain milk production will reduce fat reserves at weaning to a level at which major problems will occur with continued reproduction. However, producers have generally modified their management of the replacement gilt before mating and during lactation to overcome these problems. The fact that sow output levels are high in countries that produce lean pigs is evidence that such animals can be successfully managed to produce at or near their potential.

Effects of Slaughter Weight on Growth Performance and Carcass Lean Yield

Slaughter weights vary considerably between countries, ranging from as low as 80 kg live weight in countries such as the United Kingdom to as high as 150 kg in Italy. Slaughter live weights in the US average 110 to 115 kg, a weight typically used in a number of other countries.

In any situation, there are a number of potential advantages to increasing slaughter weight including.

Reduced overhead costs per unit weight of output for producer, slaughterer and processor.
Increased carcass yields.
Greater muscle size and thickness?
Improved meat to bone ratio
Lower chilling and processing losses
Improved meat quality?

However, there are also possible disadvantages to heavier slaughter weights including:

Increased carcass fat levels
Poorer feed efficiency
Muscle size and thickness too large?
Poorer meat quality?

The slaughter weight used in any situation is often dictated by the size and fat content of the cuts and portions required by the consumer. The optimum economic slaughter weight, defined as the weight at which profit per pig is maximized, will depend on the balance between the effects of slaughter weight on production costs and carcass value and will vary between different countries and over time within a given production system.

One factor favoring heavier slaughter weights is the genetic improvement in carcass lean content which has occurred over recent years. In theory, modern, high-lean growth potential genotypes can be taken to heavier weights than traditional genotypes without compromising growth and carcass traits and the economics of taking pigs to heavier slaughter weights should improve over time.

The economic optimum slaughter weight will be determined by the relationship between live weight and production costs and market returns, which in turn will depend on the impact of increasing weight on animal performance, particularly growth rate and feed efficiency, and carcass value which is determined principally by lean content.

Results of three studies that have investigated the impact of slaughter weight on growth and carcass characteristics are presented in Table 23, 24, and 25. The estimated change in important traits from these studies plus the investigation of Albar et al. (1990) are summarized in Table 26. The general conclusions that can be drawn from these studies are that as slaughter weight increases above 100 kg:

Average daily gains show little change or a marginal decrease
Feed efficiency deteriorates significantly
Carcass yields and backfat thickness show substantial increases and the lean percentage of the carcass decreases significantly.
Meat quality shows little change or a small deterioration.

The magnitude of these changes in performance with slaughter weight varies between genetic lines and it is important to establish the rate of change for each genotype to provide data to estimate the optimum slaughter weight in any situation.

Table 23. Growth, carcass and meat quality characteristics of pigs slaughtered between 100 and 160 kg live weight (Cisneros et al., 1996).

	Change per 10 kg increase in liveweight
Average daily feed intake, kg	+0.1
Average daily gain, g	+ 4
Gain:Feed	-0.006
Dressing percentage (hot)	+0.32
10th rib backfat thickness, mm	+1.8
Loin eye area, cm^2	1.83
Closely trimmed boneless cuts:	
Weight, kg	1.40
Percentage	-0.32
Curing yields:	
Ham yield, %	-0.10
Belly yield, %	+0.83
pH (45 minutes)	-0.01
pH (24 hours)	-0.02
Drip loss, %	0.29
Tenderness[a]	- 0.15
Juiciness[a]	-0.06
Warner-Bratzler shear, kg	-0.08

[a] 15 point scale; lower scores = poorer quality.

Table 24. Influence of slaughter weight on growth carcass and meat quality characteristics (Ellis et al., 1996).

	Slaughter weight (kg)			
	80	100	120	se
Average daily gain, g	785	769	725	8.5
Dressing percentage (hot)	76.9	78.6	80.0	0.14
P2 backfat, mm	14.7	15.7	16.9	0.47
Loin eye area, cm^2	34.6	40.7	44.6	0.59
Muscle reflectance (EEL)	46.5	45.2	44.7	0.48
Tenderness[a]	4.72	4.40	3.95	0.062
Juiciness[a]	3.89	3.67	3.61	0.006
Warner-Bratzler shear force, kg	5.37	5.58	5.87	0.085

[a] 8 point scale; lower values = poorer quality.

Table 25. Growth, carcass and meat quality characteristics of pigs slaughtered at 80, 100 and 120 kg live weight (Schmitten et al., 1986).

	Slaughter weight (kg)		
	80	100	120
Average daily gain, g	755	754	725
Dressing percentage,	76.7	79.0	80.3
Backfat thickness, mm	20.0	22.0	26.0
Loin eye area, cm^2	38.2	46.2	52.1
Meat percentage	57.2	56.8	55.6
Halothane negative pigs:			
Muscle pH, 45 minutes	5.99	6.03	5.97
Muscle reflectance (Gofo)	64.6[a]	60.4[b]	59.7[b]
Halothane positive pigs:			
Muscle pH (45 minutes)	5.73	5.64	5.58
Muscle reflectance (Gofo)	55.l[a]	48.8[b]	47.6[b]

Table 26. Estimated change in growth and carcass characteristics with increasing slaughter weight.

	Estimated change (per 10 kg liveweight in slaughter weight)			
Study:	**1**	**2**	**3**	**4**
Average daily gain, g	+4	-8 to –15	0 to -8	0 to -10.0
Feed conversion ratio	+0.05	-	-	+0.10 to +0.15
Dressing percentage	+0.3	+0.8	+0.9	+0.5
Backfat thickness, mm	+1.8	+0.6	+0.1 to +1.5	+1.6
Lean meat percentage	-0.3	-	-0.2 to -0.4	-1.0
Muscle pH (24 hrs)	-0.02	-	-	0
Muscle reflectance	-	-0.5	-1.2 to -1.9	0

[1] Cisneros et al. 1996. Growth measured from 60 kg start weight to slaughter weights from 100 to 160 kg . Castrates and gilts. Ad libitum feeding.
[2] Ellis et al., 1996. From 40 kg start weight to slaughter weights of 80 to 120 kg. Castrates and gilts. Ad libitum and restricted feeding combined.
[3] Schitten et al., 1986. From 30 kg start weight to slaughter weights of 80 to 120 kg. Castrates and gilts.
[4] Albar et al, 1990. From 24 kg start weight to slaughter weight of 105 to 135 kg. Castrates and gilts.

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