Diss. ETH No. 16069

Influence of alternative semi-outdoor housing systems in comparison with the conventional indoor housing on carcass composition and meat and fat quality of finishing pigs.

A dissertation submitted to the
SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZÜRICH
for the degree of
Doctor of Science ETH Zürich

presented by

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Zürich 2005

In Dankbarkeit für meinen Vater

Hans Beat Bärlocher

1921 bis 2004

Acknowledgements

The success of this dissertation (March 2000 to June 2005) was based on the participation of several companies and institutions and many people. Each contribution and help, no matter how large or small, was at its moment a piece of the puzzle of the larger work. I would like to say THANK YOU to all of you.

Particularly I must address my thanks to:

All the farmers who participated and provided their data, which represent the basis for this Ph.D. thesis.

BVET[1] (Bern), who funded the project and approved funds for a three-month extension (project number 2.98.08).

Prof. Dr. Caspar Wenk, ETH[2] (Zürich), who took over the project on his competence, including providing the contact to slaughterhouses and other companies. Through his connections, I was able to make a stay in the U.S.A.

Prof. Dr. Walter Meier, former director of Agroscope FAT[3]-Tänikon (Ettenhausen), who hosted the project at the FAT. He made possible a stay in the USA and funded a six-month extension.

Dr. Ruth Badertscher, Agroscope FAT-Tänikon (Ettenhausen), head of the overall project: Overall Assessment of Selected Housing Systems of Dairy Cows and Fattening Pigs, No. 2.98.08; she was in charge of the planning and organisation and managed the present subproject until her leave in June 2004. She offered her technical support in the office and went to the pH measurements in the slaughterhouses, when needed.

Dr. Martin R. L. Scheeder, ETH (Zürich), who advised me in technical and theoretical matters (interpretations, text, etc.) throughout the study, carried out the gas-chromatographic analyses of back fat samples, and for his engagement as the first co-examiner.

Prof. Dr. James E. Pettigrew, University of Illinois at Champaign (USA), who hosted me in his lab for four months (April – July 2002), and for his engagement as a co-examiner

Dr. Sandra Rodriguez-Zas (Associate Professor at the University of Illinois) for her statistical support, and for her engagement as a co-examiner.

Dr. Reto Schnider, Agroscope FAT-Tänikon (Ettenhausen), who managed the farm visits including the questionnaires, the feed samples, and the temperature loggers, and who provided much other information in the scope of his veterinarian Ph.D. thesis. He also went to the slaughterhouse for pH measurements, when needed.

Dr. Stephan Pfefferli, Agroscope FAT-Tänikon (Ettenhausen), who took over the responsibility for the project and was the contact person after Ruth's leave.

Dr. Hans Rudolf Roth, Statistical Seminar ETH (Zürich), who supported me in statistical and SAS aspects.

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[1] BVET: Bundesamt für Veterinärwesen (Swiss Federal Veterinary Office)

[2] ETH: Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)

[3] FAT: Eidgenössische Forschungsanstalt für Agrarwirtschaft und Landtechnik (Swiss Federal Re search Station for Agricultural Economics and Engineering)

Prof. Dr. Karl-Otto Honikel, Director of Bundesforschungsanstalt für Ernährung und Lebensmittel/Federal Research Centre for Nutrition and Food (Kulmbach, Germany), who gave me advices regarding aspects of pH data (interpretation, extrapolation, etc.).

Heinrich Hauswirth and Peter Stoll, of Agroscope Liebefeld-Posieux (Posieux), who were in charge of the feed sample analyses, and controlled the analyses results.

Dr. Daniel Schwörer, and Dr. Andreas Hofer SUISAG (Sempach), who gave me theoretical support in pH reading and information about the Swiss pig population.

The staff of Agroscope FAT (Tänikon-Ettenhausen) for their support during my nearly five years there.

The staffs of animal marketing companies Anicom (Seuzach) and Prosus (Weinfelden), who provided the addresses of the majority of the farmers. They were the link between farmers and the office and informed us about slaughtering dates and times for pigs designated for the study; also to their truck drivers, who filled out and brought the questionnaires from the farmers at the deliveries, and the office staff who provided data about breeds according to the reading of ear tags after slaughtering.

Further animal marketing companies that provided farmers' addresses: IPS Kuvag and IGA (both at Sursee) and others.

The staff of slaughterhouses SBA AG and Bell AG (Basel), and Micarna (Bazenheid) for the possibility of reading ear tags and measuring pH during the slaughtering process and in the chillers. They made possible the physical distinguishing of study- market groups by tattooing them differently and provided the data of weight and fat-free lean of the carcasses.

The laboratory staff of the slaughterhouses who left us the processed back fat samples after analysing them for their own purposes and allowing us to use the fat scores. The perfect collaboration facilitated my job to a great extent (lists and labeling of samples, etc.)

Willi Wirz, Wintion AG (Mühledorf), for the technical support regarding pH measurements (calibration solution and free electrode use).

The Stipendienamt of the ETH for a grant in 2005.

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V. Abbreviations

ad lib	ad libitum feeding regime
ALT	alternative housing system
$ALT_{Complete-Feed}$	alternative housing and complete feeding systems
$ALT_{Whey-Feed}$	alternative housing and whey feeding systems
am	ante meridiem (time of day)
AutoFOM	fully automatic ultrasonic carcass grading system
Avg	average (in some tables)
BW	body weight (for carcass weight see "weight")
18:1	oleic acid, in this context the *cis* n-9 oleic acid
18:2	linoleic acid
18:3	linolenic acid
Comp.	comparison (of housing systems or season)(in some tables)
CON	conventional housing system
$CON_{Complete-Feed}$	conventional housing and complete feeding systems
$CON_{Whey-Feed}$	conventional housing and whey feeding systems
CT_{low}	lower critical temperature
CT_{upper}	upper critical temperature
CV, cv	coefficient of variance
DE	digestible energy
DFD	dark, firm, and dry meat
DM	dry matter
Duca	sire line of Piétrain (♂) and Duroc (♀) breed in Switzerland
FOM	Fat-O-Meater ("Meater" for 'meat' and 'meter'), manual carcass grading with FOM-device
fs	feeding system
F	F-values of model effects
h	hour(s)
hs	housing system
LR	Swiss Landrace breed
ls-means	least square means (Mittelwerte der kleinsten Quadrate)
LW	Swiss Large White breed
LWxLR	crossing of Swiss Large White and Swiss Landrace breed
M.	Musculus (muscle)
Max	maximum (upper case)
MH	malignant hyperthermia

M.l.d.	Musculus longissimus dorsi
Min	minimum (upper case)
min	minute (lower case)
MJ	mega joule
MUFA	monounsaturated fatty acids
n	number (in tables and captions)
N_Resid	normal distribution of residuals (in residual distribution plots)
p.m.	postmortem
pH-35 min	pH at 35 minutes postmortem/p.m. (also early p.m. pH)
pH-2 h	pH at 2 hours postmortem/p.m. (also early p.m. pH)
pH-24 h	pH at 24 hours postmortem/p.m. (also ultimate pH, pH-ultimate)
pm	post meridiem (time of day)
Obs.	observed value(s) (in tables)
P	Probability of error (significance level)
Pred	predicted/estimated value (in predicted-observed plots)
PSE	pale, soft, and exudative meat
PUFA	polyunsaturated fatty acids
Q1, Q3	first (25 %), third quartile (75 %)
QQ-plot	quantile-quantile plot (of residuals)
REML	Restricted Maximum Likelihood method
Resid	residual (only in residual distribution plots)
SD, sd	standard deviation
SE	standard error
sl	slaughterhouse (in tables sometimes sl'house)
SM	Semimembranosus muscle
sn	season
T, (T_a)	ambient temperature
UFA	unsaturated fatty acids
Sub-model-ALT	model including only alternative farms
Sub-model-CON	model including only conventional farms
W	carcass weight hot in kg
*, ×	interaction; example: season*housing system (sn*hs, also $sn \times hs$)
Ø; Δ; Σ	arithmetic average; difference (delta); sum

1. Summaries

1.1. Summary

General aspects

A survey was carried out during the years 2000 to 2001 in Switzerland to investigate the influence of two housing systems, the conventional (CON) and an alternative (ALT) housing system, on the quality aspects of fattening pigs: fat score, fat-free lean percentage, and pH of the M.l.d.. CON housing comprised fully-slatted floors with minimal legal pen size (0.45 to 0.65 m^2 per growing-finishing pig) whereas ALT referred to an advanced animal welfare housing system with more space (0.60 to 0.90.m^2 per growing-finishing pig), a multi-surfaced floor including a feeding place (mostly perforated), a non-perforated littered rest area, and a limited permanent accessible outdoor area (0.45 to 0.65 m^2 per pig in addition to the indoor surface). The farms were further classified into two different feeding systems, the whey- (=liquid; in CON mainly cheese dairies) and complete feeding system. The study plan was a split-plot design where farm was considered as a random class effect nested in the fixed effects housing and feeding system. Observations (pH-measurements) from a summer (2000) and a winter (2000/2001) fattening period were carried out in two major Swiss slaughterhouses with CO_2 stunning, which kindly provided the carcass data of the monitored pigs (fat score, fat-free lean, and slaughter weight). The pigs (usually 20 to 30 per farm and fattening period) previewed for monitoring were raised and fed as the others in the farms but kept in separate pens. Feed samples of the entire fattening period were collected and analysed (Weender analysis and gas-chromatographic fatty acid profile). The farmers usually practised a split marketing according the weight of the animals into 1 to 3 market groups per fattening period. The experimental unit of the criterion fat score was market group, whereas records of individual pigs made up the experimental unit for the criteria fat-free lean and pH. Several covariates (given below) were regarded in the linear mixed effects models adjusting the ls-means. The unbalanced data set was analysed with the computer package of SAS, 8.02 release, PROC MIXED, using the Restricted Maximum Likelihood (REML) approach.

Fat score of adipose tissue

Fat scores are surveyed routinely in the major Swiss slaughterhouses and represent a mixed fat sample combined from all individual carcasses of one market group. The fat score is an index based on the amount of double bonds in the fatty acids of the outer layer of the back fat. Scores above 62 (comparable to an iodine value of about 68 to 69) entail monetary deductions for the producer (farmer) aiming to ensure an acceptable back fat quality in terms of consistency and oxidation stability of the processed fat in meat products. It is of interest

whether ALT-pigs feature a different firmness of back fat than CON-pigs do (housing effect). A possible seasonal influence (season effect), i.e., of the ambient temperature (T) was of interest particularly regarding the fat score rising and endogenously synthesised oleic acid (18:1) that was computed in an analogous second model. The housing effect was analysed in each season and each feeding system interacting the three effects resulting in four housing comparisons. The estimated ls-means were adjusted for the effect of the covariates dietary PUFA [g/MJ] for the response variable fat score, or dietary 18:1 [g/MJ] for the response variable 18:1, and fat-free lean [%] for both response variables. Data of 291 market groups (99 and 192 for CON and ALT, respectively) from 89 different farms (37 and 52 for CON and ALT, respectively) were included.

The ls-means ranged from 58.9 to 60.3. Three housing comparisons exhibited no significant difference (P>0.2) whereas the CON-pigs of the fourth comparison in the category whey feeding system and in winter exhibited a significantly higher fat score than the ALT-pigs (P=0.0002). The same CON-pigs also showed a significantly higher fat score as in the precedent fattening period in summer (P=0.047), whereas the other three seasonal comparisons were not significant (P>0.15). Concomitantly, the ls-means of the temperature-dependent and fat score-influencing 18:1 showed as well one significant housing and season comparison which were, however, not congruent to those in the criterion fat score. Here the CON-pigs from farms with complete feeding systems and in summer were significantly higher than their ALT-pigs counterparts (P=0.019). The other three housing comparisons featured no significance (P>0.3). Within the seasonal comparisons a significantly higher ls-means of 18:1 in ALT-pigs in winter compared to the precedent summer period (P=0.008) was estimated where also the lowest temperature average of 10.5 °C (summer 16.9 °C) was recorded (average of the last sixty fattening days with 24 records per day). The other three seasonal comparisons were not significant (P>0.25). The range of the four comparisons of 18:1 was between 42.0 to 43.8 % of total fatty acids.

The results showed that there was a fat score- and oleic acid-raising housing effect in CON-pigs, and an oleic acid-raising effect at cold T in winter in ALT-pigs as well that did not influence, however, the fat score substantially. Endogenous synthesis of 18:1 was probably enhanced in some cases in CON-pigs at a temperature level of 18.5 °C in the finishing period.

Fat-free lean proportion

The analysis of the fat-free lean proportion [%] based on a total of 5,295 AutoFOM-classified pigs from 87 farms (CON: 36 farms, 1,973 pigs; ALT: 51 farms, 3,322 pigs). The housing effect was structured alike in the fat score model but additionally computed within each slaughterhouse realising so eight housing comparisons (sixteen ls-means). The estimated ls-

means have been adjusted for the effects of the covariates digestible energy [MJ], crude protein [%], carcass weight hot [kg], and 'time 25 kg to market' [days].

The majority of the comparisons showed that the CON-pigs exhibited a higher fat-free lean than the ALT-pigs. This was particularly so in the first recording period (summer) where three comparisons were significant at P<0.05, and the fourth featured P=0.10. In the summer the adjusted ls-means of the CON-pigs amounted to 55.6 to 56.1 %, those of the ALT-pigs to 53.4 to 55.0 %. In the second period (winter) there were no significant housing comparisons anymore due to particularly higher ls-means of the ALT-pigs. Two housing comparisons featured comparable ls-means in a range of 55.8 to 56.0 % (P>0.6), and two other ones revealed a slightly higher level of CON-pigs in a range of 55.5 to 56.5 % (P~0.2). The noticeably increase of the ALT-pigs in the second period cannot be explained exactly with these data. However, it can be assumed that farmers implemented significant corrections in their management (feeding and other aspects) in order to attain the performance (and the profit margin) of the precedent periods. The data recording fell indeed together with the period of managing the fattening pigs in the newly adapted ALT-housing systems (conversion from CON to ALT) in many ALT-farms. A second cause for the small differences between CON and ALT in the winter period could be the extraordinary mild climate (April 2001 was the coldest month in the winter 2000/2001) which was favorable in view of a relatively smaller quantity of dietary fat and energy is deposited as back fat than a pig most likely would deposit at an expected cold temperature level in winter. An exact investigation of these presumptions would, however, be subject of a new (third) survey.

PH of Musculus longissimus dorsi

The pH was monitored at three stages postmortem, at 35 min, 2 and 24 hours. The models of the initial and ultimate pH featured a different number of records due to mainly carcass availability the day after initial pH monitoring: 4,731, 4,682, and 3,925 at the three stages p.m., respectively. The housing effect was structured as in the model fat-free lean. The estimated ls-means were adjusted for the effects of the covariates fat-free lean [%], and fasting-, transport-, and lairage time, each in hours.

The pH range of the sixteen housing subclasses (=eight comparisons) was 6.35 to 6.50, 5.90 to 6.19, and 5.29 to 5.44 in the three stages p.m., respectively (the ultimate pH was recorded systematically at a relatively low level). The pH at 35 min p.m. did not differ relevantly in six of the eight housing comparisons (P 0.175 to 0.661), while in two comparisons the CON-pigs featured a significantly (P=0.020) and near significantly (P=0.074) lower pH-35 min, which was also reflected in the pH at 2 h p.m. (P 0.023 and 0.137). The other comparisons differed again not significantly (P>0.20 to 0.921). No significant housing comparison was observed in the ultimate pH (P 0.104 to 0.875). The differences when P<0.3 were not consistent, i.e., the simultaneously compared housing systems in each slaughterhouse showed opposed pH-24 levels (the housing comparisons in summer with whey feeding systems and those in winter with complete feeding systems). Considering the pH computed as ls-means at class levels compared to the course in an individual carcass no intrinsic interrelationship between early and ultimate pH was observed, i.e., a faster decline in the early p.m. stage did not necessarily result in a lower ultimate pH. The feeding practise the eve before marketing should be in line with the expected slaughtering the next morning in order to provide a sufficiently long fast, i.e., no ration for early in the night transport and slaughtering, else postponed backwards into the afternoon. An extra whey supply late at the evening should be prevented in view of a lower falling ultimate pH.

1.2. Zusammenfassung

Allgemeine Aspekte

Im Rahmen einer Feldstudie wurde der Einfluss von Haltungssystemen auf die Fleischqualität von Mastschweinen in der Praxis untersucht. Dabei wurden drei Merkmale ausgewertet, die Fettzahl, der Magerfleischanteil (MFA) und der pH des langen Rückenmuskels. Als Haltungssysteme definiert waren die beiden häufigsten Aufstallungsarten in der Schweiz: die konventionelle Haltung (CON) mit Vollspaltenböden und minimalen gesetzlichen Abmessungen (0,45 bis 0,65 m^2 pro Tier für Vor- und Ausmast) und die Labelhaltung (ALT) mit Mehrflächensystemen (0,60 bis 0,90 m^2 pro Tier für Vor- und Ausmast), unterteilt in Fressplatz (meistens mit perforiertem Boden), einen festen (unperforierten) und eingestreuten Liegeplatz und zusätzlich einen stetig zugänglichen Aussenklimabereich mit minimal 0,45 bis 0,65 m^2 pro Tier für Vor- und Ausmast. Die Betriebe waren in solche mit flüssiger Molkefütterung (bei CON zumeist Käsereien) und in solche mit Alleinfutter kategorial weiter unterteilt. Der Plan der Studie war ein Split-plot design, indem der Betrieb ein zufälliger Effekt, hierarchisch verknüpft in den Effekten Haltung- und Fütterungssystem, war. Die pH-Messungen wurden in zwei grossen Schweizer Schlachthöfen durchgeführt, die auch die dazugehörigen Schlachtdaten (MFA und Schlachtgewicht) freundlicherweise zur Verfügung stellten. In beiden Schlachthöfen wurde bei einer Stundenleistung von ca. 240 Tieren mit CO_2 betäubt. Die Daten stammten aus einer Sommer- (2000) und einer Wintermast (2000/2001). Die für die Messungen vorgesehenen Schweine, meistens 20 bis 30 pro Betrieb und Durchgang, wurden als Gruppen in separaten Buchten gehalten, sonst jedoch wie die anderen Schweine eines Betriebes gefüttert und betreut. Futterproben wurden über die gesamte Mastperiode gesammelt und durch Weender Analysen und gaschromatographische Fettsäurenprofile charakterisiert. Entsprechend der gängigen Praxis einer Selektion der Schweine nach Marktreife, ergaben sich ein bis zu drei Schlachtposten pro Mastdurchgang, die alle in der Studie berücksichtigt wurden. Beim Kriterium Fettzahl war die Versuchseinheit der Schlachtposten, da die zur Analyse bestimmte Fettprobe einer Mischprobe von Fettabstrichen aller Schlachtkörper eines Schlachtpostens entspricht, währenddem bei den Kriterien MFA und pH die Werte des individuellen Tieres die Versuchseinheit definierten. Die LS-Mittelwerte wurden von den Effekten verschiedener variabler Faktoren korrigiert (bei den Kriterien weiter unten erwähnt), indem sie als Kovariablen in den linearen Modellen mit gemischten Effekten modelliert wurden. Der unbalancierte Datensatz wurde mit der Prozedur Mixed von SAS (Ausgabe 8.02) mit der Methode der Restricted Maximum Likelihood (REML) ausgewertet.

Fettzahl vom Auflagefett

Die Fettzahl ist ein Index für die Anzahl Doppelbindungen der Fettsäuren der äusseren Schicht des Auflagefettes und wird an den grösseren Schweizer Schlachthöfen routinemässig erhoben. Schlachtposten mit Werten höher als 62 (vergleichbar mit Iodwerten von 68 bis 69) werden mit einem Abzug belegt, um so eine akzeptable Qualität bezüglich Konsistenz und Oxidation des zu Fleischprodukten verarbeiteten Fettes zu erzielen. In den letzten Jahren hat eine Diskussion stattgefunden, ob ALT-Schweine höhere Fettzahlen als CON-Schweine aufwiesen (Haltungs- und Saisoneffekt). Ein möglicher saisonaler Effekt, das heisst hauptsächlich die Umgebungstemperatur (T), ist vor allem wegen der endogen synthetisierten und Fettzahl-steigernden Ölsäure (18:1) interessant, die neben der Fettzahl in einem analogen Modell gerechnet wurde. Der Haltungseffekt wurde demzufolge innerhalb Saison und Fütterungssystem analysiert, indem diese drei fixen Effekte zu je zwei Klassen verknüpft (interagiert: Haltung*Fütterung*Saison) wurden, was zu acht LS-Mittelwerten und vier Haltungsvergleichen führte. Die geschätzten LS-Mittelwerte sind von den variablen Effekten PUFA [g/MJ] (beim Modell Fettzahl) oder 18:1 [g/MJ] (beim Modell 18:1) und in beiden Modellen vom Effekt Magerfleischanteil [%] korrigiert. Daten von 291 Schlachtposten (99 CON und 192 ALT) aus 89 verschiedenen Betrieben (37 CON und 52 ALT) wurden analysiert.

Die LS-Mittelwerte reichten von 58,9 bis 60,3. Drei Haltungsvergleiche waren nicht signifikant (P>0,2), währenddem im vierten Vergleich die CON-Schweine der Unterklasse (Kategorie) Molkefütterung im Winterdurchgang eine signifikant höhere Fettzahl als ALT-Schweine aufwiesen (P=0,0002). Dieselben CON-Schweine zeigten auch eine signifikant höhere Fettzahl als im vorangehenden Sommerdurchgang (P=0,047), währenddem bei den anderen drei saisonalen Vergleichen kein signifikanter Unterschied aufgetreten ist (P>0,15). Ein analoges Bild zeigte sich bei den 18:1-Vergleichen bei denen ebenfalls je ein signifikanter Haltungs- und Saisonvergleich vorhanden war, jedoch nicht die gleichen wie bei den Vergleichen der Fettzahl. Unter den Haltungsvergleichen wiesen die CON-Schweine im Sommer der Unterklasse (Kategorie) Alleinfutter höhere Werte als die entsprechenden ALT-Schweine (P=0,019) auf, währenddem bei den saisonalen Vergleichen die ALT-Schweine der Unterklasse (Kategorie) Alleinfutter im Winter gegenüber dem Sommerdurchgang signifikant höhere Werte zeigten (P=0,008). Die anderen nicht signifikanten Vergleiche wiesen P-Werte >0,25 auf. Die 18:1-Werte lagen im Bereich von 42,0 bis 43,8 % der Fettsäuren im Auflagefett.

Es zeigte sich, dass ein Fettzahl- und Ölsäure-steigernder Haltungseffekt des CON-Haltungssystems vor allem im Winter vorhanden war und ein Ölsäure-steigernder Effekt bei ALT-Schweinen bei kalter Temperatur im Winter, der die Fettzahl jedoch nicht merklich beeinflusste. Die endogene Synthese von 18:1 war bei CON-Schweinen bei durchschnittlich 18,5 °C während der Ausmast wahrscheinlich in einigen Fällen erhöht.

Magerfleischanteil in Prozent

Die Resultate basierten auf 5295 AutoFOM-klassifizierten Schweine aus 87 Betrieben (CON: 1973 Schweine, 36 Betriebe; ALT: 3322 Schweine, 51 Betriebe). Der Haltungseffekt war statistisch gleich untereilt wie beim Modell Fettzahl, wurde jedoch zusätzlich innerhalb beider Schlachthöfe analysiert (Haltung*Fütterung*Saison*Schlachthof), was zu acht analogen Haltungsvergleichen (16 LS-Mittelwerte) führte. Folgende Kovariablen wurden zur Korrektur in das Modell einbezogen: verdauliche Energie [MJ], Rohprotein [%], Schlachtgewicht warm [kg] und Mastdauer [Tage].

Die Mehrheit der Vergleiche zeigte, dass die CON-Schweine generell einen höheren MFA als ALT-Schweine aufwiesen. Das traf vor allem auf den ersten Durchgang (Sommer) zu, wo drei der vier Haltungsvergleiche signifikant höher waren ($P<0{,}05$) und beim vierten diese Eigenschaft ebenfalls vorhanden war ($P=0{,}10$). Die LS-Mittelwerte lagen im Sommer bei CON-Schweinen im Bereich von 55,6 bis 56,1 % und bei ALT-Schweinen von 53,4 bis 55,0 %. Im zweiten Mastdurchgang (Winter) war kein signifikanter Unterschied mehr zu verzeichnen, was vor allem auf höhere Werte bei ALT-Schweinen zurückzuführen war; zwei Vergleiche lagen nahe beieinander mit LS-Mittelwerten von 55,8 bis 56,0 % ($P>0{,}6$) und in den zwei anderen Vergleichen zeigten die CON-Schweine im Bereich von 55,5 bis 56,2 % ($P\sim0{,}2$) leicht höhere Werte. Der bemerkenswerte Anstieg bei ALT-Schweinen kann anhand dieses Datensatzes nicht genau erklärt werden. Es muss jedoch angenommen werden, dass bei manchen ALT-Betrieben entscheidende Verbesserungen im Management (Fütterung, Auslese zur Schlachtreife, etc.) gemacht wurden, um die Mastleistungen (und damit die Gewinnmarge) vorhergehender Mastperioden wieder zu erzielen. Die Datenerhebung fiel genau in die Zeit, wo manche ALT-Betriebe das neue Haltungssystem eingeführt hatten. Ein zweiter Grund für die kleinen Unterschiede zwischen CON- und ALT-Schweinen im Winter dürfte auf das *ausserordentlich* milde Winterklima zurückzuführen sein mit den kältesten Temperaturen des Winters 2000/2001 erst im Monat April. Das anhaltend milde Klima in den Monaten Januar bis März verhinderte höchstwahrscheinlich einen erhöhten Fettansatz der Schweine, der generell beobachtet wird bei kalten Aussentemperaturen, in den meisten ALT-Betrieben. Diese Annahmen müssten anhand eines neuen Datensatzes nachvollzogen werden.

PH-Wert des langen Rückenmuskels (M.l.d.)

Der pH wurde in drei Stadien postmortem gemessen, bei 35 Minuten, 2 und 24 Stunden. Die Modelle des Anfangs- und des End-pHs wiesen eine unterschiedliche Anzahl Datensätze auf weil nicht an allen Schlachtkörpern der End-pH gemessen werden konnte. Beim pH-35-Minuten war die Anzahl 4731, beim pH-2-Stunden 4682 und beim pH-24-Stunden 3925

Schlachtkörper. Der Haltungseffekt war statistisch gleich unterteilt wie beim Model MFA das heisst acht Haltungsvergleiche. Die LS-Mittelwerte sind korrigiert nach den Zeiten für die Nüchterung, den Transport und die Ruhezeit am Schlachthof. Der pH-Bereich der 16 Unterklassen (acht Vergleiche) erstreckte sich beim pH-35-Minuten auf 6,35 bis 6,50, beim pH-2-Stunden auf 5,90 bis 6,19 und beim pH-24-Stunden auf 5,29 bis 5,44 (der End-pH ist systematisch auf relativ tiefem Niveau gemessen worden). Der pH-35-Minuten unterschied sich nicht relevant bei sechs von acht Haltungsvergleichen (P 0,175 bis 0,661). In zwei Vergleichen waren die CON-Schweine signifikant tiefer (P 0,020) und fast signifikant (P 0,074), was in dieser Weise auch beim pH-2 Stunden zu sehen war (P 0,023 und 0,137). Die anderen waren bei 2 Stunden p.m. ebenfalls nicht signifikant (P>0,20 bis 0,921). Im End-pH lagen die LS-Mittelwerte recht nahe beieinander, so dass kein signifikanter Vergleich festzustellen war (P 0,104 bis 0,875). Der pH als LS-Mittelwert einer Unterklasse gesehen zeigte keine spezifische Anfangs-Endbeziehung wie es bei Einzelmessungen zu einem gewissen Grad zu erwarten wäre, Unterklassen mit einem tieferen Anfangs-pH wiesen sowohl einen relativ tieferen als auch einen höheren End-pH auf. Die Fütterungspraxis am Abend vor dem Schlachten sollte auf eine genügend lange Nüchterungszeit ausgerichtet sein, das heisst bei frühem Verlad kann sie ausgelassen sonst in den Nachmittag vorverlegt werden. Eine extra Molkegabe spätabends ist mit Blick auf einen tiefer fallenden End-pH zu vermeiden.

1.3. Résumé

Aspects généraux

Dans le cadre d'une étude menée dans des différentes exploitations, on a examiné l'influence du mode de détention sur la qualité de la viande des porcs d'engraissement. Dans ce but, trois caractéristiques de la carcasse ont été exploitées: l'indice de graisse, le pourcentage de viande maigre (PVM) et le pH du muscle longissimus dorsi. Dans cette étude, on a pris en compte les deux systèmes de détention les plus représentatifs en Suisse: le système de détention conventionnel (CON) avec caillebotis intégral et dimensions minimales définies par la loi (0,45 à 0,65 m^2 par animal en pré- et en finition d'engraissement) et le système de détention des programmes de label, dit aussi alternatifs (ALT) avec système multi-surfaces (0,60 à 0,90 m^2 par animal en pré- et en finition d'engraissement), subdivisé en une aire d'alimentation (la plupart du temps avec sol perforé), une aire de repos en dur (non-perforée) couverte de litière, et en plus, un accès permanent à une aire avec climat extérieur de dimensions minimales de 0,45 à 0,65 m^2 par animal en pré- ou en finition d'engraissement. Les exploitations étaient encore subdivisées en deux catégories: celles avec une alimentation au petit-lait liquide (venant la plupart du temps de fromageries pour les CON) et celles affourrageant un aliment complet. Le plan de l'étude était basé sur un dispositif split-plot, pour lequel un effet dû au hasard pour l'exploitation était hiérarchiquement lié aux effets du système de détention et d'alimentation. Les mesures de pH ont été effectuées dans deux grands abattoirs suisses qui ont également mis gracieusement à disposition les données d'abattage qui en découlaient (PVM et poids mort). Pour les deux abattoirs, le débit horaire était d'environ 240 animaux étourdis avec du CO_2. Les données ont été récoltées pour la saison d'engraissement d'été 2000 et la saison d'hiver 2000/2001. Les porcs prévus pour l'étude, en général 20 à 30 par exploitation et par période d'engraissement, étaient gardés en groupe dans des boxes séparés ; pour le reste, ils étaient nourris et soignés comme les autres porcs de l'exploitation. Des échantillons d'alimentation ont été prélevés tout au long de la période d'engraissement et caractérisés par l'analyse de Weender et une chromatographie en phase gazeuse des acides gras. Les porcs étaient déclarés prêts à l'abattage conformément aux méthodes de sélections habituelles. Il y a eu un à trois lots d'abattage par période d'engraissement qui ont tous été inclus dans l'étude. Pour le critère indice de graisse, l'unité expérimentale était le lot d'abattage, car l'échantillon de graisse destiné à l'analyse correspondait à un mélange de prélèvements de graisse de toutes les carcasses d'un lot d'abattage. Par contre, pour les critères PVM et pH, on a défini comme unité expérimentale les valeurs individuelles de chaque animal. Les moyennes des moindres carrés ont été pondérées par les effets des différentes variables (suivant les critères mentionnés plus bas) en étant modélisées comme covariables d'un mo-

dèle linéaire à effets mixtes. La saisie non-balancée des données a été analysée avec le procédure MIXED de SAS (édition 8.02) en utilisant la méthode du maximum de vraisemblance restreinte (REML:, Restricted Maximum Likelihood Method).

Indice de graisse du tissu adipeux

L'indice de graisse exprime le nombre des doubles liaisons des acides gras de la couche externe du tissu adipeux et il est mesuré en routine dans les grands abattoirs suisses. Les lots d'abattage avec des valeurs supérieures à 62 (comparable à des valeurs d'iode de 68 à 69) sont frappés d'une déduction, ceci pour obtenir une qualité acceptable quant à la consistance et à l'oxydation de la graisse des produits carnés à élaborer. Ces dernières années a eu lieu une polémique pour savoir si les porcs ALT obtenaient un plus grand indice de graisse que les porcs CON (effets du système de détention et effets saisonniers). Un possible effet saisonnier, principalement dû à la température ambiante, est avant tout intéressant à cause de l'acide oléique (18:1) synthétisé de manière endogène qui peut augmenter l'indice de graisse et qui a été calculé selon un modèle analogue à côté de celle de l'indice de graisse. L'influence du mode de détention a été par la suite analysée pour chaque saison et chaque type d'alimentation en associant ces trois effets fixes comprenant chacun deux classes (interaction détention*alimentation*saison), ce qui a conduit à huit moyennes des moindres carrés et quatre groupes de comparaison de détention. Les estimations des moyennes des moindres carrés sont pondérées par les effets variables PUFA [g/MJ] (pour le modèle d'indice de graisse) ou 18:1 [g/MJ] (pour le modèle 18:1), et dans les deux simulations par l'effet du pourcentage de viande maigre [%]. Les données des 291 lots d'abattage (99 CON et 192 ALT) de 89 exploitations différentes (37 CON et 52 ALT) ont été analysées.

Les moyennes des moindres carrés passaient de 58.9 à 60,6. Trois des comparaisons du mode de détention ne montraient pas de différences significatives (P>0,2), alors que pour la quatrième comparaison, les porcs CON de la sous-classe (catégorie), alimentation au petit lait pendant la période d'hiver, montrait un indice de graisse significativement plus haut que celui des porcs ALT (P=0,0002). Ces mêmes porcs CON montraient aussi un indice de graisse significativement plus haut que pendant la période d'été précédente (P=0,047), alors que pour les trois autres groupes de comparaison saisonnière aucune différence significative n'apparaissait (P>0,15). Une image analogue ressortait de la comparaison des 18:1, pour lesquels une comparaison des conditions aussi bien de détention que saisonnières était significative, mais par contre pas dans les mêmes catégories que pour la comparaison de l'indice de graisse. Dans la comparaison des modes de détention, les porcs CON présentaient en été dans la sous-classe (catégorie) aliment complet, de plus hautes valeurs que la catégorie correspondante chez les porcs ALT (P=0,019), alors que pour les comparaisons saisonnières, les porcs ALT de la sous-classe (catégorie) aliment complet en hiver mon-

traient des valeurs significativement plus élevées que pour la saison d'été (P=0,008). Les autres comparaisons présentaient des valeurs de P>0,25 non significatives. Les valeurs de 18:1 se situaient dans une zone allant de 42.0 à 43.8% d'acide gras dans le tissu adipeux.
Les résultats montraient qu'il existait, en particulier en hiver avec le mode de détention CON, un effet potentialisateur du mode de détention sur l'indice de graisse et les acides oléiques et, chez les porcs ALT, un effet potentialisateur sur les acides oléiques lors de basses températures en hiver, mais qui n'influençait pas de façon perceptible l'indice de graisse. Chez les porcs CON, la synthèse endogène de 18:1 était probablement augmentée dans quelques cas à une température moyenne de 18,5 °C pendant la période de finition.

Pourcentage de viande maigre

Les résultats se basaient sur 5295 porcs classifiés par AutoFOM, provenant de 87 exploitations (CON: 1973 porcs, 36 exploitations; ALT: 3322 porcs, 51 exploitations). L'effet du mode de détention a été statistiquement subdivisé de la même manière que pour la simulation de l'indice de graisse, mais a en plus été analysé dans les deux abattoirs (détention*alimentation*saison*abattoir), ce qui mène à huit le nombre de comparaisons analogues du mode de détention (16 moyennes des moindres carrés). Les covariables suivantes ont été ajoutées pour pondérer le modèle: l'énergie digestible [MJ], la protéine brute [%], le poids de la carcasse chaude [kg] et la durée de l'engraissement [jours].
La majorité des comparaisons montrait qu'en général les porcs CON présentaient un plus grand PVM que les porcs ALT. C'était particulièrement frappant pendant la première période de relevés (été), pendant laquelle trois des quatre comparaisons du mode de détention étaient significativement plus élevées (P<0,05), et que ces caractéristiques se retrouvaient aussi dans la quatrième (P=0,10). Les moyennes des moindres carrés se situaient en été chez les porcs CON entre 55,6 et 56,1% et pour les porcs ALT entre 53,4 et 55,0%. Pendant la deuxième période d'engraissement (hiver), il n'y avait plus de différences significatives à remarquer, ce qui était principalement attribuable aux plus hautes valeurs des porcs ALT; deux comparaisons se trouvaient très proches l'une de l'autre avec des moyennes des moindres carrés de 55,8 et 56,0% (P>0,6) et dans les deux autres comparaisons les porcs CON montraient des valeurs légèrement plus élevées avec des moyennes des moindres carrés de 55,5% et 56,2% (P~0,2). L'augmentation remarquée chez les porcs ALT ne peut pas être précisément expliquée par la saisie de ces données. Il faut pourtant admettre que dans maintes exploitations ALT, une nette amélioration de la gestion (alimentation, sélection des animaux prêts à l'abattage, etc.) a été faite pour atteindre les performances d'engraissement (et donc la marge de bénéfice) de la précédente période d'engraissement. La saisie de données est tombée exactement pendant la période où beaucoup d'exploitations ont adopté le nouveau système de détention. Une deuxième raison pouvant

expliquer le peu de différence entre les porcs CON et ALT en hiver pourrait être due à une saison d'hiver 2000/2001 *extraordinairement* douce, avec les températures les plus froides de la saison qui n'apparaissent qu'en avril. La douceur persistante du climat janvier à mars empêchait probablement une augmentation de la synthèse de graisse des porcs qui a normalement lieu, dans la plupart des exploitations ALT, lorsque les températures extérieures sont froides. Ces hypothèses devraient être confirmées par de nouvelles saisies de données.

Valeur du pH du muscle longissimus dorsi (M.l.d.)

Le pH a été mesuré post-mortem à trois intervalles différents, à 35 minutes, 2 heures (pH initial) et 24 heures (pH final). Les mesures de pH pour chaque intervalle de temps présentaient un nombre différent de relevés, car les dernières mesures du pH n'ont pas pu être effectuée sur toutes les carcasses. Pour le pH à 35 minutes, le nombre était de 4731 carcasses, à 2 heures de 4682 et à 24 heures de 3925. Les effets du mode détention étaient subdivisés comme pour la simulation PVM, cela veut dire huit comparaisons du mode de détention. Les moyennes des moindres carrés sont pondérées par les temps de jeûne, de transport et de repos à l'abattoir. La zone du pH pour les 16 sous-classes (8 comparaisons) s'étendait pour le pH à 35 minutes de 6,35 à 6,50, pour le pH à 2 heures de 5,90 à 6,19 et pour le pH à 24 heures de 5,29 à 5,44 (le pH final a systématiquement été mesuré à un niveau assez bas). Le pH à 35 minutes ne se différenciait pas de façon significative dans six des huit comparaisons du mode de détention (P 0,175 à 0,661). Pour deux comparaisons, les porcs CON étaient significativement plus bas pour l'un (P 0,020) et presque significativement plus bas pour l'autre (P 0,074), ce qui se retrouvait de la même manière pour le pH à 2 heures (P 0,023 et 0,137). Les autres n'étaient pas non plus significatifs 2 heures p.m. (P>0,20 à 0,921). Pour la mesure finale du pH, les moyennes des moindres carrés étaient très proches les unes des autres, si bien qu'aucune comparaison significative n'a pu être faite (P 0,104 à 0,875). Le pH considéré comme moyenne des moindres carrés d'une sous-classe ne montrait pas de relation entre le pH initial et le pH final, comme on aurait pu, dans une certaine mesure, s'y attendre chez le pH des carcasses individuelles. Les sous-classes avec un pH initial bas présentaient aussi bien un pH final bas, qu'un pH final haut. Les pratiques alimentaires la veille de l'abattage doivent intégrer un intervalle de jeûne suffisamment long, ce qui veut dire que lors du chargement aux petites heures du matin, l'affouragement peut être supprimé le soir avant ou alors déplacé à l'après-midi. Une ration supplémentaire de petit-lait tard dans la soirée est à éviter dans l'optique d'éviter un pH final bas.

2. Introduction and research issues

A rising public demand for more animal welfare in pig housing systems had practical consequences in 1999 in Switzerland. Two new animal protection ordinances in the Animal Protection Act became effective in January 1999, defining better standards for pig housing systems, either with or without an outdoor area (ordinances SR[4] 910.132.4 and SR 910.132.5). The legislation outlined the aim for higher animal welfare standards in pig production through a coeval implemented act prescribing a non-perforated floor type in the rest area for new and altered buildings (SR 455.1, Animal Protection Act 21). This encouraged a remarkable number of farmers to change their housing systems and to allow the fattening pigs access to an outdoor area meeting the regulations of SR 910.132.5. Fig. 1 shows this development of pigs and farms from 1993 to 2003. A noticeable increase (doubling) was registered in the year 1999 compared to the year 1998, when the Act became effective (in 1999).

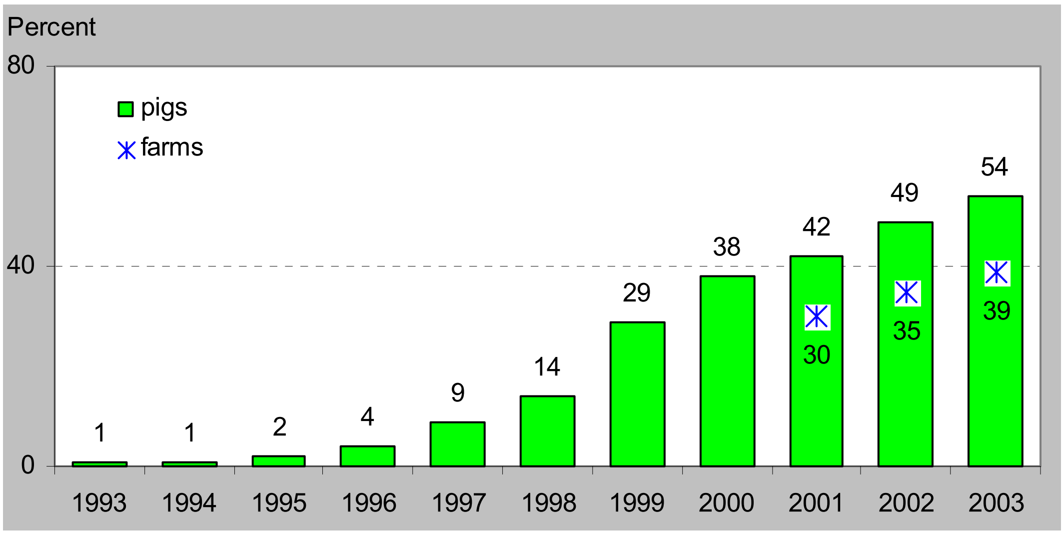


Fig. 1: Development of alternative housing systems (proportions of pigs and farms)

According to the Swiss ordinance SR 910.132.5 (Source: BLW, Agrarberichte/Agricultural annual reports 2002 to 2004). The proportion of farms was available only back to 2001.

To which extent (if at all) does the housing system and related potentially interacting effects (e.g. feeding system, season) influence carcass and pork quality traits? – The aim of this study was to evaluate under field conditions possible differences between the two most common housing systems for fattening pigs in Switzerland: the conventional (indoor) housing system (CON), featuring a fully slatted concrete floor; and a semi-open, alternative housing system (ALT), featuring multi-surface floor types and including a permanent, accessible outdoor area.

[4] Systematische Sammlung des Bundesrechts (SR)

The present study investigated three criteria related to pork quality: the fat score, the fat-free lean proportion and the pH of M.l.d. The fat score (comparable to the iodine value) is a measure for the saturation of fatty acids of the adipose tissue. Fattening pigs in ALT-housings are exposed to changing ambient temperature levels and more extreme temperatures as well than pigs in CON-housings (where they don't have access to an outdoor area). Particularly extreme temperatures influence the fatty acid composition (and hence the consistency) of the back fat (e.g. Fuller et al., 1974; Lefaucher et al. 1991). The hypothesis is that ALT-pigs could have a softer back fat than CON-pigs either due to an effect of colder or warmer temperature level than indoors. Furthermore, extreme climatic conditions also have an impact on the proportion of fat-free lean (e.g. Verstegen et al., 1978 and 1985; Lefaucher et al. 1991) leading to the hypothesis that ALT-pigs could feature a lower fat-free lean proportion than CON-pigs.

The pH of the longissimus dorsi muscle (M.l.d.) is one parameter describing the meat quality postmortem. The pH is influenced greatly by the conditions during the last day before slaughtering such as fasting time, transport and lairage time, and undergone stress before stunning (e.g. Warriss et al., 1994; Van der Wal et al., 1997 and 1999). Furthermore, ALT-pigs are thought to be better accommodated with changing ambient temperatures, and, based on the more animal friendly pen arrangements allowing more exercising their natural exploring habits, also can cope better with stressors on transport and in the lairage (Beattie et al., 2000b). The hypothesis was whether ALT-pigs exhibited therefore a higher, i.e., slower pH-decline and a higher ultimate pH than CON-pigs.

3. Literature review

There is little scientific literature published comparing meat quality traits of pigs from intensive indoor and (intensive) outdoor-access housing systems, and if so, then they often included free range pigs on pasture or similar systems with outside lot, yard, paddock, etc. (e.g. Warriss et al., 1983; Enfält et al., 1996; Sather et al., 1997; Bridi et al., 1998; Gentry et al., 2002; Stern et al., 2003). They all have in common an outdoor system designated as extensive or semi-intensive housing systems. The alternative housing systems in this study should be seen as an intensive or at least semi-intensive system concerning performance, but by no means as an extensive one.

3.1. Fat score

3.1.1. Fat score in Switzerland

Prabucki introduced an analysis method classifying the adipose tissue's firmness for practical use in the slaughterhouses, referring to the iodine value (Margosches et al. 1929), called the fat score (Häuser and Prabucki, 1990). Based on this method, the routine measurements in Swiss slaughterhouses started in 1988. Figures from one major slaughterhouse show that in the first year (1988), only about 50 % of the analysed samples (slaughtered market groups) met the requirements of the processing industry; a year later in 1989 the rate rose to 80 %, improving continuously until 1998 to over 90 % (Scheeder et al., 1999). Today the major slaughterhouses in Switzerland have adapted the classification of the adipose tissue in their routine quality control. A threshold of fat score ≤62 has been implemented by Prabucki (Häuser et al., 1989; Prabucki, 1991) in order to meet the requirements from the food technological point of view (preventing fat-degrading processes during storage of meat products such as oxidation, rancidity and colour changes). Accompanying educational publicity addressing the feed industry (total fat and PUFA in diet), the farmers (management, feed intensity), breeding organisations (leanness and back fat, watery fat cells, etc.), and the slaughterhouses (fat sampling and analysis) has been carried out (Prabucki, 1991; Schwörer et al., 1996). The threshold corresponds to a PUFA level in the back fat of 12 to 13 % (Häuser and Prabucki, 1990).

3.1.2. Unsaturated fatty acids in the diet and the adipose tissue

Oleic acid (18:1) is the major component representing >40 % in the fatty acid profile of lard (Christie et al., 1972; Wood et al., 1989). Oleic and linoleic acid (18:2) feature a clear positive correlation to objective and subjective firmness measure methodologies (Wood et al., 1989; Gläser et al., 2004). Within the PUFA fraction, 18:2, an n-6 fatty acid, is the main component in the pig's adipose tissue (12 to 13 %) besides a small amount of ≤1 % linolenic acid (18:3, an n-3 fatty acid) (Wood et al., 1989; Mourot, 2001). According to Enser (1974), 18:2 is twelve times more susceptible to oxidative degradation, as compared to 18:1 in pork on the shelf.

Numerous investigations report the close relationship between dietary linoleic acid (and other PUFA) and linoleic acid (and other PUFA) in adipose and other fat tissue (e.g. Ellis and Isbell, 1926; Koch et al., 1968; Brooks, 1971; Morgan et al., 1991; Warnants et al., 1996; Wiseman and Agunbiade, 1998; Lebret and Mourot, 1998) in intensively fed pigs. Linoleic acid, together with other PUFA, are thought to be deposited almost completely into adipose tissue (Brooks, 1971; Warnants et al., 1996; Lebret and Mourot, 1998), mainly at the expense of endogenously synthesised 18:1 (Warnants et al., 1999), and not in competition with dietary 18:1 (Eder et al., 2001). However, the latter statement seems to be fat proportion-dependent (see next paragraph). The main response in the adipose tissue after changing the concentration of dietary linoleic acid is seen within the first two weeks, thereafter showing a decreasing effect for about six weeks (Courboulay and Mourot, 1995; Warnants et al., 1999).

The relationship of back fat thickness and iodine value (and fat score) are inverse, such that fatter pigs feature lower fat scores on a given diet, owing to a dilution of linoleic acid in a greater proportion of back fat (Martin et al., 1972; Wood, 1984; Lebret and Mourot, 1998; Pettigrew and Esnaola, 2001). Feeding a low-energy diet (e.g. 35 g fat and 13.0 MJ DE/kg during 20 to 68 kg BW) or a restrictive regime (e.g. 4.8 % lipid, 10.8 MJ DE/kg, 5 % 18:2 of DE, 0.8. to 2.0 kg intake/day during 20 to 90 kg BW) has a back fat-softening effect, resulting in significantly higher water and linoleic acid levels in a concomitantly decreased lipid fraction (Wood, 1984; Wood et al., 1986). Generally, the pigs fed restrictively feature a diminution of back fat proportional to the reduction of daily feed intake (Seewer et al., 1994). On the other hand, feeding a high-energy diet based on more fat (e.g. up to 13 % fat in diet) causes a higher proportion of back fat via incorporation of dietary fat with a simultaneous reduction of the de novo synthesised fatty acids (Allee et al., 1971). However, keeping the fat fraction constant (4 %) and increasing the linoleic proportion (36, 48 and 61 % of 18:2) in an isoenergetic diet causes a stimulation of the de novo synthesised fatty acids (including the monounsaturated 18:1), increasing eventually the back fat proportion via two ways: incorporating linoleic acid from the diet and an enhanced de novo synthesis (Mourot et al., 1994).

The crucial evidence of dietary PUFA and back fat firmness is reflected by the linear increase of the iodine value (Wood, 1984) with a correlation of 0.8 to 0.9 (Madsen et al., 1992; Warnants et al., 1996) which means that dietary factors and body composition are effects to be regarded in fat score models of the present study.

3.1.3. Optimal ambient temperature ranges for fattening pigs

The impact of ambient temperature on development of the body (carcass, allocation and composition of back fat) has been the subject of many studies during the last decades and is well known (e.g. Verstegen et al., 1973; Holmes and Close, 1977; Close et al. 1978; Mount, 1979; Lefaucher et al., 1991). From the point of view of the homeothermic pig, the environmental temperature is either in a thermoneutral zone, defined with an upper (CT_{upper}) and a lower (CT_{low}) critical temperature, or beyond it. The thermoneutral zone is the temperature range in which basal metabolism (heat production) is minimal, constant, and independent of the ambient temperature. It depends, inversely interrelated, on the growth stage of a pig (Holmes and Close, 1977; Mount, 1979). Pigs can modify heat loss through different behaviours (physical activity, nest building, huddling together, spreading out, etc.) when pen structure and facilities allow choosing their microenvironment, and can adapt to different temperatures (Mount, 1979). This is important in considering different housing types and pen arrangements. Verstegen and van der Hel (1974) calculated the CT_{low} for group-housed pigs (40 kg BW) in pens on different floor types. For pigs kept on a fully-slatted concrete floor (comparable to the conventional housing systems), the CT_{low} is 19 to 20 °C and on asphalt covered with a 2.5 to 3 kg/m^2 straw bed (comparable to the alternative housing systems), the CT_{low} is 11.5 to 13 °C, corresponding to a 16 % lower heat loss in the bedded floor type. Holmes and Close (1977) calculated the thermoneutral zone, giving values (averaged from different floor types) of group-housed fattening pigs at different growth stages of 17 and 30 °C (20 kg BW), and of 14 and 28 °C (100 kg BW) each for CT_{low} and CT_{upper}, respectively. The complexity of thermal environment aspects are not subject to being discussed here in detail, but the differences of minimal T_a at different housing conditions might be considered in the context of altering an existing housing system. Mount (1979) gave following lower temperature limits for different housing conditions:

Examples	minimal T_a (35 kg BW)
- Insulated housing and floor, no draughts	14 °C
- Insulated, draughts present	20 °C
- Uninsulated, no draughts, winter	16 °C
- Uninsulated, draughts, winter	22 °C
- Good straw bed	10 °C

In practise, for housed pigs the minimal temperature level is recommended at 24 °C at weaning, falling to 15 °C for growing-finishing pigs (100 kg BW) (Mount, 1979).

3.1.3.1. Ambient temperature below the lower critical temperature

When ambient temperature (T_a) remains continuously below the lower critical temperature (CT_{low}), a shift from leaf- to back fat takes place (Fuller and Boyne, 1971a and b; Verstegen et al., 1978; Verstegen et al., 1985; Le Dividich et al., 1987; Lefaucher et al., 1991), resulting in a lower lean-to-fat ratio of the carcass. The quantity of metabolisable energy or feed per unit of weight gain is increased, due to more energy used for maintaining the body temperature (Mount, 1979, p. 206; Verstegen et al., 1985; Le Dividich et al., 1985).

Fat deposition during the growth is constantly increasing, as compared to a decreasing protein accretion, building particularly in the finishing period an increasing subcutaneous fat layer (e.g. Kirchgessner, 1997). Fatty acids of the adipose tissue are de novo synthesised mainly in the adipose tissue's fat cells, as compared with other species (e.g. birds) where the liver (being protected from the ambient temperature) is the organ of fat synthesis (O'Hea and Leveille, 1969). Cold-exposed back fat cells are stimulated, increasing the proportion of endogenously synthesised monounsaturated oleic acid (18:1) softening the back fat with falling temperatures (Mac Grath et al. 1968; Lefaucher et al., 1991). Fuller et al. (1974) reported inverse temperature-dependent iodine values of several carcass sites (shoulder, mid-back and rump) of pigs raised from 20 to 90 kg BW at 5, 13, and 23 °C (the latter representing the thermoneutral range). This increment is coercive a result of a higher activity of the endogenously synthesis of 18:1, stimulated by cold ambient temperatures. Le Dividich et al. (1987) and Lefaucher et al. (1991) noticed significantly higher 18:1 (and other UFA, 16:1, 18:1, 20:1) at 12 than at 28 °C, and, furthermore, higher percentages for external and total fat.

3.1.3.2. Ambient temperature above the upper critical temperature

Ambient temperatures above the thermoneutral zone (the upper critical temperature is 28 °C) cause a reduction of feed intake (Holmes, 1973; Stahly and Cromwell, 1979; Quiniou et al., 2000), reduced energy retention (Quiniou et al., 2001) and back fat layer, leading to a reduced growth rate (Holmes, 1973; Giles et al., 1988; Rinaldo et al., 2000). Moreover, at high T_a, nitrogen retention and protein deposition is reduced. Feeding an energy-enriched diet (higher fat proportion) in order to compensate for the reduced feed intake (and reduced growth rate) ensures that the energy surplus is deposited as fat (Holmes, 1973; Stahly and Cromwell, 1979; Katsumata et al., 1996; Le Bellego et al., 2002).

At a temperature level above CT_{upper}, opposite to the climatic situation below CT_{low}, a shift of adipose to internal fat (leaf fat) takes place, resulting in less subcutaneous fat (Le Dividich et al., 1987; Lefaucher et al., 1991). The de novo synthesis in back fat cells is also influenced by high temperatures, altering the profile featuring more saturated (16:0 and 18:0) and less monounsaturated (18:1) fatty acids, and leading to a firmer fat with a lower iodine value (McGrath et al. 1968; Lefaucher et al., 1991).

3.2. Fat-free lean proportion

Non-nutritional and nutritional factors determine the growth of a pig. If the first factor, in this context the ambient temperature, is within the thermoneutral range (see next paragraph) for the pigs' need, then growth is, beside genetic factors, mainly determined by nutritional factors. In the context of this study, energy and protein are most important. These two main nutritional factors were considered different between the two feeding systems due to the fact that farms with whey feeding systems are preparing the liquid soup daily on farm (see 4.1). One kilogram of fresh whey consists of 50 to 60 g dry matter containing 78 % carbohydrates, 13 % protein, traces of fat (0.4 to 0.7 %), 8 % minerals, and an energy content of 14.7 MJ (Boltshauser et al., 1993). The whey-proteins (mainly albumines) typically have a high nutritive value, i.e., rich in lysine (Kallweit et al., 1988; Boltshauser et al., 1993), the first limiting amino acid for pigs (Close, 1994).

On the time axis of growth, the basic body components – bone, muscles and fat – are built in that order (Kirchgessner, 1997). In the finishing stage, the daily gain consists of about 50 % fat that reflects about 80 % of gained energy (Menke and Huss, 1987). This implies limiting the pig's life period at the optimal point of interest between production factors, such as feed-to-gain ratio, and physiological factors, mainly the additional protein accretion. The latter, in relation to fat deposition, determines the leanness of the carcasses. The conceptual relationship (Fig. 2) of protein accretion (b) and energy intake (a) shows that protein accretion increases linearly at a certain intake of energy until it reaches an upper limit given by nutritional and/or non-nutritional factors (flat curve). A surplus of energy will result in fat deposition. The pig accretes protein at a lower level and for a restricted time frame also when energy intake is close to maintenance (M), taking then the energy from the body fat. This means that each increment of energy intake results in a relatively higher fat deposition then protein accretion. The important consequences are, firstly, a more complicated energy than protein management, and secondly, in a group of pigs, the speed of growth determines the fatness in such a way that faster growing pigs are fatter than the others (Pettigrew and Esnaola, 2001). The farmers (in this study) reacted on this aspect practising split marketing.

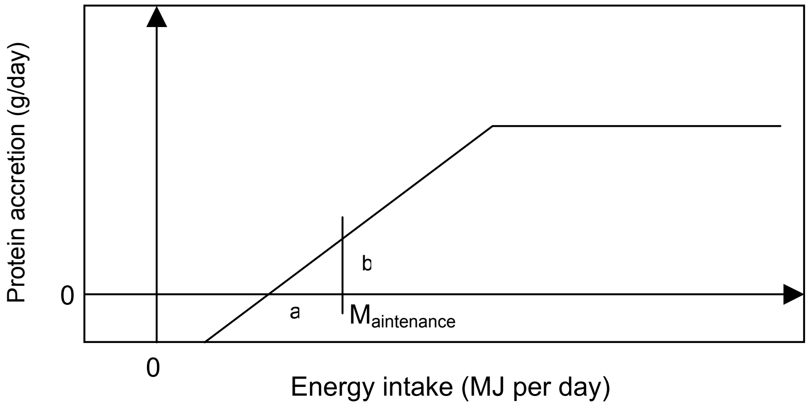


Fig. 2: Conceptual relationship of protein accretion rate to energy intake
(adapted from Pettigrew and Esnaola, 2001.)

In connection with the alternative housing system used in our study, the impact of mainly low but also high ambient temperatures on the fat-free lean are of interest. Some general and important facts of ambient temperature and growth performance shall be cited. When temperature falls beyond the thermoneutral range, the range where energy for maintaining body temperature is minimal, constant and not dependent on ambient temperatures (Mount, 1979), then the pig needs additional energy for either evaporative heat loss at high temperatures, or for heat production at low temperatures (e.g. Holmes and Close, 1977; Mount, 1979). This means that the energy metabolism, the use and deposition of energy, depends on the ambient temperature. The energy needed for maintenance rises gradually and significantly at lower than thermoneutral levels i.e., at 13 °C, and more accentuated at 5 °C, as compared to a normal 23 °C (in the entire growing-finishing period), and the retention of energy is higher as well (Fuller and Boyne, 1971b). Newer experiments show a continuous significant weight gain reduction at falling temperatures beginning at 28 °C when the dietary energy level remains constant (that is, no extra energy to compensate the increasing heat loss) which is more accentuated in the range below 20 °C than above. Le Dividich et al. (1987) published data of 49 g/day less weight gain in the range above 20 °C (28 to 20 °C), and 107 g/day in the range below 20 °C (20 to 12 °C). The extra digestible energy to compensate that, according this study, amounts to 0.20 and 0.44 MJ per °C between 28 to 20 °C and 20 to 12 °C, respectively. A similar value (15 g/°C) for the range 20 to 5 °C was reported by Verstegen et al. (1978).

The consequences of varying temperatures on the carcass composition depend, therefore, primordially on the energy (including fat) regime. Considering an energy supply to be in practise rather somewhat higher than the effective need (assuming that farms implementing elaborated feed regimes that would include the ambient temperature as a factor were virtually not existing), focuses the interest on possible changes of carcass composition at temperatures beyond thermoneutrality. At such conditions, low temperatures (below CT_{low}) lead to fatter ad lib fed pigs (Verstegen et al., 1978; Verstegen et al., 1985) or increase the subcutaneous fat layer, generally due to a shift from internal to adipose fat (back fat) (Lefaucher et al., 1991). If the energy level is not increased at 12 °C (that is no compensation for the heat loss), the carcasses then are leaner than those from pigs kept at 20 °C (Verstegen et al., 1978; Le Dividich et al., 1985).

Generally at high ambient temperatures, the opposite devolution as before, a shift from subcutaneous to internal (leaf) fat occurs (Lefaucher et al., 1991). Increasing temperatures and surpassing the CT_{upper} (above 28 °C) cause a reduced feed intake (Holmes, 1973; Stahly and Cromwell, 1979), which is curvilinear relative to temperature, and also body weight-dependent in such a way that finishing (heavier) pigs are more susceptible than growing (lighter) ones (Quiniou et al., 2001). This causes a decreased energy retention leading to a smaller percentage of back fat and a reduced growth rate (Holmes, 1973; Giles et al., 1988; Rinaldo et al., 2000).

For optimal growth it is important to provide a microclimate, which enables maintaining the ambient temperature within the thermoneutral zone (Verstegen et al., 1978; Mount, 1979). However, the pig can modify its heat loss through different behaviours (nest building, huddling together, spreading out, etc.) when pen structure and facilities allow choosing different microenvironments, and so can adapt to different temperatures (Mount, 1979). These behaviour properties allow implementing new housing systems (i.e. open-front buildings) and different pen arrangements (i.e. covered and littered resting area). Quiniou et al. (2001) calculated a CT_{low} of 23 °C to be valid for the entire growing-finishing stage (30 to 90 kg BW). The extra feed compensating the heat loss when T_a falls below that limit depends on body weight and increases, the lower the actual ambient temperature falls. The authors calculated an average extra feed intake (DE: 15.7 MJ/kg DM) of 19 g/day per °C for the range of 12 to 24 °C, and 27 g/day per °C for the range of 12 to 18 °C (see also 3.1.3).

3.3. PH postmortem

3.3.1. PH course

The decline of pH p.m. depends on intrinsic factors (species, type of muscle, animal factors) and extrinsic effects such as environmental temperature during slaughter process, administration of drugs (Lawrie, 1998), fasting time, handling and time of transport and lairage (see further below of this paragraph). Falling from a level of 7 in the living animal, the normal course of the pH-curve postmortem in the M.l.d. is assumed to be linear, passing a value of about 6.2 after one hour at a speed of 0.01 units per minute, then featuring a slower curvilinear fall towards the end pH of 5.4 to 5.5 after 3 to 6 hours (Offer, 1991; Lawrie, 1998; Honikel, 1998). However, the variation from pig to pig is large (Kallweit et al., 1988; Lawrie, 1998; Honikel, 1998) and can vary remarkably between the slaughterhouses as well (Kallweit et al., 1988; Honikel, 1998; Gispert et al., 2000).

A precipitate fall below 5.8 at 45 min p.m. (about 0.02 units per minute), designated as pale, soft and exudative (PSE) meat, is caused by an enhanced catabolism of glycogen to lactate at concomitant higher temperatures (>38 to 41 °C at 45 min p.m.), which in turn causes protein denaturation leading to undesired higher drip loss and eventually, depending on the cooking temperature as well, to a shrinkage of chops with lower eating quality (Honikel, 1987b; Offer, 1991; Lawrie, 1998; Honikel and Schwägele, 1998). This is related to a genetic predisposition expressed as stress susceptibility, the malignant hyperthermia MH (Fuji et al., 1991; McLennan and Phillips, 1992). MH-positive pigs are more likely to show PSE-meat than MH-free pigs (e.g. Webb and Simpson, 1986; Eikelenboom et al., 1988), a situation becoming more serious when diverse pre-slaughter stressors affect the animals (Warriss et al., 1994; D'Souza et al., 1998; Gispert et al., 2000; Fernandez et al., 2002). However, especially developed low-stress handling and devices applied during lairage and the moments before stunning showed that slaughterhouse conditions can be optimised not to impair meat quality (Aaslyng and Barton Gade, 2001). A second defect called DFD-meat (dark, firm, dry) is, contrary to PSE, characterised by a slow fall of the pH course remaining at a too high ultimate pH. of above 6.2 (Kallweit et al., 1988; Honikel and Schwägele, 1998) or 6.1 (Barton Gade et al., 1995) in the M.l.d.

3.3.2. PH and fasting time

The feed withdrawal (access to water has to be provided during the entire fast) on the farm determines the energy store in form of glycogen in the muscles until and at killing (Warriss and Brown, 1983). In order to prevent a too high or too low energy level, the fast has to take into account the transport and lairage time. Depending on these factors a total fasting period of 8 to 18 hours is recommended, resulting in a feed withdrawal on the farm of 4 to 12 hours. A too short fast, or no fast at all, let the pigs' energy reserve be high at the moment of killing, leading to more PSE-meat with lower levels than the normal pH at 45 min p.m. (a special case concerns the Hampshire breed, see 3.3.5 second paragraph), whereas a too long fast can lead to DFD-meat with higher pH levels than normal at 45 min and 24 h p.m., due to exhausted energy reserves and in consequence little lactic acid production in the muscle cells (Warriss and Brown, 1983; Fischer et al., 1986; Kallweit, 1992; Troeger et al., 1998; Eikelenboom et al., 1991). Numerous trials report differences of pH-45 min and/or pH-24 h when comparing diverse fast durations (e.g. Warriss et al., 1989; Eikelenboom et al., 1991; Wittmann et al., 1994; Stalder et al., 1998) and underline the negative effects on meat quality (i.e. ultimate pH) of inadequate fasting times. However, a prolonged total fast, either on the farm and/or by a longer lairage, is not a remedy facing PSE-, but raises the risk of negative effects such as DFD-meat in the M. semispinalis capitis (Fischer et al., 1986) and weight loss in the liver and carcass (Warriss, 1982b; Fischer et al., 1986). The genetic factors are discusses below.

3.3.3. PH and handling before slaughtering

A great impact has the last handling before stunning, which can nullify a proper fast and stress-reducing lairage (e.g. Van der Wal et al., 1997; Van der Wal et al., 1999). If a particularly low-stress treatment to fit in with pig behaviour, developed in Denmark, is applied in the pre-slaughter stage, then pigs are able to cope with new environments and conditions, including when mixed during transport and the following lairage. A trial carried out by Aaslyng and Barton Gade (2001) showed that under such conditions (e.g. no electrical goad in lairage, building groups of 5 out of 15 pigs, and gently moving them to the stunning point, etc.), effects like the duration of lairage (<0:30 h, 1:20 h and 3 h), the lack of sprinkling (in spring at relatively low ambient temperatures, ≤11 °C) as well as letting the pigs build mixed groups of 15 at the loading on the farm, did have no negative impact on the pH levels and the temperature postmortem or on the meat quality the day after.
But in general (in practise), stressors (new environment, mixing groups, fighting, noise, heat, electric goad, etc.) during transport, lairage and in the gangways to the stunning place enhance the energy mobilisation in the pig, whereas stress-lowering handling, such as not mixing unfamiliar groups, sprinkling during lairage, moving pigs gently with a board, etc., prevent this meat quality-impairing effect (Kallweit et al., 1988; Warriss et al., 1994; Warriss, 1995).

3.3.4. PH in relation with housing system

Alternatively housed pigs with free access to an outdoor area live in a more animal-friendly environment where they can explore their motional habits to a greater extent. They feature lower stress-related hormone levels during their lifetime and spend more time in exploration than conventional pigs (Beattie et al., 2000b; Jönsall et al., 2001; Lebret et al., 2003).
Beside the advanced and beneficial animal welfare situation in alternative housing systems, the assessment of pork (technological and sensorial) is not consistent among authors of different studies. Negative quality traits of pork from alternatively raised pigs and their impact were reported by Enfält et al. (1996), and negative and positive by Lebret et al. (2003), whereas no differences were reported by Warriss et al. (1982), Gandemer et al. (1990), Van der Wal et al. (1993), Bridi et al. (1998), Geverink et al. (1999), and Stern et al. (2003). Positive impacts have been published by Petersen et al. (1997a/b), and Beattie et al. (2000a). The colour of meat relates to pH decline postmortem and water-holding capacity in such a way that darker muscles (more red fibres) feature a lower glycolytic potential, resulting in a

slower pH fall and a better water-holding capacity as compared to meat with more white muscle fibres. The colour can also be connected to normal, DFD and PSE-meat. This means that meat featuring a higher proportion of red muscle cells (less light reflectance, darker colour) would be less sensitive to a precipitate post mortal pH decline and the concomitant negative impacts on meat quality (Kallweit et al, 1988; Offer et al., 1989; Kauffman et al., 1993; Fernandez et al., 1995; Larzul et al., 1997; Honikel, 1998). Reports about meat colour from pigs raised in alternative housings are not consistent. Enfält et al. (1996) report paler colour (and concomitant lower pH-24 h and higher drip loss), whereas gradually more reddish colour in part of the carcass muscles is observed in several studies (Petersen et al., 1997b; Bridi et al., 1998; Stern et al., 2003; Gentry and McGlone, 2003; Lebret et al., 2003). Others have found no relevant impact on meat colour of different housing systems (Warriss et al., 1983; Van der Wal et al., 1993).

3.3.5. Breed aspects and pH

The genetic aspects in connection with meat quality have been regarded in the Swiss breeding policy since the late 1970s. The objective was a genetic MH-free population. The elimination of MH-carrier was carried out by halothane and genetic (blood group) tests (Vögeli et al., 1985), with concomitant inclusion of performance traits in the breeding index. Thus, during the years 1977 to 1985, the efforts resulted in a reduction of MH-positive pigs from 7 and 29 % to a rate of 4 and 7 %, and up to 1998, the rate was lowered to <0.5 and 0.0 % in the Swiss Large White and Swiss Landrace, respectively. On the other hand, the inclusion of performance traits in the breeding index improved the fat-free lean by about 5 %, reducing the proportion of back fat by the same rate (Vögeli et al., 1985; Schwörer et al., 1993 and 1999).
The Hampshire breed is known to be carrier of the Rendement Napole (RN^-) gene. This dominant gene brings about a higher glycolytic potential (without exhibiting PSE-like symptoms) resulting in a lower ultimate pH, while the early postmortem pH is normal (Sayre et al., 1968; Monin and Sellier., 1984; Larzul et al., 1998). The genetic frequency of this meat-impairing effect is assumed to be absent in the Swiss pig population, based on analysis of the glycolytic potential from meat samples of 160 pigs (Swiss Large White, Swiss Landrace and Duroc) at the Swiss Performance Testing Station (Bee and Schwörer, 2002).

The present study investigated aspects of meat quality of pigs (firmness of back fat, fat-free lean, and pH of M.l.d.) raised in confined indoor and in semi-outdoor housing systems, including dietary, environmental, management, animal, and slaughterhouse-related aspects.

4. Material and methods

Geographically, the farms originated from Central- to Northeast Switzerland. This belt covers a region including nine cantons where pig fattening represents a traditional branch of farms and cheese dairies. The cantons were represented broadly according to the density of pig units, three cantons counting for the majority of the participants (Luzern, St. Gallen and Thurgau). One batch within a pig unit (farm), designated for the study, counted about 30 pigs of both sexes (sex-separated fattening was not yet common), kept in the same barn but in a separate pen (or in separate pens), and managed in the same way as the others (feeding, etc.). The farmer was asked to participate in both fattening periods (summer and winter).

The pig units had to conform to the highest sanitary level, called A-status of the SGD (Schweizerischer Schweinegesundheitsdienst), the official Swiss veterinary survey organisation that controls and testifies that farms are free of the following epidemics: Enzootic Pneumonia, Pleuropneumonia (certain serotypes of Actinobazillus Pleuropneumonia, APP), Rhinitritis athrophicans (RA), Leptospirose, Salmonella choleraesuis, and Ectoparasites (sarcoptic mange and louse).

The present Ph.D. thesis went along with a parallel veterinarian Ph.D. thesis investigating health aspects of animals and farmers (interdisciplinary project). The latter was published by Schnider (2002). Both were embedded in a project initialised and funded by the BVET, Bundesamt für Veterinärwesen (Swiss Federal Veterinary Office). Data collected on the farms and the slaughterhouses were partly used in both studies. However, due to the different study objectives and requirements the datasets were eventually not fully compatible.

4.1. Housing and feeding systems, diet sampling

The comparison includes the two most common housing types, the conventional fully-slatted floor type in a closed building (CON), and a new alternative housing system (ALT) featuring a multi-surface floor type including a permanent accessible limited outdoor area. A minimal pen surface[5] of 0.45 m^2 (<60 kg BW) and 0.65 m^2 (>60 kg BW) for growing and finishing pigs, respectively, is required in the CON. The minimal surface for the total area in the ALT amounts to 1.15 to 1.30 m^2 and 1.40 to 1.60 m^2 for growing and finishing pigs, respectively. The minimal outdoor area in addition to the indoor surface has to be 0.45 m^2 and 0.65 m^2 for growing (<60 kg BW) and finishing pigs (>60 kg BW), respectively. The law specifications allow fixing a roof over the outdoor area covering maximal 50 % of it, usually located at the feeding site, and maximal 30 % of the outdoor floor to be perforated (e.g. slats). The majority (70 %) of the alternative pig housings were converted conventional housing systems,

[5] the measurements refer to the surface per pig.

whereas 30 % featured new constructions partly in open-front buildings. The study does not include housing systems with huts in a field surrounded by a free-range area and similar housing systems usually used in organic farm labels.

Throughout Switzerland, about 900 cheese dairies, mainly family enterprises, process about 41 % of the Swiss milk production into diverse cheese products (Milchstatistik 2002). Traditionally the by-product whey is mixed, together with other feed components, to a soup and distributed via tubes to the troughs, usually three times a day, and in about 60 % of the farms in a lukewarm stadium (not heated and neither cold). This daily on-farm diet preparation is considered to be different from the complete feeding system with usually mill-mixed (sometimes on-farm mixed) and silo-stored feed.

The farmers collected feed samples of each fattening period. The farmers with whey feeding systems collected weekly 0.1 to 0.3 litres of the ready-made soup, poured it into 1.5 litre PET-bottles, and stored them in a deep freezer. The farmers with the complete feeding system took one sample (≤0.5 kg) of each delivery in a plastic bag. These sub-samples (bottles and bags) were aggregated to a final analysing sample. The mixing proportion of the sub samples was calculated by taking into account the time intervals of each sub-sample and an estimated feed intake for this interval. The estimation of the feed intake was based on the growth performance (total weight gain/fattening time). Total weight gain has been calculated, based on the carcass weight and the weight at the beginning of the fattening period: carcass weight/0.8 minus initial weight. The diet was characterised by the Weender analysis, and the fat fraction additionally by the gas-chromatographic fatty acid profile.

4.2. Number of farms, market groups and pigs

The number of farms, market groups and pigs varied between the criteria, and as well within the models of the criterion pH.

4.2.1. Fat score

The experimental unit was represented by records on the level of market groups. The covariate fat-free lean was averaged from the individual commercial readings of the pigs (hot carcasses), whereas the response variable fat score represented the routinely assessments in the labs of the slaughterhouses. One analysing fat sample combines smears of the outer layer of the adipose tissue in the loin region of all carcasses of a market group. In order to carry out the chemical-based lab analysis described by Scheeder et al. (1999) the minimal number of pigs should be five; the range in this study went from 4 to 74 with an average of 22 ± 11 pigs (the analysis of a sample of less than five pigs is sometimes successfully).

Table 1 represents the numbers (data structure) of farms and market groups. Four housing comparisons (comparisons 1 to 4) were analysed within the third-degree housing interaction $sn \times fs \times hs$ (for explanations of interactions, see 4.5.4.1). The fourth-degree interaction including the fixed effect slaughterhouse was here not possible due to a low number in the experimental unit (=market group) in several subclasses of each slaughterhouse. The criterion fat score included 291 market groups (+46 compared to the criterion fat-free lean) from 89 farms (+2). The relatively large difference of the number of market group between fat score compared to fat-free lean and pH was due to the allocation of market groups to be processed in slaughterhouse 1-affiliated abattoirs. The fat score samples, however, were analysed in the laboratory of slaughterhouse 1 and considered as those being slaughtered in slaughterhouse 1. A possible disparity of the 46 FOM-classified market groups summarised with the 245 AutoFOM-classified market groups was considered to be small since the covariate fat-free lean, averaged of the individual carcasses of a market group, looses part of the variation. The reason for not having regarded them for the criterion fat-free lean was that pigs processed other than in slaughterhouse 1 and 2 were FOM-classified, while only AutoFOM-classified pigs where included for the analysis of that criterion.

Table 1: Number of farms and market groups (fat score)

Season	Feed / housing	Comparison	**Slaughterhouse 1+2** Farms	**Slaughterhouse 1+2** Market groups	Slaughterhouse 1 Farms	Slaughterhouse 1 Market groups	Slaughterhouse 2 Farms	Slaughterhouse 2 Market groups	Total [a] within housing and season Farms	Total [a] within housing and season Market groups	Total within housing Farms	Total within housing Market groups
Summer	*Whey Feed*											
	CON	1)	**25**	**42**	10	16	15	26	CON [b]			
	ALT		**13**	**24**	8	13	5	11	37	62		
	Complete Feed											
	CON	2)	**12**	**20**	4	4	8	16	ALT [b]		CON	
	ALT		**31**	**61**	22	44	9	17	44	85	37 a	99
Winter	*Whey Feed*										ALT	
	CON	3)	**19**	**25**	6	8	13	17	CON		52 a	192
	ALT		**17**	**36**	11	24	6	12	28	37		
	Complete Feed											
	CON	4)	**9**	**12**	3	4	6	8	ALT			
	ALT		**34**	**71**	25	53	9	18	51	107		
Grand Total			**-**	**291**	-	166	-	125	-	291	89 [b]	291

[a] These totals refer to the sum of both slaughterhouses, e.g. 37 CON-farms=10+15+4+8, analogously for the other sums.
[b] The "Grand Total" of farms does not correspond to the sum of the eight subclasses (comparisons 1 to 4) due to repetition in winter (62 %; half of the other 38 % delivered in either season) and due to the fact that few farms (<5 %) delivered in either slaughterhouse.
- The bold figures of "Market group" (=sum of slaughterhouse 1 and 2) represent the experimental unit and the editing number in the regression model. The residual-based only excluded record belonged to the subclass ALT, comparison 2 in slaughterhouse 1.

The criterion fat score featured four housing comparisons. The subdivision into slaughterhouse 1 and 2 as done in the criteria fat-free lean and pH was here not possible due to low numbers (n<8) of the experimental unit 'market group' (see numbers of slaughterhouse 1 and 2 in Tab 1).

4.2.2. Fat-free lean proportion

Farms: Table 2 represents the structure of the following data: number of farms, market groups and pigs (=observations, Obs.) classified into 16 subclasses, equal to eight comparisons (1 to 8) according the interaction $sl \times sn \times fs \times hs$ (explanation of interaction see 4.5.4.1). The response variable fat-free lean was based on 87 farms (36 CON and 51 ALT). Of these 87, 54 farms (20 CON and 34 ALT) participated in both seasons (periods), while 33 farms in either one. The farmers usually practised split marketing according to the growth (performance), delivering finished pigs split into 1 to 3 market groups. This resulted in a total of 246 market groups in both seasons. Between the first and the second, there was a fluctuation of farms due to an ongoing change of housing systems during the recording period (2000 to 2001). As a matter of fact, farms with conventional housing systems were more numerous in combination with the whey feeding system (i.e. these farms were cheese dairies with an affiliated pig unit), whereas the situation for the farms with alternative housing systems was contrary, representing the fact that real farms with an affiliated pig branch were more numerous in combination with complete feeding systems.

Market groups: The 36 CON-farms delivered 92 and the 51 ALT-farms 154, of the total of 246 market groups.

Pigs: The corresponding number of pigs regarded in the models amounted to 5,295 individuals, 1,973 CON- and 3,322 ALT-pigs. The detailed figures of the CON and ALT subclasses are given in Table 2.

Table 2: Number of farms, market groups and pigs (fat-free lean)

Season	Feed / Group	Comparison	Slaughterhouse 1 Farms	Market groups	Obs. (pigs)	Obs. excl.	Comparison	Slaughterhouse 2 Farms	Market groups	Obs. (pigs)	Obs. excl.	Total[a] within housing and season Obs. (pigs)	Total within housing Farms	Market groups	Obs. (pigs)
Summer	*Whey Feed*														
	CON	1)	10	13	326	1	2)	14	24	427	1	CON			
	ALT		7	10	265	4		5	12	238	1	1062			
	Complete Feed														
	CON	3)	4	4	110	2	4)	8	16	199	0	ALT	CON		
	ALT		22	41	823	8		9	17	342	2	1668	36 [b]	92	1973
Winter	*Whey Feed*												ALT		
	CON	5)	5	7	139	2	6)	14	18	520	3	CON	51 [b]	154	3322
	ALT		9	16	353	3		6	11	284	1	911			
	Complete Feed														
	CON	7)	2	2	66	0	8)	6	8	186	0	ALT			
	ALT		19	33	687	1		8	14	330	1	1654			
Gand total			-	126	2769	21		-	120	2526	9		**87 [b]**	**246**	**5295**

[a] These totals refer to the sum of both slaughterhouses, e.g. 1062 CON-pigs=326+427+110+199, analogously for the other sums.
[b] The "Grand total" of farms does not correspond to the sum of the 16 subclasses (comparisons 1 to 8), see footnote b of Table 1.
- Obs.=Observation, corresponds to the editing number in the regression model; Obs. excl.: residual-based excluded observations.

4.2.3. PH of M.l.d.

The dataset was similar to that of the criterion fat-free lean. However, pH recording was not possible for some delivered market groups, resulting in different numbers of observations (-10.7 %), market groups and farms. Table 3 lists the detailed figures for the pH models at pH-35 min, 2 and 24 h postmortem. Between the models at 35 min and 2 h p.m., a slight difference of 79 observations (-1.8 %) was noticed. The dataset of the model pH-24 h p.m. in turn featured 16.5 % less observations than the model pH-35 min p.m. due to demand from the shelf causing the processing of carcasses in some cases already at the day of slaughtering. The dataset of pH-2 h p.m. differed little (-1 %) from the one of pH-35 min postmortem.

Table 3: Number of farms, market groups and pigs (pH)

			Slaughterhouse 1					Slaughterhouse 2					Total[a] within housing and season	Total within housing		
			Comparison	Farms	Market groups	Obs. (pigs) at 35 min p.m.	Obs. (pigs) at 2 h[c] p.m.	Comparison	Farms	Market groups	Obs. (pigs) at 35 min p.m.	Obs. (pigs) at 2 h[c] p.m.	Obs. (pigs)	Farms	Market groups	Obs. (pigs)
pH 35 min and 2 h p.m.																
Summer	*Whey Feed*															
		CON	1/9)	10	13	306	do.	2/10)	13	23	348	do.	CON			
		ALT		7	10	261	do.		5	11	162	do.	948			
	Complete Feed															
		CON	3/11)	4	4	112	do.	4/12)	8	16	182	do.	ALT	CON		
		ALT		22	40	779	-4		9	17	305	-11	1507	35 [b]	91	1767
Winter	*Whey Feed*													ALT		
		CON	5/13)	5	7	138	-1	6/14)	14	20	482	-5	CON	51 [b]	145	2964
		ALT		9	16	340	-8		6	10	253	do.	819			
	Complete Feed															
		CON	7/15)	2	2	66	do.	8/16)	4	6	133	do.	ALT			
		ALT		19	28	590	-20		7	13	274	do.	1457			
Grand total				-	120	2592	-33		-	116	2139	-16		**86 [b]**	**236**	**4731**

				Farms	Market groups	Obs. (pigs)	Obs. excl.		Farms	Market groups	Obs. (pigs)	Obs. excl.	Titels as above: Obs.(pigs)	Farms	Mark.gr.	Obs.
pH 24h p.m.																
Summer	*Whey Feed*															
		CON	17)	9	11	232	0	18)	13	22	324	1	CON			
		ALT		7	10	261	0		5	10	157	1	809			
	Complete Feed															
		CON	19)	3	3	89	1	20)	8	15	164	4	ALT	CON		
		ALT		22	36	681	0		9	17	287	3	1386	33 [b]	76	1363
Winter	*Whey Feed*													ALT		
		CON	21)	5	7	136	0	22)	8	11	268	4	CON	50 [b]	129	2562
		ALT		9	14	276	3		6	10	250	3	554			
	Complete Feed															
		CON	23)	2	2	66	0	24)	3	5	84	2	ALT			
		ALT		15	20	396	1		7	12	254	2	1176			
Grand total				-	103	2137	5		-	102	1788	20		**83 [b]**	**205**	**3925**

[a] These totals refer to the sum of both slaughterhouses, e.g. 1062 CON-pigs=326+427+110+199, analogously for the other sums.
[b] The "Grand total" of farms does not correspond to the sum of the 16 subclasses (comparisons 1 to 8), see footnote b of Table 1.
[c] The differences to pH-35 min are given.
- Obs.=Observation, corresponds to the editing number in the regression model.
- Obs. excl.: residual-based excluded observations, occurred only at pH-24 h.
- Comparison 1/9, 2/10,...,8/16 refer to comparison 1, 2,..,8 at pH-35 min, and comparison 9, 10,...,16 at pH-2 h in Table 22.

4.2.4. Proportion of breeds

Before dissection, ear tags of the pigs were recorded, providing information about genetic background (breed). During the recording period (2000 to 2001) a new on-farm labelling system was introduced with the effect that not all the ear tags were traceable. Those records (33.9 %) are gathered in the category “Undefined”

Table 4: Proportion of breeds

Model		Breed							Total
		LW ≥75 %	LWxLR 50 %	LR 100 %	Duroc 50 %	Duca ¼Pi + ¼Du	Hampsh. 50 %	Undefined	
Fat-free lean	n pigs	3905	- [a]	95	298	842	155	- [a]	5295
	% of Total	73.7	-	1.8	5.6	15.9	2.9	-	100
pH-35 min	n pigs	1875	502	- [a]	270	338	144	1602	4731
	% of Total	39.6	10.6	-	5.7	7.1	3.0	33.9	100
pH-2 h	n pigs	1862	501	- [a]	268	327	144	1580	4682
	% of Total	39.8	10.7	-	5.7	7.0	3.1	33.7	100
pH-24 h	n pigs	1508	471	- [a]	194	236	144	1372	3925
	% of Total	38.4	12.0	-	4.9	6.0	3.7	35.0	100

[a] pooled with LW since no extra model benefit resultet (high p-value of the respective breed subclass).
-LW: Swiss Large White; LR: Swiss Landrace; Duca: sire line of Piétrain x Duroc; Undefined: assumed mainly LW or LWxLR.
-The complementary part of the percentages were LW or LWxLR.
- In the model fat score no effect breed was regared because fat score is a mixing sample of all pigs of one market group.

The majority was represented by the Swiss Large White (≥75 % LW) followed by the group “Undefined”. The latter represented presumably LW and LWxLR (Swiss Landrace) due to the fact that these breeds are the most common ones. The group LWxLR had been set up in order to take into account a genetic effect of higher percentages of Swiss Landrace (LR). Ninety-three pigs of pure LR were tested first separately but without additional variance effect (high P-value) and joined to the group LWxLR. Duroc and Hampshire both are 50 % crossings; the first was introduced at the Swiss Pig Performance Testing Station in 1995, whereas the latter was regarded only in the 1980s (Schwörer, 2004b). The group Duca (PiétrainxDuroc) takes into account a presumed genetic effect of the heavier muscled Piétrain breed. Duca is a sire line featuring 25 % Piétrain (sire) and 25 % Duroc (dam) blood in the offspring designated for fattening. It is part of the breed stock of the Swiss company Anicom offering pig genetics.

The proportion of sex was nearly balanced, featuring 51.6 and 48.4 % for castrates and females, respectively (figures for the pH-35 min model).

4.3. Ambient temperature and season

The winter 2000 to 2001 was extremely mild[6] with only one lasting cold period in April 2001 (ca. 5 °C below long-term average), whereas the winter months November 2000 (1.5 to 3 °C above-), December 2000 (4 to 6 °C above-), January 2001 (0.5 to 1.5 °C above-), February 2001 (3 to 5 °C above-) and March 2001 (3 to 5 °C and more above the long term average) were unusually mild. In March, the influence of subtropical air and a lasting cloud cover were responsible for keeping temperatures clearly above freezing point during the night time in the geographical lower regions where most of the farms were located. The weather in the summer months was within normal ranges. In spite of these meteorological, and in way "joy-killing" circumstances, the temperature differences among the farms in the housing systems were remarkable (Table 12 section F). An expected temperature effect was therefore considered, being analysed as more correct within each housing system separately, resulting in two additional regression models (Table 7).

4.4. About data recording

A field study owing, its coordination required an accommodation among farm, slaughterhouse and data recording, which could not always be accomplished. Some time-delay led to an extension of both the summer and the winter fattening period that weren't planned. The data recording at the slaughtering representing the summer fattening period lasted from the very begin of August to the end of December 2000, and the one representing the winter fattening period started actually at the end of February (including sporadic slaughter groups in January and February) and lasted until the middle of June 2001. With respect to the study design (repetitive recordings from the farms in summer and winter) it has been decided not to shift records from the second period, that is the few records in June 2001, back to the first period (summer) and vice versa (December 2000 records ahead to the winter period), but taking into account a possible slight influence of season-atypical temperature within each recording period. The second reason not to shift records between the seasons was an assumed effect of "possibly improving management ability" in farms with alternative housing systems, that had recently changed from CON to ALT.

Data corresponded either to the commercial data from the slaughterhouses (fat-free lean, hot carcass weight, fat score) or extra collected (planned) data (pH records, ear tag, sex and breed records, feed samples, temperature readings).

[6] Monatliche Witterungsberichte der Meteo Schweiz (Monthly weather reports of Swiss Meteo) 2000 to 2001.

4.4.1. Slaughtering and data collecting

The data collecting was carried out during the regular processes around slaughtering. In the lairage, the pigs usually were showered, unless climatic conditions were bad and the temperature fell below 10 °C. The pigs designated for our monitoring were tattooed differently from the rest of the daily commercial deliveries, in order to recognize the batches online and in the chiller. The farmers and drivers reported fasting and transport durations on a questionnaire, which was sent to the farmers and returned by the drivers at the delivery. The pigs were mixed neither during transport nor in the lairage, according to the usual practice.
The slaughtering frequency was 240 to 250 pigs per hour (about 4 pigs per minute). After delivery, the designated pigs to be monitored at the slaughter line and in the chillers were managed as the other commercial pigs concerning showering and resting in the lairage. On the few days when deliveries of pigs designated for monitoring were numerous, the groups had to be scheduled in the lairage with regard to ear tag, sex and tattoo registration before dissection, and the readings at 35 minutes and two hours postmortem. This occasioned a somewhat longer lairage for a few groups, yet not an unusually long one.
The stunning (CO_2, two pigs per cabin) was same in both slaughterhouses, whereas the scalding differed in length and method. In slaughterhouse 1, a scalding chamber was installed were the stunned pigs passed hanging within 8 minutes, while in slaughterhouse 2 the pigs were lowered into a water tank during 15 minutes, in both cases at 60 °C. After dissection, the carcasses were chilled in a blast cooler during 80 minutes at minus 10 °C in slaughterhouse 2, whereas in slaughterhouse 1, the carcasses were not extra-fast cooled (no blast cooler installed). This caused a time displacement of the initial pH recording in both slaughterhouses of 10 minutes, which was synchronised by extrapolation in one slaughterhouse (see 4.4.3). Fat scores, fat-free lean and carcass weight corresponded to the commercial data recording of the slaughterhouse whereas the pH was monitored extra.

4.4.2. Calibration of pH device and pH recording

The pH recording was carried out with two devices of WTW 340 portable and WTW SenTix® SP electrodes (WTW GmbH, 82362 Weilheim, Germany).
A two-point calibration (7.00 and 4.67) was done daily before starting the measurements with a solution of Wintion® AG, 3116 Mühledorf, Switzerland) at solution temperatures of 35 to 40 °C for the pH-35 min and pH-2 h, and 0 to 5 °C for the pH-24 h. The measurement of the carcass temperature combined with the pH recording was not possible online, mainly due to the slaughtering frequency. Based on preliminary measurements, default values of 39, 27 without and 25 °C with blast cooler, and 2 °C for pH-35/45 min, pH-2 h and pH-24 h, respec-

tively, were set. The relatively small difference of 2 °C of the carcass core temperature after passing a blast cooler or not is an expected value (Honikel, 2004).
The readings of initial pH had to be carried out before the carcasses went into the blast cooler in slaughterhouse 2. This is the reason for the measurement at 35 minutes postmortem, while in slaughterhouse 1 the measurements could not be carried out at 35 but only at 45 minutes postmortem. The consequences for the readings of pH-35 min (time) and pH-2 h (temperature) are discussed in 4.4.3.
PH measurements were recorded at the 7th to 8th thoracic rib area (Barton Gade et al., 1995) and monitored (if possible) in the same incision for one pH set (35 min, 2 and 24 h p.m.), with the consequence that the pH-2 h readings were systematically 0.10 to 0.15 units lower compared to measurements that would have been taken in new incisions (Honikel, 2004). This approach was carried out to keep the number of incisions in commercial carcasses low, and for a faster recording procedure in the cooler at two hours postmortem (recognition of first incision) in view of minimising the time displacement (see below), and as well at 24 h postmortem.
The measuring time for pH at 35 min p.m. was limited to 20 seconds per carcass, with a net 15 second gap for letting the electrode inserted in the muscle. This is the minimum required time for reliable readings (Honikel, 1998). The accuracy wanted at pH-2 h implied an extended effective measuring time of about 30 seconds per carcass due to lower temperatures. Hence an inevitable time expansion occurred gradually increasing from the first to the last carcass of a slaughtering unit (batch of carcasses in a row), as compared to pH at 35 min. This was regarded in the models (see 4.5.2.3).

4.4.3. Plausibility of pH records and pH-45 min adjustment

A proper pH recording online depends on many factors, such as acquaintance with the slaughter process, the portable pH-device, experience of pH-measurements, etc.
Implausible pH values have been excluded from the regression models, that is when pH-35 min < pH-2 h, when pH-35 min < pH-24 h, and in the pH-24 h model when pH-24 h > pH-2 h + 0.1. These 0.1 units regarded measuring errors at 24 hours p.m. of possible low pH-2 h readings which would then be excluded unjustified. The frequency of excluded records due to these implausibility conditions amounted to 2.4 and 8.6 % in slaughterhouses 1 and 2, respectively. The higher rate can partly be explained by the fact that other persons were more frequently engaged in recording the pH of carcasses in slaughterhouse 2 due to parallel deliveries of pigs to both slaughterhouses.
The 10-minute time displacement of the initial pH between slaughterhouses has been adjusted in slaughterhouse 1 by extrapolating the measured pH-45 backwards to pH-35 min postmortem. The adjustment was based on the assumptions of a linear pH-fall between 6.8

and 6.0, the early postmortem stage. The adjustment factor was calculated on a random 100 record (98 different records) sub-sample out of 1,322 records. The latter represented slightly >50 % of the total in slaughterhouse 1, and featured a pH-2 h p.m. of >6.0. This approach assured excluding PSE or PSE-near pigs, which would have adulterated the factor and the extrapolation. The 98 records were extrapolated individually from pH-45 min with an average of 6.517 to pH-35 min with an average of 6.559 (Table 5). The resulting difference (=slope) of 0.042 pH units was set in relation to the pH-45 min (of 98 animals) resulting in an adjustment factor of 0.0064 corresponding to 0.64 % (Honikel, 2004).

Table 5: Approach of the pH adjustment from 45 to 35 min p.m. in slaughterhouse 1

Random selection of 100 records resulting in 98 different ones of a total of 1,322 records			
pH-35[1] of 98 animals		=	6.559
pH-45[1] of 98 animals		=	6.517
Difference between pH 35 and 45		=	0.042
Adjustment factor	= 0.042/6.517	=	0.0064
Recorded pH-45 of 1,332 animals (=the total regarded for the adjustment)		=	6.378
New (extrapolated) pH-35 of 1,322 animals	= 6.378+(6.378*0.0064)	=	**6.419**

[1] at 35 and 45 minutes p.m., respectively; explanations see text of this chapter

The extrapolated pH-35 min in slaughterhouse 1 was 6.419 (and averaged over all the records, 6.418), compared to a synchronic average in slaughterhouse 2 of 6.436 at 35 min postmortem.

The installation of a blast cooler in slaughterhouse 2 could be another effect influencing the pH-fall (until pH-2 h p.m.) disparately. However, preliminary temperature recordings combined with pH-2 h measurements in both slaughterhouses revealed a mere 2 °C difference, i.e., on average 25 and 27 °C with and without blast cooler, respectively. A temperature difference of 2 °C would have caused pH curves deviating <0.05 units and was assumed not to be relevant in the scope of this study (Honikel, 2004).

The PSE-limit of 5.80 (Honikel, 1998) or 5.90 (Barton Gade, 1995) at 45 min p.m. has been adjusted by the same factor to a new limit at 35 min p.m. of 5.84 or 5.94 according to their mentioned 45-min values.

4.5. Statistical methodology

The structural design is given in Fig. 3. Data were collected at three experimental levels (units), either on animal level (carcass weight, fat-free lean, pH, and time at pH, sex and breed), market group level (fat score, ambient temperature, fasting, transport and lairage time), or farm level (dietary PUFA, energy, and protein). The SATTERTHWAITE option was used to compute the accurate numbers of degrees of freedom (SAS OnlineDoc, 2004). Characteristic to the unbalancedness of the dataset in present field study the comparisons (contrasts) were not orthogonal; hence a certain dependency among the comparisons is inherent. The data were analysed in linear mixed effects models with the restricted maximum likelihood method (REML) using PROC MIXED of SAS 8.02 release (Statistical systems, Institute Inc., N.C., U.S.A.). The P-values of the pre-planned housing- and season comparisons were not adjusted. This entails an increased chance of a Type I error, i.e., falsely rejecting the null hypothesis (stating the comparison to be significant when it is not). Reducing the Type I error (setting the alpha-level at e.g. 0.01 instead at 0.05) entails concomitantly an increase of the Type II error, i.e., falsely rejecting the alternative hypothesis (stating the comparison not to be significant when it is). On the other hand, the Type II error can be reduced increasing the sample size (higher number of records). When adjusting the P-values with the conservative Bonferroni method (other methods have a less conservative effect) entails multiplying them by the number of contrasts released from a model output, that means by four and by eight in the present models.

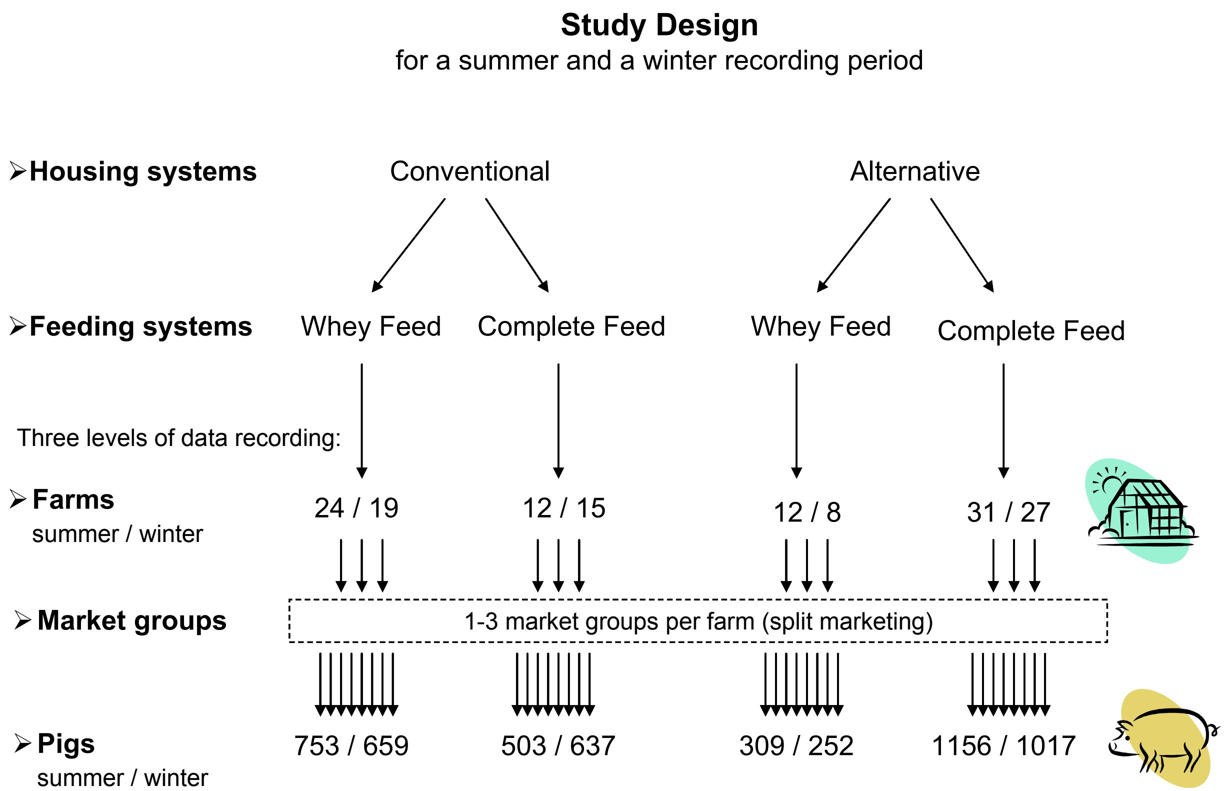


Fig. 3: Scheme of the study design

The experimental unit was the market group in the criterion fat score and the individual pig in the criteria fat-free lean and pH. The random effect farm was nested within the fixed effects housing and feeding system, i.e., a farm belonged to one and the same housing and feeding system. Figures refer to the database for fat-free lean.

4.5.1. Class effects

An overview of all class effects and covariates is given in Table 6.

4.5.1.1. Fixed effects

The following fixed effects featured two classes: housing system (hs), feeding system (fs), season (sn), slaughterhouse (sl) and sex (x). The fixed effect market group (mg) featured three classes. The contrasts of the originally six subclasses of the effect breed (b) (Table 4) have been tested in a series of model steps. The number of subclasses was reduced to the number of significant subclasses resulting in five for the model fat-free lean, and six for the pH models. In the model fat score no breed effect was regarded.

4.5.1.2. Random effect (farm)

The effect farm was considered random and nested in the class effects housing and feeding system (hierarchical structured), i.e., one and the same farm belonged to one and the same housing and feeding system. The effect farm was grouped within the effects slaughterhouse, season and housing system in the model fat score, within season, feeding- and housing system in the model fat-free lean, within slaughterhouse and season in the models pH-35 min and pH-2 h, and within housing system and season in the model pH-24 h postmortem. The standard deviation (=square root of the variance) of a group describes the homogeneity of that group. The variance was set in relation with the random error term resulting in a ratio. The significance of grouping was tested in each model with the table values of the chi-square distribution based on the difference of the chi-square values from the models with and without the grouped random effect farm. The number of the degrees of freedom corresponded to the number of grouped effects (two, four and eight according to the models).

4.5.2. Covariates

The covariates included in the models reflected the real variation in the field. No planning of the variables (covariates) had been done.

4.5.2.1. Model fat score

The ls-means of the response variable fat score were adjusted by two covariates, namely, the parameters fat-free lean [%], and dietary PUFA in gram per mega joule digestible energy [g/MJ]. The covariate ambient temperature [°C] was analysed separately in each housing system, as described in the second paragraph of 4.5.2.2. The covariates fat-free lean and

PUFA were fitted linearly, the one of ambient temperature linearly in the sub-model-CON and quadratically in the sub-model-ALT each according to the best model fit.
Fatness (or leanness) are back fat-determining factors in such a way that fatter pigs feature a firmer back fat due to a dilution of incorporated dietary PUFA into a relative larger amount of back fat (e.g. Lebret and Mourot, 1998; Pettigrew and Esnaola, 2001). These two parameters were hence key variables (see also 3.1.2).

4.5.2.2. Model fat-free lean

The ls-means of the response variable fat-free lean were adjusted by dietary, animal and environmental covariates. The dietary effects covariates energy [MJ per kg DM] and crude protein [%] were both linearly fitted. The animal covariate carcass weight hot [kg] was linearly and quadratically, and "time 25 kg to market" [days] was linearly fitted. Records beyond the range of 65 to 108 kg carcass weight and records below a fat-free lean level of 43 % were preliminarily excluded from the models. Further 30 excluded records were based on the residual analysis (see Table 2 "Obs. excl.", and 5.2.2).
The covariate ambient temperature [°C] was fitted quadratically in both sub-models, CON and ALT. In the scope of this study, an averaged value over the last 60 fattening days based on 24 measurements per day was considered. This approach prevented a confounding of a qualitative different requirement on ambient temperature of piglets (beginning-growing phase) and finishing pigs. A second constraint to regard was including a sufficiently long period which in turn was not too long, such as warmer and colder periods would neutralise mutually. In the alternative housing systems, temperature corresponded to $(T_{indoor}+T_{outdoor})/2$ regarding the fact that ALT-pigs were exposed to both indoor and outdoor temperature.
Other experimental designs from different authors regarded a six weeks period at the end of the finishing period (Mac Grath et al., 1968), or a 16 weeks period regarding the body weight from 20 to 90 kg (Fuller et al. 1974) and 8 to 92 kg BW (Lefaucher et al., 1991), the latter including also the post-weaning period.

4.5.2.3. Model pH of M.l.d.

The ls-means of the response variable pH were adjusted by the covariates fasting-, transport- and lairage time [all in hours] of each market group, and fat-free lean of each pig. The fasting time was defined as feed withdrawal on farm until the departure with the lorry; the transport time represented the time on the road, and lairage the time at the slaughterhouse until stunning. The covariate fat-free lean regarded the relation between muscling and pH (Vögeli, 1978; Schwörer, 1982). The parameter carcass weight did not feature an important interrelationship with pH (P>0.50) and was hence omitted.

The gradual time expansion of the response variable pH-2 h (see 4.4.2) has been regarded by the covariate describing the time between death and the effective time at the previewed 2 hours postmortem, a consideration taken into account in a work by De Smet et al. (1996) as well. No influence of a slight (±1 hour) time displacements of the response variable pH-24 h postmortem was assumed for the ultimate pH is reached at about 6 h p.m. (Honikel, 1998).
The response variable pH-24 h was adjusted by the preceding pH at 35 minutes regarding the positive interrelationship of initial and ultimate pH (Warriss, 1982a; Van der Wal et al., 1995; Aaslyng and Barton Gade, 2001; Allison et al., 2002; Honikel, 2004).

4.5.3. Configuration of the linear mixed effects model

The following model equations feature all single effects and the most extended interactions, but not the intermediate ones due to the length of the equation (readability). For example the main model fat-free lean features the fourth-degree interaction $sl \times sn \times fs \times hs$, whereas the preceding second- and third-degree interactions ($sl \times sn$, $sl \times fs$, $sl \times hs$, $sn \times fs$, $sn \times hs$, $fs \times hs$, $sl \times sn \times fs$, $sl \times sn \times hs$, $sn \times fs \times hs$) are not showed in the equation. However, the SAS syntax (e.g. $sl | sn | fs | hs$) regarded all intermediate interactions (via the vertical bars). The models were developed by a stepwise regression method. The effects used are summarised in Table 6.

Table 6: Overview of model effects (fat score, fat-free lean, and pH)

Model components	Unit	Abbreviation[a]	Levels
Class effects			
1. Fixed effects			
Housing system		hs	2
Season		sn	2
Feeding system		fs	2
Sex		x	2
Slaughterhouse		sl	2
Market group		mg	3
Breed		b	3-6[b]
Interaction effects (example)		hs*fs*sn*sl	16 analogue housing effects
2. Random effect			
Farm (nested within housing and feeding system)			86 to 89 [d]
Covariates			**Response variable**
PUFA/energy	g/MJ	Pu	Fat score
Fat-free lean	%	Ffl	Fat score
Ambient temperature	°C	T[c]	Fat score
Energy	MJ/kg	E	Fat-free lean
Protein	%	Pr	Fat-free lean
Weight of carcass hot	kg	W	Fat-free lean
Time 25 kg to market	days	D for duration or days	Fat-free lean
Ambient temperature	°C	T[c]	Fat-free lean
Fasting on farm	hours	Fas	pH fo M.l.d.
Transport	hours	Tra	pH fo M.l.d.
Lairage	hours	Lai	pH fo M.l.d.
Fat-free lean	%	Ffl	pH fo M.l.d.
Time at 2 hours p.m.	hours	T(pH-2 h)	pH fo M.l.d.
pH-35 minutes p.m.	units	pH(35 min)	pH fo M.l.d.

[a] Abbreviations in upper case designate covariates (except pH(35 min)), such in lower case fixed effects, the random effect is not abbreviated in the model equations in the chapter 5.3.3.

[b] Fat-free lean model: Sub-model-CON = 3, Sub-model-ALT = 4, Main model = 5 levels; and pH models = 6 levels.

[c] The effect T (or T_a) is not regarded in the Main models, but in the Sub-models CON and ALT.

[d] According to the response variables (criteria).

4.5.3.1. Fat score

The model designations for the criteria fat score and fat-free lean are listed in Table 7.

Table 7: Model designation (fat score and fat-free lean)

Model designation	Housing system	Destination
Main model	Both	Housing effect
Sub-model-CON	Conventional	Temperature effect
Sub-model-ALT	Alternative	Temperature effect

Main model:

$$Y_{abcdefg} = \mu + Farm + hs_a + fs_b + sn_c + mg_d + sl_e + Ffl_f + Pu_g + (hs \times fs \times sn)_{abc} + (hs \times fs \times mg)_{abd} + (fs \times Pu)_{bg} + \varepsilon_{abcdefg}$$

including intermediate interactions $sn \times fs$, $sn \times hs$, $fs \times hs$, $mg \times fs$, $mg \times hs$.

Sub-model-CON

$$Y_{abcdefg} = \mu + Farm + sn_a + fs_b + sl_c + mg_d + Ffl_e + Pu_f + T_g + (fs \times Pu)_{bf} + (fs \times mg)_{bd} + (sn \times T)_{ag} + (sn \times fs \times sl)_{abc} + \varepsilon_{abcdefg}$$

including intermediate interactions $sl \times sn$, $sl \times fs$, $sn \times fs$.

Sub-model-ALT

$$Y_{abcdefgh} = \mu + Farm + sn_a + fs_b + sl_c + mg_d + Ffl_e + Pu_f + T_g + T^2{}_h + (fs \times Pu)_{bf} + (fs \times mg)_{bd} + (sn \times fs)_{ab} + \varepsilon_{abcdefgh}$$

All interactions are listed.

4.5.3.2. Fat-free lean

The detailed setup given below shows the differences among the regression models. Interactions of covariates among models differed according their housing specific significances.
Main model:

$$Y_{abcdefghijk} = \mu + Farm + hs_a + fs_b + sn_c + sl_d + x_e + b_f + E_g + Pr_h + D_i + W_j + W^2{}_k + (sl \times b)_{bf} + (fs \times Pr)_{bh} + (sn \times D)_{ci} + (hs \times fs \times sn \times sl)_{abcd} + \varepsilon_{abcdefghijk}$$

including intermediate interactions $sl \times fs$, $sl \times fs$, $sl \times hs$, $sn \times fs$, $sn \times hs$, $fs \times hs$, $sl \times sn \times fs$, $sl \times sn \times hs$, $sl \times fs \times hs$, and $sn \times fs \times hs$. The covariate weight featured a linear and a quadratic term in all three model variants, while all other variables were set as linear terms.

Sub-model-CON:

$$Y_{abcdefghijkl} = \mu + Farm + fs_a + sn_b + sl_c + x_d + b_e + E_f + Pr_g + D_h + W_i + W^2{}_j + T_k + T^2{}_l + (sl \times b)_{ce}$$
$$+ (fs \times E)_{af} + (sn \times T)_{bk} + (sn \times T^2)_{bl} + (fs \times sn \times sl)_{abc} + \varepsilon_{abdcefghijkl}$$

including intermediate interactions $sl \times sn$, $sl \times fs$ and $sn \times fs$.

Sub-model-ALT:

$$Y_{abcdefghijkl} = \mu + Farm + fs_a + sn_b + sl_c + x_d + b_e + E_f + Pr_g + D_h + W_i + W^2{}_j + T_k + T^2{}_l + (sl \times x)_{cd}$$
$$+ (fs \times Pr)_{ag} + (sn \times D)_{bh} + (sn \times T)_{bk} + (sn \times T^2)_{bl} + (fs \times sn \times sn)_{abc} + \varepsilon_{abcdefghijkl}$$

including intermediate interactions: $sl \times sn$, $sl \times fs$ and $sn \times fs$. The difference between the sub-model-ALT and the sub-model-CON concerned the effects $b \times sl$, $x \times sl$, $E \times fs$, $Pr \times fs$, and $D \times sn$, which were strongly housing specific.

4.5.3.3. PH of M.l.d.

The set up of the effects and interactions was equal in the early postmortem models, but different concerning covariates and their interactions in the pH-ultimate model.

Model for pH-35 min and pH-2 h p.m:

$$Y_{abcdefghij} = \mu + Farm + hs_a + fs_b + sn_c + sl_d + x_e + b_f + Ffl_g + Fas_h + Tra_i + Lai_j + (sl \times b)_{df}$$
$$+ (hs \times fs \times sn \times sl)_{abcd} + (sn \times Fas)_{ch} + (sl \times Tra)_{di} + (sn \times Lai)_{cj} + (sl \times Lai)_{dj} + \varepsilon_{abcdefghij}$$

Model for pH-24 h p.m:

$$Y_{abcdefghij} = \mu + Farm + hs_a + fs_b + sn_c + sl_d + x_e + b_f + Ffl_g + Fas_h + Tra_i + Lai_j + (sl \times b)_{db}$$
$$+ (hs \times fs \times sn \times sl)_{abcd} + (sn \times Fas)_{ch} + (hs \times sl \times Tra)_{adi} + (sn \times sl \times Lai)_{cdj} + (hs \times sn \times Lai)_{acj} + \varepsilon_{abcdefghij}$$

The difference concerns the effects transport and lairage, which are extended to third-degree interactions $Tra \times hs \times sl$, $Lai \times sn \times sl$ and $Lai \times sn \times hs$ in the pH-24 h model. Two model-specific covariates are not listed in the equations due to readability but explained here (see also 4.5.2.3 paragraph 2 and 3). The model pH-2 h was extended by the variable time between stunning and pH measurement ($T[pH{-}2\ h] \times sl$), respecting the exact time point of each record in each slaughterhouse. The model pH-24 h contained the covariate pH-35 min set in interaction with the fixed effect slaughterhouse ($pH[35\ min] \times sl$) and sex ($pH[35\ min] \times x$).

4.5.4. Interactions

In general, interactions between a fixed effect and a covariate were removed from the models when not significant at α=0.05. However, the limit of excluding such effects depended also on the homology between the model variants; therefore, the significance could be higher but usually not above P 0.20 to 0.30. This approach enabled comparing the effects among models.

4.5.4.1. Interactions among fixed effects

Due to expected influences (contrary trends or significant comparisons) of the fixed effects slaughterhouse, season, and feeding system, the fixed effect housing system was interacted with these effects (each effect features two levels). In the criterion fat score the housing effect was analysed within season and feeding system expressed as a third-degree interaction $sn \times fs \times hs$. This interaction resulted in $2^3 = 8$ ls-means for $2^3 / 2 = 4$ analogue housing comparisons (statistic contrasts). In the criteria fat-free lean and pH the housing effect was analysed within slaughterhouse, season and feeding system in the fourth-degree interaction $sl \times sn \times fs \times hs$. This interaction resulted in $2^4 = 16$ ls-means for $2^4 / 2 = 8$ analogue housing comparisons (see Table 15 and Table 22).

4.5.4.2. Interactions between fixed effects and covariates (fat score)

The covariate PUFA was analysed within the fixed effect feeding system ($Pu \times fs$). This interaction was significant in the main model and the sub-model-CON, whereas in the sub-model-ALT it was not significant yet not removed from the model. The covariate ambient temperature was also tested quadratically and in interaction with season. In the sub-model-CON the linear term interacted with season ($T \times sn$) was, though not significant, maintained (P=0.333), and in the sub-model-ALT the linear and quadratic term were both significant (P<0.05) but the interaction effects did not show any importance.

4.5.4.3. Interactions between fixed effects and covariates (fat-free lean)

The covariates in the models explaining the response variable fat-free lean was “time 25 kg to market”, carcass weight hot, dietary energy and protein. “Time 25 kg to market” was season dependent ($D \times sn$) in the main model and the sub-model-ALT, but not in the sub-model-CON. The covariate carcass weight featured a linear and a quadratic term and was not interacted with any other effect in all three models. The covariate energy showed no important interaction effect (e.g. tested with the effects season, housing or feeding system) in the main model and the sub-model-ALT, but an interaction with the effect feeding system ($E \times fs$) was maintained at P=0.257 in the sub-model-CON. The covariate protein was significant when interacted with the effect feeding system ($Pr \times fs$) both in the main model and the sub-model-ALT, but was not significant in the sub-model-CON (P>0.7).

4.5.4.4. Interactions between fixed effects and covariates (pH)

The covariate fasting time was season dependent ($Fas \times sn$) in all the models. The covariate transport time featured a close interrelationship with the effect slaughterhouse ($Tra \times sl$) in the early postmortem models, and in the ultimate pH model additionally with the effect hous-

ing system ($Tra \times sl \times hs$). The covariate lairage time was in the early postmortem stage slaughterhouse and season dependent ($Lai \times sl$ and $Lai \times sn$). The ultimate pH stage showed a more complicated interrelationship featuring two third-degree interaction with the effects slaughterhouse, season and housing system ($Lai \times sl \times sn$ and $Lai \times sn \times hs$). Neither of the foregoing variables was (somewhat unexpectedly) feeding system dependent.
The model specific covariates, “time at pH-2 h” and “pH-35 min” (see Table 6), were both slaughterhouse-dependent ($T[pH\text{-}2\,h] \times sl$ and $pH[35\,min] \times sl$), the latter additionally with the effect sex ($pH[35\,min] \times x$).

5. Results and discussion

The subchapters “Descriptive statistics” of the parts fat score and fat-free lean present the average, standard deviation, minimum, maximum, and coefficient of variance (in percent) of the model variables of the subclasses. Furthermore, the average of each housing system and the total average, minimum and maximum are given. The order (sections A, B, C etc.) corresponds to the model configuration from chapter 4.5.3, first the dependent then the co-variates. In the criterion pH the fasting-, transport- and lairage time are given in a graphic with columns, average, minima and maxima providing an easier and faster overview. A table is given in the Appendix. Next to “Descriptive statistics”, the residual analyses and the results (ls-means of the housing and season effects, and temperature regression curves) are given closing the main chapter “Results” with the discussion.

5.1. Results fat score

5.1.1. Descriptive statistics

The descriptive statistics are listed in Table 8 section A to D.
Fat score (section A): The overall average of the response variable fat score was higher in CON-pigs with 59.9 compared to 58.9 in ALT-pigs. This was also seen when looking at the subclasses of the four housing comparisons (1 to 4). The differences were more accentuated in farms with whey feeding systems (above all in the winter period) than were those with complete feeding systems in both seasons. The biggest difference (Δ=2.6 units) was observed in the winter period in farms with whey feeding systems with averages of 60.2 and 57.8 for CON- and ALT-pigs, respectively, while the farms with complete feeding systems also in the winter period featured the same level (average of 59.4 and 59.3 for CON and ALT, respectively).
Fat-free lean (section B): The variable fat-free lean was involved in all three parts, in the criteria fat score and pH as a covariate and in criterion fat-free lean as the response variable. The averages, based on individual records that were averaged to market group level, were consistently higher in CON-pigs in all subclasses (comparisons 1 to 4) with larger differences in summer (Δ +1.9 and +1.3 % in whey and complete feeding systems, respectively) than in winter (Δ +0.5 and +0.4 % in whey and complete feeding systems, respectively). A description of individual fat-free lean values is given in Table 12 section A, criterion fat-free lean.

Dietary PUFA[7] (section C) and dietary 18:1[8] (App. II and App. III): In general, the farms with whey feeding systems had a higher proportion of the oleic acid (18:1) fraction in the fat (7 to 23 %). This was more accentuated in the CON-farms (=cheese dairies) than the ALT-farms, and as well more accentuated in the winter as in the preceding summer period. Vice versa the farms with complete feeding systems had more of the PUFA fraction (23 to 125 %, App. III Part 2 A). When looking at these values in g/MJ energy it was more typical for the 18:1 and less for the PUFA (Part 1 A). A second characteristic was the lower levels of both PUFA (9 to 21 %) and 18:1 (12 to 27 %) (in g/MJ) in the winter compared to the summer period (Part 1 B), which was mainly due to lower total fat contents but slightly lower energy levels as well (App. I). The differences of PUFA and 18:1 proportions between the housing systems are given in App. III Part 1 C in g/MJ and in Part 2 C in percent.

Ambient temperature (section D): The ambient temperature (of the finishing period) was as expected higher in the conventional housing system with 22.6 °C (15 to 28 °C) and 18.8 °C (12.7 to 22.9 °C), as compared to 17.1 °C (9 to 22 °C) and 11.5 °C (3.2 to 20.3 °C) in the alternative housing system, each in summer and winter, respectively. The temperature varied in the farms, typically more in ALT-farms featuring twice to three times the variation reflected by higher coefficients of variance. The temperatures in CON-farms covered a range of 15 to 28 °C, and more than half of the farms maintained a climate above 22 °C (the maximum of ALT-farms). In about 30 % of the ALT-farms, a winter temperature below 10 °C was measured.

[7] Dietary PUFA and 18:1 in g/MJ digestible energy per 1 kg dry matter.

[8] 18:1=endogenously synthesized oleic acid; used for an extra model in the discussion, see chapter 5.1.3.

Table 8: Descriptive results (fat score)

Season	Feed / Group	Comparison	Average / SD	Min	Max	CV-%	Overall		
A) Fat score									Market groups
Summer	*Whey Feed*								n
	CON	1)	59.8 ± 1.9	53.6	63.2	3.1			42
	ALT		58.0 ± 2.2	53.5	63.0	3.7			24
	Complete Feed						CON Average	59.9	
	CON	2)	60.1 ± 1.9	56.3	62.8	3.1	ALT Average	58.9	20
	ALT		59.5 ± 1.7	56.1	62.4	2.8			61
Winter	*Whey Feed*								
	CON	3)	60.2 ± 1.7	57.6	63.8	2.8	Total		25
	ALT		57.8 ± 1.6	54.5	60.9	2.8	Average	59.3	36
	Complete Feed						Min	53.5	
	CON	4)	59.4 ± 1.9	57.0	62.6	3.2	Max	63.8	12
	ALT		59.3 ± 1.9	55.5	63.1	3.1			71
B) Fat-free lean [%]									Market groups
Summer	*Whey Feed*								n
	CON	1)	55.7 ± 1.4	51.8	58.2	2.6			42
	ALT		53.8 ± 1.6	49.1	56.1	3.1			24
	Complete Feed						CON Average	55.8	
	CON	2)	55.9 ± 1.8	51.9	59.6	3.2	ALT Average	55.0	20
	ALT		54.6 ± 1.5	51.5	58.4	2.7			61
Winter	*Whey Feed*								
	CON	3)	56.0 ± 1.6	53.7	59.8	2.9	Total		25
	ALT		55.5 ± 1.0	53.1	57.8	1.7	Average	55.3	36
	Complete Feed						Min	49.1	
	CON	4)	55.9 ± 1.7	53.1	57.9	3.0	Max	59.8	12
	ALT		55.5 ± 1.4	52.9	58.9	2.5			71
C) PUFA [g/MJ energy]									Farms
Summer	*Whey Feed*								n
	CON	1)	0.65 ± 0.15	0.35	0.95	22.3			23
	ALT		0.74 ± 0.20	0.44	1.18	27.0			13
	Complete Feed						CON Average	0.67	
	CON	2)	0.82 ± 0.15	0.46	0.97	18.7	ALT Average	0.74	10
	ALT		0.86 ± 0.18	0.46	1.42	21.2			31
Winter	*Whey Feed*								
	CON	3)	0.57 ± 0.15	0.19	0.87	26.5	Total		17
	ALT		0.59 ± 0.12	0.31	0.75	20.7	Average	0.72	17
	Complete Feed						Min	0.19	
	CON	4)	0.75 ± 0.08	0.62	0.86	10.4	Max	1.42	8
	ALT		0.71 ± 0.18	0.28	1.41	25.6			33
D) Ambient temperature[a] [°C]									Market groups
Summer	*Whey Feed*								n
	CON	1)	23.2 ± 2.2	15.2	28.0	9.3	Sommer:		40
	ALT		17.5 ± 3.6	10.5	22.0	20.9	CON Average	22.6	22
	Complete Feed						ALT Average	17.1	
	CON	2)	21.5 ± 2.2	17.6	24.8	10.3			18
	ALT		16.9 ± 3.6	9.0	21.8	21.2			60
Winter	*Whey Feed*								
	CON	3)	18.5 ± 3.2	12.7	22.3	17.4	Winter:		23
	ALT		13.5 ± 4.0	6.7	20.3	29.8	CON Average	18.8	34
	Complete Feed						ALT Average	11.5	
	CON	4)	19.6 ± 1.7	16.9	22.9	8.9			10
	ALT		10.5 ± 2.2	3.2	14.7	21.3			62

[a] Temperature of finishing period (averaged over the last 60 days), CON indoor-, ALT average of in- and outdoor readings. Furthermore, the number of market groups is somewhat smaller in each subclass due to missing temperature recordings.

- Sections B and D are listed as well in the part fat-free lean, where figures differ slightly due to different number of market groupes (section D), and due to both averaged fat-free lean values and different number of market groups (section B) .
- Results of oleic acid (18:1) see table App II.

5.1.2. Results (fat score)

5.1.2.1. Residual analysis, model fit, F- and P-values

The residual plots in Fig. 4 show the distribution of 292 and 291 residuals before and after exclusion of 1 record, respectively. The excluded record was neither an outlier nor a leverage point, and did not relevantly influence the below-discussed ls-means. However, the distance between the observed and its predicted value was highest. Excluding it resulted in a smaller residual variance of 0.81±0.10 compared to 0.89±0.11 before exclusion, and a more balanced residual distribution. The model fit (AIC[9]) was nearly equal (Δ 0.3 %).

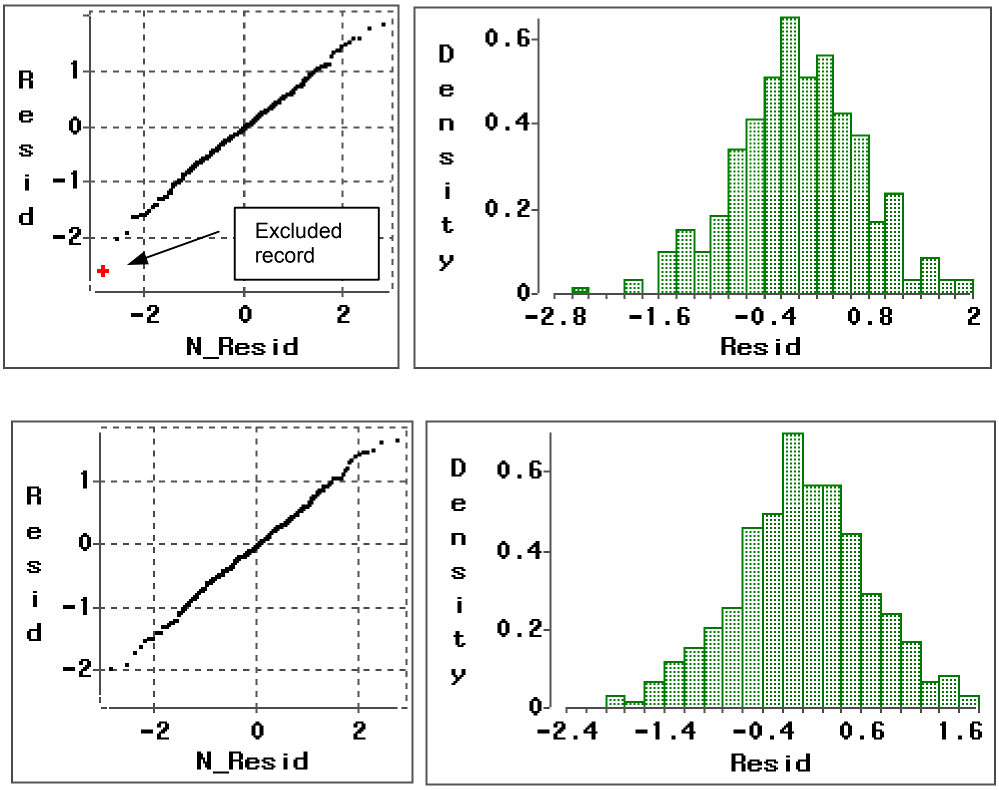


Fig. 4: QQ- and normal distribution plot of residuals (fat score)

Representative for all three models, the plots of the main model (housing comparison) are shown before (above, n=292) and after (below, n=291) exclusion of 1 record (cross); scale of x-axis 0.02 units (right plots).

A rough criterion of the goodness among models is the correlation between predicted and observed values. The correlations in all three models (main model, sub-model-CON, sub-model-ALT) were ≥0.93. Fig. 5 shows the residual and correlation plot of predicted versus observed values.

[9] AIC: Akaike's Information Criterion for the goodness of model fit when using ML and REML-methodology. In SAS PROC MIXED: a smaller AIC refers to better model fit.

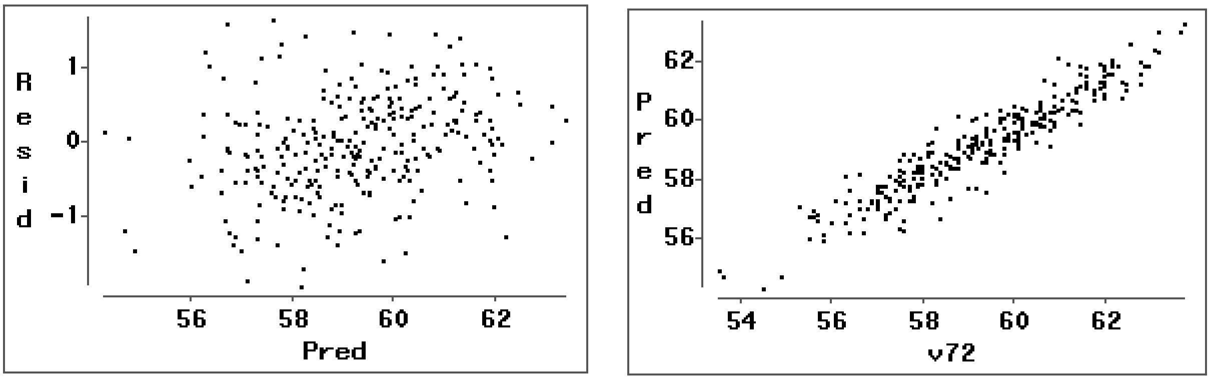


Fig. 5: Residual- and correlation plot of predicted v. observed (fat score)

v72=observed values; representative for all three models, the plots of the main model (housing comparison) are shown; $correlation_{Pred.-Obs.}$=0.94 (right plot, after exclusion); one dot represents one market group, n=291.

The variances and P-values of the model effects are given in Table 9. The fat score-dominating effect (in the main model) was the covariate fat-free lean (F=62.0 or 40 %) followed by the two PUFA-related effects (F=28.8+13.5=42.3 or 18+9=27 %), the effects of slaughterhouse (F=15.6 or 10 %) and feeding system (F=14.5 or 9 %), all of them featuring a P<0.01. The housing effect was significant when interacted with feeding system (F=14.5 or 4 %, P=0.013). The extended interaction $hs \times fs \times sn$ exhibited a lower importance (F=1.8 or 1 %, P=0.184) indicating that only few comparisons (contrasts) were significant (each, one of the four edited housing and season comparisons).

The effect temperature was as expected clearly more important in the sub-model-ALT featuring a linear (F=6.8 or 10 %, P=0.011) and quadratic (F=5.7 or 9 %, P=0.012) term but was interestingly not season-dependent (P>0.90). In the sub-model-CON the seasonal interaction effect was actually not of importance (summer and winter F=1.0 or 2 %; P=0.33) but remained in the model in order to compare the regression curves. The corresponding interacted quadratic terms showed P-values >0.90 and was removed from the model.

Table 9: F- and P-values of model effects (fat score)

Model Effects	Main model			Sub-model-CON		Sub-model-ALT	
	df [a]	F-value	P-value	F-value	P-value	F-value	P-value
Fix effects							
Slaughterhouse (sl)	149	15.6	0.0001	8.6	0.0049	4.3	0.0404
Market group (mg)	122	2.4	0.0975	1.1	0.3397	1.2	0.3073
mg * fs	122	3.0	0.0553	2.1	0.1431	1.3	0.2855
• mg * hs	122	0.1	0.8682				
• mg * fs * hs	122	3.1	0.0484				
Season (sn)	149	0.2	0.6949	0.9	0.3428	2.5	0.1201
• Housing system (hs)	149	1.8	0.1854				
Feeding system (fs)	149	14.5	0.0002	6.2	0.0163	2.3	0.1342
sn * fs	149	3.2	0.0750	6.8	0.0119	0.1	0.8122
• sn * hs	149	0.1	0.7746				
• fs * hs	149	6.4	0.0125				
• sn * fs * hs	149	1.8	0.1837				
• Σ (sn * fs * hs) -effects		27.9					
sl * sn * fs				3.3	0.0734	0.3	0.5591
Covariates							
PUFA/energy	122	28.8	<.0001	3.2	0.0885	4.3	0.0403
PUFA/energy * fs	122	13.5	0.0004	7.4	0.0123	0.7	0.3986
Fat-free lean	122	62.0	<.0001	13.1	0.0014	37.9	<.0001
Temperature				1.0	0.3340	6.8	0.0110
Temperature * sn				1.0	0.3331		
Temperature * Temperature						5.7	0.0189
Sum of F-values		156.3		54.7		67.5	

• housing-related effects; [a] the degrees of freedom (df) are given only for the Main model (n=291 records).

The variances of the random effect farm and the residual are listed in the Table 10. The standard deviation (square root of the variance) describes the distribution of the fat score of farms within groups. The farms were grouped within the effect slaughterhouse (lab effect), season and housing system and compared with the model without grouping (chi-square P≈0.25). The grouping was maintained although not significant at alpha=0.05 and in spite of a somewhat higher AIC but resulting in a smaller residual variance of 0.81±0.10 compared to 1.00±0.10 without grouping. A second reason was that the analogue grouping in the sub-model-CON and sub-model-ALT (grouped within slaughterhouse and season, housing drops out) were significant in both models (P<0.01) at a residual variance of 0.86±0.25 and 0.92±0.14 for the sub-model-CON and sub-model-ALT, respectively (not listed in the table below).

There were two characteristics among the three grouping effects, each featuring one exception. The first characteristic was a housing related pattern: CON-farms exhibited a distinctive smaller variation and hence a smaller ratio than ALT-farms (0.09 to 0.96 and 10 to 120 % in CON-farms compared to 1.53 to 2.55 and 190 to 320% in ALT-farms, each for the and variance and ratio, respectively. The exception concerned the CON-farms in summer delivering to slaughterhouse 2 featuring the highest variability among the CON-farm groups at the same level as the corresponding ALT-farms (1.92 and 240 % for the variance and the ratio, respectively). The second characteristic was that in summer there was a larger variability than in winter. The grouped farms in summer featured a variance of 0.96 to 2.35 corresponding to a ratio of 120 to 290 %, whereas the analogue winter values amounted to a variance of 0.09 to 2.55 and a ratio of 10 to 240 %. The exception concerned the ALT-farms delivering to slaughterhouse 2 showing the highest variation in winter with values of 2.55 and 320 % for the variance and ratio, respectively.

Table 10: Variance of the random effect farm and the residual (fat score)

Random effect farm grouped in:									
Slaughterhouse	1				2				Residual
Season	Summer		Winter		Summer		Winter		
Housing system	CON	ALT	CON	ALT	CON	ALT	CON	ALT	
Main model									
Number of farms	14	30	9	36	23	14	19	15	
Variance ± SE	0.96 ± 0.6	2.35 ± 0.8	0.09 ± 0.4	1.53 ± 0.5	1.92 ± 0.7	1.90 ± 0.9	0.71 ± 0.5	2.55 ± 1.2	0.81 ± 0.1
Ratio in % of residual[a]	120	290	10	190	240	240	90	320	

[a] Variance*100 diveded by the residual variance, and rounded to the nearest ten; example: 0.96*100/0.81=119, rounded to 120.

5.1.2.2. Housing and season effects

CON and ALT refers to CON- and ALT-pigs. From the third-degree interacted housing effect, eight ls-means, resulting in comparisons 1 to 4, are listed in Table 11. Predictions were higher in CON in combination with the whey feeding systems (differences are described as Δ): in summer (comparison 1) not significantly (59.6, $\Delta_{to\ ALT}$ +0.7, P=0.242), and in winter (comparison 3) significantly (60.3, $\Delta_{to\ ALT}$ +1.4, P=0.002). Predictions of CON with complete feeding systems exhibited in summer (comparison 2) no relevant difference to ALT (59.9, $\Delta_{to\ ALT}$ +0.01, P=0.933), whereas in winter (comparison 4) lower values were predicted in CON (59.1, $\Delta_{to\ ALT}$ -0.6, P=0.267), contrary to the housings with whey-feeding systems in winter (comparison 3) and in summer (comparison 1).

The season comparisons were more accentuated in the CON (comparisons 5 and 6) than in the ALT (7 and 8), and featured an inverse constellation within feeding systems. Fat scores from pigs raised in farms with whey feeding systems (comparison 5) were in winter significantly higher than in summer (60.3, $\Delta_{to\ summer}$ +0.7, P=0.047) whereas those of pigs from farms with complete feeding systems (comparison 6) were higher in summer (59.9, $\Delta_{to\ winter}$ +0.8, P=0.151) than in winter. The ls-means of whey fed pigs in the ALT (comparison 7) were balanced between the seasons (58.9, Δ 0.0, P=0.941), those of ALT with complete feed regime (comparison 8) were slightly higher in summer (60.0, $\Delta_{to\ winter}$ +0.3, P=0.481) than in winter. The standard errors of ls-means over all subclasses featured a range of 0.3 to 0.5.

Table 11: LS-Means of housing and season comparisons (fat score)

Main model			Comparison	LS-Means [a]	SE	P-value [b]
Housing comparisons						
Summer	*Whey Feed*	CON	1)	59.6	0.31	0.242
		ALT		58.9	0.47	
	Complete Feed	CON	2)	59.9	0.46	0.933
		ALT		60.0	0.34	
Winter	*Whey Feed*	CON	3)	60.3	0.28	**0.002**
		ALT		58.9	0.40	
	Complete Feed	CON	4)	59.1	0.43	0.267
		ALT		59.7	0.27	
Season comparisons						
Conventional	*Whey Feed*	Summer	5)	59.6	0.31	**0.047**
		Winter		60.3	0.28	
	Complete Feed	Summer	6)	59.9	0.46	0.151
		Winter		59.1	0.43	
Alternative	*Whey Feed*	Summer	7)	58.9	0.47	0.941
		Winter		58.9	0.40	
	Complete Feed	Summer	8)	60.0	0.34	0.481
		Winter		59.7	0.27	

[a] LS-Means are computed with the REML approach; [b] P-values are unadjusted and bold marked when <0.05.

- Frames provide an overwiew for comparisons when P<0.3; quadrate: ALT>CON/Winter>Summer, circle: ALT<CON/Winter<Summer.

5.1.2.3. Temperature effect

The housing separate analysed temperature effect (Fig. 6) on fat score revealed in general a relatively weak interrelationship. The majority of the predictions were scattered within a range of 57 to 63 and 56 to 62 in CON and ALT, respectively. This is reflected by somewhat higher levelled regression curves in CON (and as well in the ls-means above). The temperature effects in CON with linear coefficients featured no trend in summer (P=0.988), and a weak trend in winter (P=0.333). The linear and quadratic regression curves in the ALT, not interacted with season, were significant (P<0.02). Within a relatively large range of 10 to 22 °C, the curves were virtually horizontal. Below 10 °C in the winter period the fat scores showed an increasing trend.

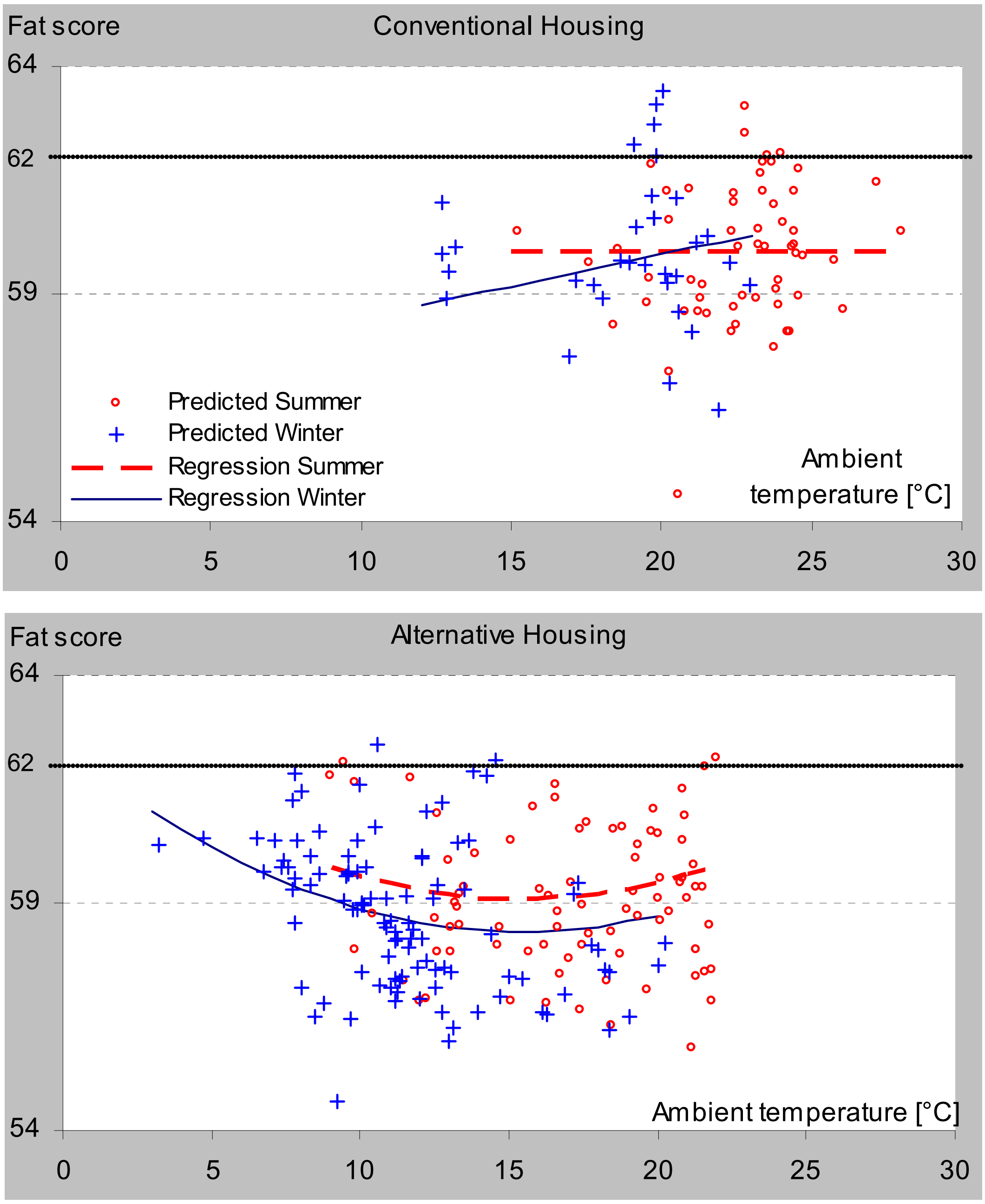


Fig. 6: Regression curves of the variables fat score and ambient temperature

The significance (P_t--values) of the slopes was: CON_{summer} 0.333, CON_{winter} 0.988; ALT_{linear} 0.011, $ALT_{quadratic}$ 0.019. One dot represents one market group. Above the threshold at 62 monetary deductions for too soft back fat become effective. A confounding of the fixed effect season and the covariate T can be excluded due to the fact that the main temperature range covered both seasons. If temperature data were clearly different in summer and winter then a possible temperature effect could also be a season effect (and vice versa).

5.1.3. Discussion (fat score)

5.1.3.1. Season and housing effects

Housing effects can be assumed to be closely related to ambient temperature and seasonal effects. Any of them cannot be regarded in isolation but are interrelated with the other ones. To the author's knowledge, only two articles (Lebret et al., 2002 and 2003) have been published that included the criterion back fat firmness in relation with housing systems. This is presumably due to the fact that, unlike in Switzerland, back fat firmness rarely is assessed routinely at slaughtering and then included in the carcass paying system.

In the present study, the models revealed that housing system was, together with season and market group, a minor effect. Major effects concerned the effects feeding system, dietary PUFA (and 18:1, see below), fat-free lean, and the only off-farm effect slaughterhouse. The effect temperature showed little importance in the sub-model-CON (indoors), but was, on the other hand, and second to the effect fat-free lean, an important factor in the sub-model-ALT (with outdoor access) ranked before the effect dietary PUFA.

<u>Season:</u> Lebret et al. (2003) compared seasonal effects of semi-outdoor pigs and temperature effects of indoor pigs (without direct housing comparisons). In their study the semi-outdoor pigs featured a significantly softer back fat in winter, as compared to summer-raised pigs due to remarkably higher proportions of endogenously synthesised MUFA (=mainly 18:1) at concomitant lower PUFA (18:2 and 18:3) in the back fat. Their results were based on fat firm penetrometer values and were obtained in an experimental unit in the south of France.

ALT-pigs: In the present study, the ALT-pigs featured not a softer back fat in winter (softer back fat = higher fat score); in complete feeding systems the prediction was yet contrary (P=0.481), and in whey feeding systems an indifferent situation was prevalent (P=0.941). This could be ascribed to remarkably lower dietary PUFA levels in winter (-20.3 and -17.4 % in whey- and complete feeding systems, respectively) than in summer. On the other hand, the temperature regression curves of the ALT-pigs showed a significant trend towards softer back fat at falling temperatures for the range below 8 to 10 °C (the analogous curves indoors for the CON-pigs featured no significant slopes). This focuses the attention on the endogenously synthesised monounsaturated oleic acid (18:1) being stimulated in the adipose tissue at colder temperatures and accumulating there at the expense of saturated fatty acids (Mac Grath et al., 1968; Le Dividich et al., 1987; Lefaucher et al., 1991), consequently resulting in higher iodine values (Fuller et al., 1974). Indeed, an extra regression model analysing the

18:1 fatty acid[10] (ls-means see App. IV) instead of the fat score showed that this subclass featured in winter significantly (P=0.008) higher 18:1-levels (43.0 %[11]) than in summer (42.0 %).

CON-pigs: Interestingly, the comparisons of the fat scores of CON-pigs featured a contrary pattern in the two feeding systems and more significant comparisons than were those of the preceding ALT-pigs.

The first seasonal comparison, the CON-pigs from farms with whey feeding systems (mainly cheese dairies) featured a significantly higher value (P=0.047) in winter. This was inconsistent with the relatively lower dietary PUFA (and 18:1) level in winter (-12 % each), which did not entail a lower fat score as one would expect. However, the ambient temperature was at a relatively low level of 18.5 °C during the finishing period focusing the interest again on the possible effect (=stimulation) of the endogenously synthesised oleic acid. As already in the ALT-pigs, the corresponding 18:1 model corroborated this assumption in the CON-pigs as well, predicting a higher 18:1 level in winter of 43.8 compared to 43.3 % in summer, though not significantly (P=0.262). Lebret et al. (2003) reported a slightly, not significantly, softer back fat of indoor-raised pigs when kept at an ambient temperature of 24 compared to 17 °C. However, their 18:1 level in back fat was, comparable with the present results, significantly higher at the 17 °C condition but was apparently not effective enough to compensate the concomitantly and significantly lower PUFA level, the latter (polyunsaturated fatty acids) influencing the consistency to a greater extent (due to at least two or more double bonds per fatty acid molecule) than the monounsaturated 18:1 featuring only one double bond per fatty acid molecule.

The second seasonal comparison of CON-pigs, the one from farms with complete feeding systems, featured, contrary to the precedent case, lower fat scores in winter (P=0.151). This was consistent with a lower dietary PUFA value (-8.5 %) and was perhaps also influenced by a remarkably lower dietary 18:1 level (-27 %) in winter. However, when looking at the corresponding ls-means of the 18:1 model a quasi indifferent situation was prevalent (43.1 and 43.2 % in summer and winter, respectively, at P=0.908). On the other hand, the temperature level of 19.6 °C ($\Delta_{\text{to summer}}$ -1.9 °C) was in a range where a stimulation of endogenously synthesised 18:1 must be considered. The fact that the prediction of 18:1 was not lower in winter (in spite of the firmness-beneficial dietary constellation) suggests that a back fat softening

[10] Regression model analysing the response variable oleic acid (18:1) in the back fat with the same structure of effects except the covariate dietary 18:1 (instead of dietary PUFA). The results (ls-means) of this model are not documented in chapter 5.1 “Results fat score”, but in the table App. IV, and used to corroborate the discussion and conclusions.

[11] Percentage of gaschromatographic analysed fatty acid profile.

temperature effect (and/or temperature-related, i.e. housing effect) could have been prevalent in the farms with complete feeding systems as well. – The oleic acid levels (42.0 to 43.8 %) were in the range or somewhat higher than results of Lefaucher et al. (1991) who published values for pigs kept indoors at an experimental cold T (12 °C) of 40 to 41 %, and at a thermoneutral T (28 °C) of 34.7 %, and of Le Dividich et al. (1987) publishing values of 42.4, 39.1 and 34.6 % at 12, 20 and 28 °C, respectively, again based on experimental indoor conditions. Although the differences in the present study of back fat 18:1 levels between summer and winter where not of that extent as in the temperature experiments of the two foregoing examples, the qualitative trend was the same.

Housing: The housing comparisons with whey feeding systems were more distinctive than those with complete feeding systems.

In whey feeding systems: The lower fat scores of ALT-pigs (in winter P=0.002, in summer P=0.242) were, as in the foregoing seasonal examples, accompanied by inconsistently (partly little) higher dietary PUFA levels (in winter +3 %, in summer +14 % compared to the CON-pigs' diet). On the other hand the, in the author's opinion noticeably, lower dietary oleic acid levels (in winter -26 %, in summer -13 %) explain these comparisons well. Inversely argued (i.e. applied to the CON-pigs' situation), a back fat-softening and/or oleic acid rising effect at higher oleic acid levels in the diet was reported in the literature (John et al., 1987; Rhee et al., 1988; Eder et al., 2001; Gläser et al., 2002). Additionally, the above discussed temperature effect (being more effective in CON-pigs) occurred between the housing systems in winter again (with 18.5 and 13.5 °C in CON and ALT, respectively) when considering the lower 18:1 level of ALT-pigs (43.3 %, $\Delta_{\text{to CON}}$ -0.5 %, P=0.332). In summer there was no relevant difference of back fat oleic acid (43.3 %, $\Delta_{\text{to ALT-pigs}}$ -0.1 %, P=0.870) at temperatures of 23.2 and 17.5 °C in CON and ALT, respectively.

A second aspect regarding too low T in CON (< 20 to 22 °C) should be taken into account. The endogen 18:1 synthesis is at a falling temperature level gradually enhanced (Lefaucher et al., 1991). It can be imagined that at a level of 18.5 °C (CON-farms with whey feeding systems during the winter period) the continuous exposure of the skin especially during the about 80 % of the diurnally activity taking resting period (Mayer, 1999) on the slats increased the 18:1 proportion of the adipose tissue and could so also have increased the fat score. A little draft from beneath the slats for example enhances the effect of convection (heat loss via air movement). Fuller et al., 1974 in a temperature experiment calculated an increase of the iodine value of the adipose tissue of 0.22 to 0.55 iodine units per degree Celsius (equal to 1.1 to 2.25 iodine units per 5 °C) within the range of 23 to 5 °C. Tonks et al. (1972) reported a significantly higher iodine value of at 21 °C compared 28 °C again of indoor fattened pigs in a Danish-type house.

In complete feeding systems: The housing comparisons in complete feeding systems represented a different (contrary) pattern than the one of the foregoing whey feeding systems regarding the fat score and the oleic acid results. The higher fat score and the lower 18:1 level of ALT-pigs in winter was opposed to the dietary variables (PUFA -4 %, 18:1 +30 % in ALT-farms), and also the temperature levels (19.6 and 10.5 °C in CON and ALT, respectively) were not in accordance with the results. While the higher fat score would be explained by the remarkably lower temperature level, this seems to be rejected for the actual temperature dependent 18:1 level in ALT-pigs. A possible explanation for this phenomenon is that the 18:1-stimulating temperature effect was relatively more pronounced in CON- than ALT-farms even at a 10.5 °C level in the latter leading to a nearly equal 18:1 level in both subclasses but influencing the fat score not in the extent to be higher than the one of ALT-pigs (due to the above mentioned double bond interrelationship). It can be concluded that in ALT-housings the range of comfortable a temperature is wider when providing littered rest areas compared to fully slatted floors regarding the consistency of the back fat (Mount, 1979; Verstegen and Van der Hel, 1974). In summer a similar conclusion can be drawn. The fat scores were though about same (59.9 and 60.0 for CON- and ALT-pigs, respectively) but the 18:1 levels (43.1 and 42.0 % for CON- and ALT-pigs, respectively, at P=0.019) differed more distinctively than in winter. The fat scores were (in summer) in both subclasses higher levelled and can be explained by the generally higher dietary PUFA levels. However, the figures for the back fat 18:1 (43.1 and 42.0 % for CON- and ALT-pigs, respectively) were inconsistent with the dietary 18:1 levels (0.78 and 1.02 g/MJ for CON- and ALT-pigs, respectively), that is the lower back fat value in ALT-pigs went along with a higher dietary value (+31 %). Apparently, the ambient temperature of 21.5 °C in CON-farms, a level where the stimulation of 18:1 is expected (Tonks et al., 1972; Le Dividich et al., 1987), was responsible also in the summer period for the significantly higher oleic acid level.

5.1.3.2. Temperature effect

The housing-separate analysed effect of the ambient temperature on oleic acid revealed a significant response of the pigs in alternative housings in winter with a linear and negative slope of -0.145 % 18:1 per °C (P=0.016) whereas in summer no slope was prevalent (Fig. 7 below). The slope in conventional housings (above) baffle a little bit due to the unexplainable low 18:1 values (and fat scores, see also Fig. 6) of the earlier mentioned five market groups experiencing about 13 °C in the winter period (lowest of all records).

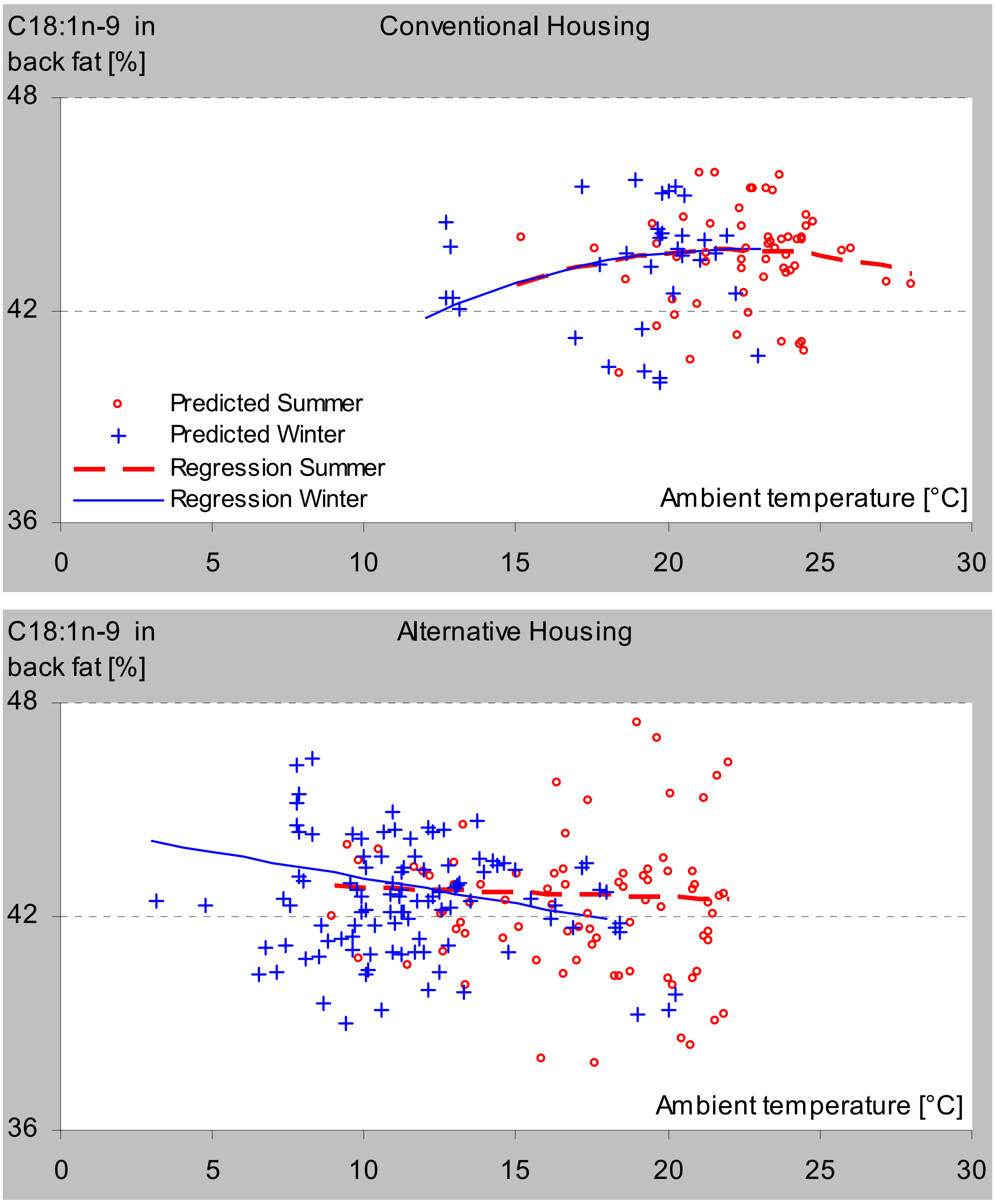


Fig. 7: Regression curves of the variables oleic acid in back fat and ambient temperature

The significance (P_t-values) of the slopes was: CON_{linear} 0.103, $CON_{quadratic}$ 0.082; and in ALT interacted with season ALT_{summer} 0.176, ALT_{winter} 0.016. One dot represents one market group.

A further aspect to consider in this context is the negative correlation of enzymatic activity of the fatty acid synthesis in the adipose tissue and thickness of the back fat (Mourot et al., 1999), enhancing the oleic acid synthesis in leaner pigs compared to fatter ones at low ambient temperatures (Lefaucher et al., 1991). In the present study, such an effect might have been present in certain cases (e.g. particularly lean animals) but was considered not of general importance. Firstly, genetically leaner pigs (i.e. Piétrain) were in a minority (3.4 %) and these pigs inherited no more than one-quarter Piétrain blood (see 4.2.3 and Table 4). Secondly, based on farm reports the feed regimes were partly ad lib (only in complete feeding systems), partly semi-restricted[12], and partly restricted, but always satiable. Most of the cheese dairies maintained a restricted-satiable feeding regime with three full meals per day, and many provided an extra pure whey meal at night (8 to 10 pm). The regression curves of pig-individual fat-free lean percentages and ambient temperatures (Fig. 12 of the criterion fat-free lean) showed no crucial interrelationship, i.e., higher lean percentages at low temperatures, which could be an indication of insatiable feed regimes. The lowermost cases at 3 and 5 °C featured, on the contrary, more fat deposition (lower lean proportion; see Fig. 12, lower plot). Consequently, the regression curves of oleic acid in function of fat-free lean revealed virtually no interrelationship between these two parameters (Fig. 8).

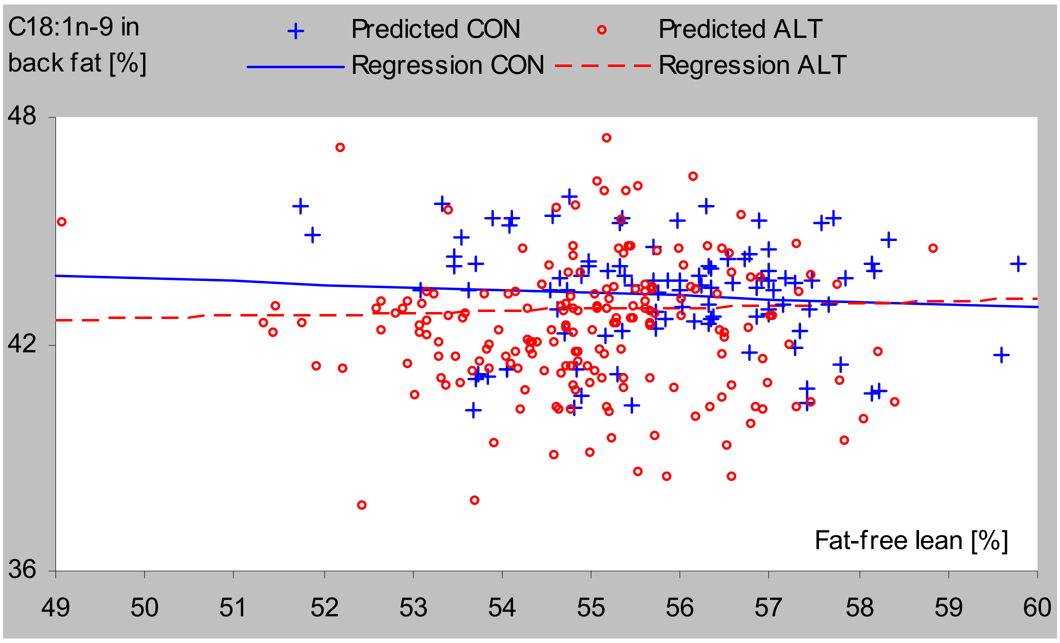


Fig. 8: Regression curves of the variables oleic acid in back fat and fat-free lean

The significance (P_t-value) of the slopes was 0.377 and 0.149 in CON and ALT, respectively. One dot represents one market group. The data structure of this study revealed a small interrelationship of oleic acid and fat-free lean.

[12]Ad lib feeders but no leftovers, whereas full ad lib is defined with leftovers within a day.

5.2. Results fat-free lean proportion

5.2.1. Descriptive statistics

Table 12 section A to F lists the averages, standard deviations, coefficients of variance, minima and maxima of the response variable and the covariates for each of the eight subclasses separately. The averages are given also within housing systems, and the average, minimum and maximum of the overall data. The number of pigs of subclasses is given in the first section repetitive thereafter.

Table 12: Descriptive results (fat-free lean)

		Comparison	Slaughterhouse 1 Avg / SD	Min	Max	CV-%	Comp.	Slaughterhouse 2 Avg / SD	Min	Max	CV-%	Overall	n pigs Slaughterhouse 1	n pigs Slaughterhouse 2
A) Fat-free lean [%]														
Summer	*Whey Feed*													
	CON	1)	55.7 ± 2.8	45.6	63.0	5.0	2)	55.6 ± 3.0	44.7	62.8	5.4		326	427
	ALT		54.3 ± 3.3	44.6	62.4	6.1		53.8 ± 3.4	43.4	60.3	6.3		265	238
	Complete Feed											CON Average 55.9		
	CON	3)	56.8 ± 3.1	46.9	61.9	5.5	4)	55.7 ± 3.2	45.0	62.9	5.7	ALT Average 55.1	110	199
	ALT		55.0 ± 3.1	45.7	62.9	5.6		54.3 ± 3.0	45.2	61.0	5.5		823	342
Winter	*Whey Feed*													
	CON	5)	57.0 ± 2.8	48.3	64.2	4.9	6)	55.8 ± 3.0	44.9	63.2	5.4	Total	139	520
	ALT		55.3 ± 3.1	46.7	61.8	5.6		55.8 ± 2.7	47.6	62.6	4.8	Average 55.4	353	284
	Complete Feed											Min 43.4		
	CON	7)	56.0 ± 3.0	49.3	61.7	5.4	8)	56.3 ± 3.0	48.4	62.5	5.3	Max 64.2	66	186
	ALT		55.9 ± 3.1	44.6	63.0	5.5		55.5 ± 3.2	47.1	63.4	5.8		687	330
B) Carcass weight hot [kg]														
Summer	*Whey Feed*													
	CON	1)	84.0 ± 7.9	65.1	103.4	9.4	2)	84.3 ± 5.5	67.5	98.0	6.6		do.	
	ALT		84.0 ± 6.7	68.8	101.0	7.9		84.6 ± 5.7	70.5	102.5	6.8			
	Complete Feed											CON Average 83.7		
	CON	3)	84.1 ± 6.3	65.1	99.1	7.5	4)	83.5 ± 6.2	68.0	97.5	7.4	ALT Average 84.0		
	ALT		83.9 ± 6.5	65.5	106.8	7.7		84.7 ± 6.9	69.5	106.5	8.1			
Winter	*Whey Feed*													
	CON	5)	84.1 ± 5.3	73.2	99.3	6.3	6)	83.6 ± 5.9	66.0	100.5	7.1	Total		
	ALT		84.0 ± 6.3	65.7	103.8	7.5		81.6 ± 6.1	65.0	99.0	7.5	Average 83.9		
	Complete Feed											Min 65.0		
	CON	7)	84.0 ± 6.6	66.1	99.9	7.8	8)	81.8 ± 6.1	66.5	97.0	7.4	Max 107.2		
	ALT		84.6 ± 6.7	66.9	107.2	8.0		84.3 ± 7.1	66.0	103.0	8.5			

to be continued

continued		Comparison	Slaughterhouse 1				Comp.	Slaughterhouse 2						n pigs Slaughterhouse	
			Avg /SD	Min	Max	CV-%		Avg /SD	Min	Max	CV-%	Overall		1	2
C) Time 25 kg to market [days]															
Summer	*Whey Feed*														
	CON	1)	98 ± 15	65	121	15.3	2)	106 ± 19	75	158	18.0			326	427
	ALT		103 ± 12	82	117	12.1		103 ± 11	88	124	10.3			265	238
	Complete Feed											CON Average	106		
	CON	3)	111 ± 34	63	141	30.3	4)	107 ± 14	88	140	13.3	ALT Average	107	110	199
	ALT		105 ± 21	61	174	20.1		106 ± 14	81	143	13.5			823	342
Winter	*Whey Feed*														
	CON	5)	107 ± 11	93	121	10.6	6)	109 ± 9	91	125	7.9	Total		139	520
	ALT		115 ± 13	96	133	11.3		112 ± 15	92	140	13.4	Average	107	353	284
	Complete Feed											Min	61		
	CON	7)	110 ± 13	100	119	12.3	8)	105 ± 15	87	133	14.2	Max	174	66	186
	ALT		108 ± 21	72	169	19.6		104 ± 13	82	128	12.8			687	330
D) Energy in diet [MJ/kg]															
Summer	*Whey Feed*														
	CON	1)	15.7 ± 0.3	15.2	16.4	2.2	2)	15.6 ± 0.4	14.7	16.0	2.6			do.	
	ALT		15.4 ± 0.2	15.2	15.6	1.1		15.6 ± 0.4	15.3	16.2	2.6				
	Complete Feed											CON Average	15.6		
	CON	3)	15.5 ± 0.3	15.2	15.9	2.0	4)	15.5 ± 0.3	15.1	15.9	1.9	ALT Average	15.5		
	ALT		15.6 ± 0.3	15.2	16.3	1.8		15.6 ± 0.6	14.6	16.6	3.8				
Winter	*Whey Feed*														
	CON	5)	15.9 ± 0.9	15.2	17.3	5.4	6)	15.6 ± 0.6	14.9	17.3	3.9	Total			
	ALT		15.6 ± 0.3	15.3	16.2	1.8		15.5 ± 0.3	15.1	15.9	1.9	Average	15.6		
	Complete Feed											Min	14.6		
	CON	7)	15.9 ± 0.4	15.6	16.2	2.6	8)	15.3 ± 0.3	14.9	15.7	1.9	Max	17.3		
	ALT		15.4 ± 0.3	14.9	16.0	1.8		15.7 ± 0.4	15.4	16.6	2.4				
E) Protein in diet [%]															
Summer	*Whey Feed*														
	CON	1)	18.3 ± 1.0	16.9	19.9	5.5	2)	19.6 ± 1.8	16.6	22.0	9.4			do.	
	ALT		19.4 ± 1.9	17.0	22.1	10.0		18.1 ± 1.5	15.7	19.4	8.2				
	Complete Feed											CON Average	19.2		
	CON	3)	19.4 ± 1.5	17.9	21.5	7.9	4)	18.3 ± 0.9	17.0	20.1	5.0	ALT Average	18.8		
	ALT		18.8 ± 1.4	16.7	23.2	7.5		18.3 ± 0.7	17.2	19.3	3.6				
Winter	*Whey Feed*														
	CON	5)	19.9 ± 2.4	16.5	22.2	12.1	6)	19.8 ± 2.3	16.5	23.2	11.5	Total			
	ALT		18.6 ± 1.8	14.8	21.5	9.8		18.9 ± 1.3	17.0	20.3	6.9	Average	19.0		
	Complete Feed											Min	14.8		
	CON	7)	18.1 ± 1.0	17.4	18.9	5.7	8)	19.0 ± 1.6	17.0	21.4	8.5	Max	23.2		
	ALT		19.2 ± 1.4	17.5	22.8	7.2		18.4 ± 0.4	17.9	18.9	2.1				
F) Ambient temperature[a] [°C]															
Summer	*Whey Feed*														
	CON	1)	22.7 ± 1.5	20.3	24.4	6.4	2)	23.6 ± 2.0	19.5	28.0	8.6			do.	
	ALT		18.4 ± 3.4	13.0	21.5	18.3		17.3 ± 4.0	10.5	22.0	23.0	CON Average	22.7		
	Complete Feed											ALT Average	17.2		
	CON	3)	19.8 ± 2.3	18.4	22.4	11.5	4)	22.1 ± 2.2	17.6	24.8	9.9				
	ALT		18.0 ± 3.1	9.0	21.8	17.3		14.9 ± 3.6	9.5	21.7	24.2				
Winter	*Whey Feed*														
	CON	5)	19.1 ± 2.9	12.8	22.3	15.4	6)	18.6 ± 3.0	12.7	21.5	15.9				
	ALT		13.7 ± 4.3	7.8	20.3	31.2		12.4 ± 3.1	7.7	17.3	25.1	CON Average	19.0		
	Complete Feed											ALT Average	11.2		
	CON	7)	19.0 ± 2.9	16.9	21.0	15.2	8)	19.7 ± 1.7	17.7	22.9	8.8				
	ALT		9.5 ± 2.4	3.2	13.3	25.4		10.9 ± 1.9	7.4	14.2	17.6				

[a] Temperature of finishing period averaged over the last 60 days, 24 records/day: CON indoors, ALT average of in- and outdoors.

- Avg: average.

The CON-pigs featured overall a higher fat-free lean (55.9 %) than the ALT-pigs (55.1 %) (section A). A second characteristic in this study was the generally higher fat-free lean percentages in winter, as compared to the foregoing summer period except in one summer-winter comparison, namely the CON-farms with complete feeding systems in slaughterhouse 1 (comparison $3_{=Summer}$ and $7_{=Winter}$) where it was inverse. The seasonal differences were particularly distinctive in the ALT-farms. The averages among the eight subclasses in winter were more homogenous reflected by a smaller difference between the highest and lowest subclass (1.7 %) compared to a difference of 3 % in summer. The extreme individual records were read at 43.3 and 64.2 % for minimum and maximum, respectively. – The carcass weight hot (section B) featured a situation with an overall average of 84 kg, and a minimum and maximum of 65 and 107 kg, respectively. – The covariate “time 25 kg to market” (section C) was in both housing systems at an average of 106 to 107 days. The majority (76 farms) started with piglets of 23 to 30 kg BW and within that range, piglets of 25 kg BW (40 % of the farms) was most common (Fig. 9). Few farms practised a different management starting the fattening period with younger or older piglets. The minimum and maximum of 61 and 174 days, respectively, and the relatively higher coefficients of variance compared to other variables reflect this.

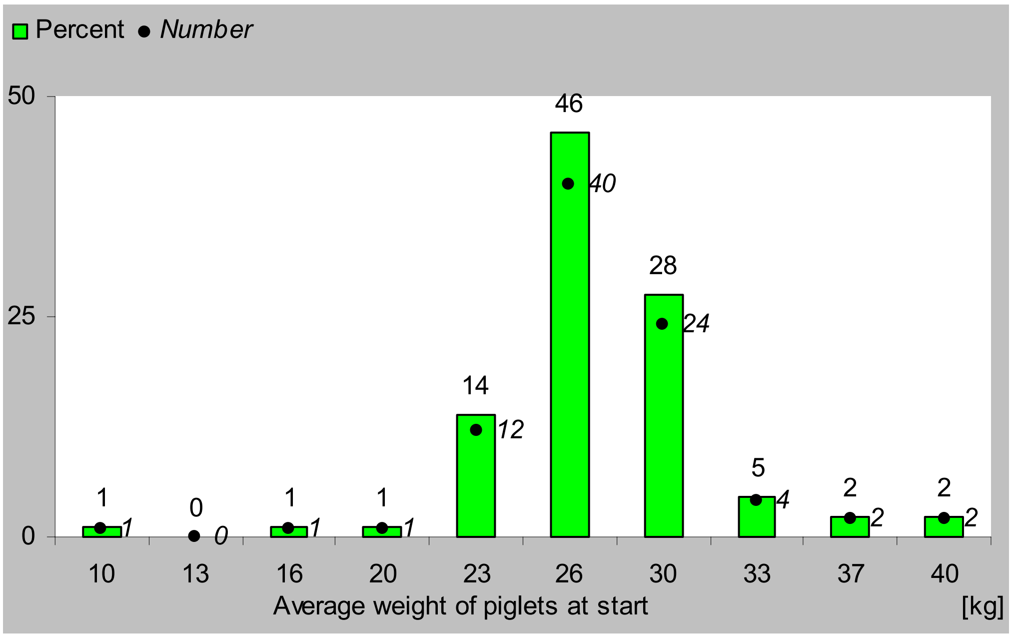


Fig. 9: Approximate weight of piglets within farms at starting

Numbers on the top of the columns define percentage, and figures beside the columns the absolute number (frequency) of farms. The piglets were weighed as an averaged record of a starting batch when arriving on a farm, or the weight was given based on values according the experience between the supplier and the farmer.

The dietary digestible energy (section D) was about equal in both housing systems with an average of 15.6 MJ DE per kg dry matter (DM) within a range of 14.6 and 17.3 MJ for minimum and maximum in farms, respectively. The averages among the subclasses differed up to 0.5 MJ, and the coefficients of variance were smallest compared to those of the other variables, reflecting a relatively homogenous situation. However, the range among the farms was larger with a minimum of 14.6 MJ and a maximum of 17.3 MJ in a farm with complete- and whey feeding system, respectively. The averages of dietary crude protein (section E) were more heterogeneous than those of energy (mostly distinctively larger coefficients of variance). The CON-farms featured a higher overall average of 19.2 %, as compared to 18.8 % crude protein in ALT-farms. This characteristic was reasoned by, though not exclusively but mainly, higher crude protein values in subclasses of farms with whey feeding systems (cheese dairies). Whey contains beside carbohydrates (lactose) mainly milk serum proteins, which is rich of lysine (Kallweit et al., 1988). Lysine is often the first limiting amino acid in pigs' diets (e.g. Close, 1994). The minimum and maximum of the crude protein level among the farms was at 14.8 % in an ALT-farm (16.6 % in a CON-farm) and 23.2 %, respectively, in farms of each feeding system.
For the description of the ambient temperature, see criterion fat score.

5.2.2. Results (fat-free lean)

5.2.2.1. Residual analysis, model fit, F- and P-values

The residual analysis of the model fat-free lean revealed a slightly left-skewed distribution (Fig. 10, plot above right) represented as well in the QQ-plot of the residual normal distribution (plot above left) by the bold marked dots. These 30 records from the lower tail of the distribution (highest negative residuals of -8.2 to -12.0) have been examined and considered for exclusion from the editing model. Most of them would have been predicted remarkably high (Fig. 11, plot above right). Common to these records was their low fat-free lean (average 45.8, minimum 43.1, maximum 49.4 %; overall average 55.4 %) as was the belly (the latter has not been a subject of this study). In contrast, their carcass weight (average 84.8, minimum 74.6, maximum 96.5 kg, overall average 83.9 kg) and "time 25 kg to market" (average 106, minimum 63, maximum 146 days, overall average 107 days) were not particularly different from the overall average. Considering these facts, the animals presumably were either genetically predisposed to deposit fat rather than accrete protein, and/or management causes (e.g. feeding related issues) would have influenced its growth negatively.

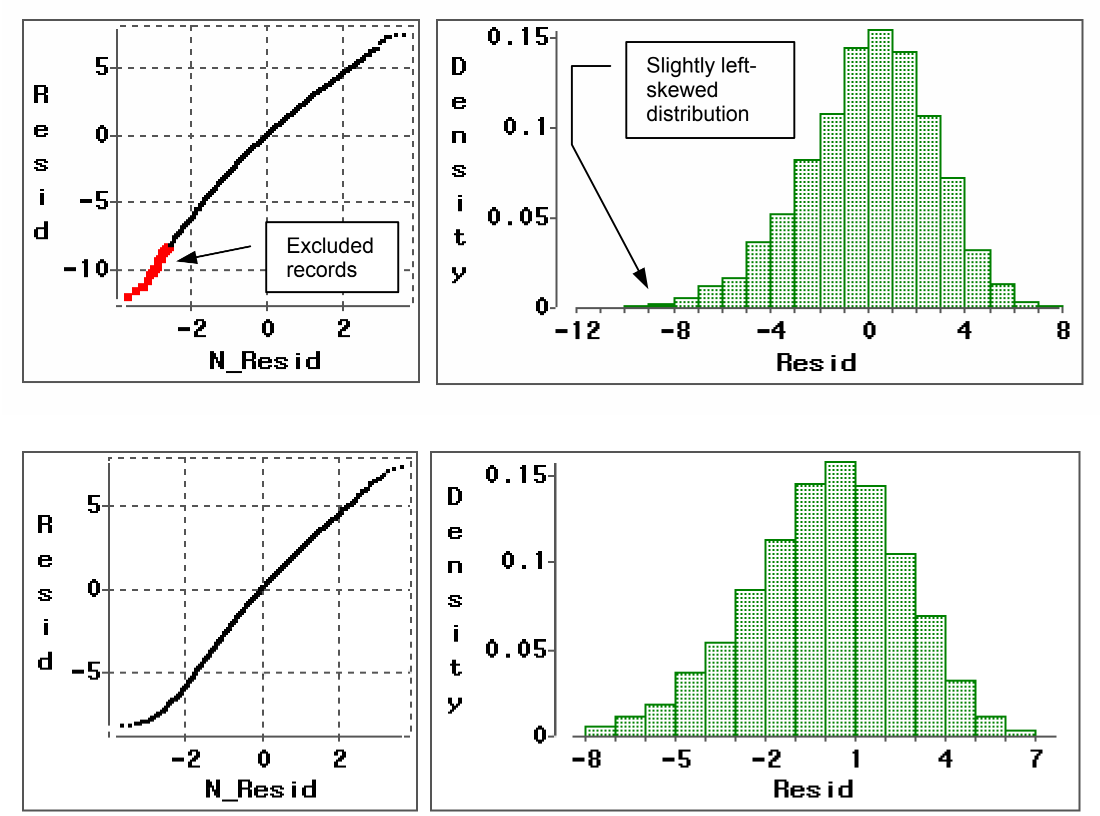


Fig. 10: QQ- and normal distribution plot of residuals (fat-free lean)

Representative for all three models, the plots of the main model (housing comparison) are shown; before (above) and after (below) exclusion of 30 records (bold marked). Total edited records 5,295; scale of x-axis: 1 %-unit.

The exclusion resulted in a nearly balanced distribution (Fig. 10 below) with a residual minimum and maximum of -8.17 and +7.66, respectively. The excluded records (pigs) were scattered among the subclasses (Table 2). It would have been a sign to focus on if all of them were raised in one particular subclass. Excluding these 30 records (0.56 % of the total) from the analysis altered five significance levels of eight comparisons by P≈0.2, revealing one comparison to become significant, two comparisons to decrease the P-value below 0.40, toppling another comparison out of the significance limit of α=0.05, and increasing the P-value of a last comparison from 0.430 to 0.687. The editing main model featured a residual variance of 6.92±0.14 corresponding to a standard deviation of 2.63 at a 1.9 % lower (=better) AIC. The correlations predicted-observed amounted to r=0.56, 0.57 and 0.53 for the main model, sub-model-CON and sub-model-ALT, respectively. These figures were remarkably lower than those from in the foregoing fat score criterion, which is explainable by the fact that this analysis based on individual animal records, whereas the analysis of the fat score based on clustered averages of market groups (loosing so part of the variation).

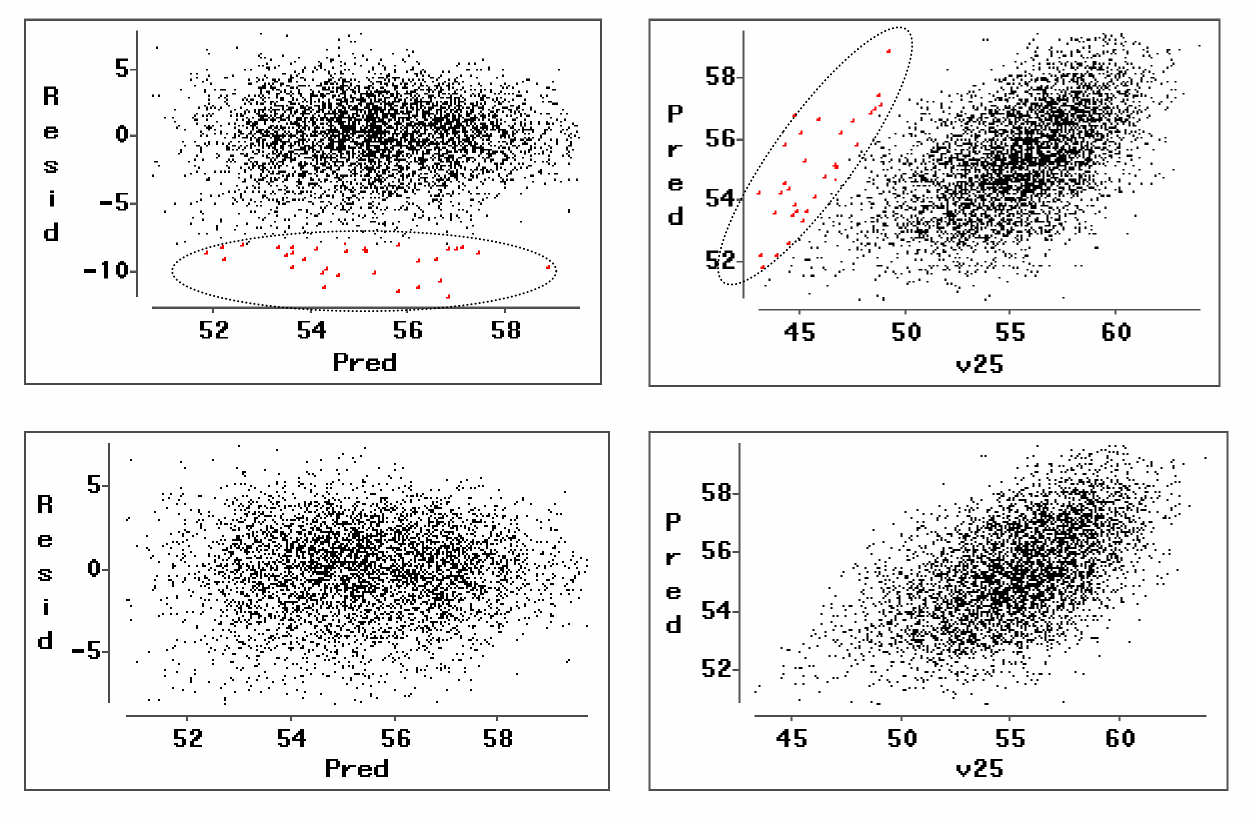


Fig. 11: Residual- and correlation plot of predicted v. observed values (fat-free lean)

v25= observed values; representative for all three models, the plots of the main model are shown: before (above) and after (below) exclusion of 30 records (isolated and bold-red marked); $correlation_{Pred.-Obs.}$= 0.55 and 0.56 before and after exclusion, respectively (right plots); n_{edited}=5,295.

The F- and P-values of all model effects are given in Table 13. One outstanding fact was that the effect sex assigned about 85 % (F=888, P<0.0001) of the model variance in all three models. The second important effect in the main model concerned the covariate “time 25 kg to market” (F=35.1+16.1, P<0.0001, equal to 3.4+1.5 % of the total explained variance). The sum of the 15 housing related interaction effects hs*fs*sn*sl featured an F-value proportion of 6.3 % and the interaction itself an F-value of 2.3 (0.2 %) at P=0.135. The linear and the quadratic interaction effect of the covariate ambient temperature in the sub-models featured F-values of 2.3 to 4.4 (0.5 to 0.7 %) at P 0.038 to 0.136 with a slightly higher importance in the sub-model-ALT.

Table 13: F- and P-values of model effects (fat-free lean)

Model effects	Main model			Sub-model-CON		Sub-model-ALT	
	df[a]	F-value	P-value	F-value	P-value	F-value	P-value
Fixed effects							
Sex (x)	5224	887.7	<.0001	311.1	<.0001	516.4	<.0001
breed (b)	125	6.1	0.0002	1.1	0.3312	7.4	<.0001
Season (sn)	545	23.8	<.0001	1.9	0.1772	0.0	0.9775
• Housing system (hs)	60.1	18.0	<.0001				
Feeding system (fs)	102	6.1	0.0002	1.4	0.2606	7.9	0.0069
Slaughterhouse (sl)	89.4	0.0	0.9026	6.2	0.0128	4.3	0.0468
sl * b	118	3.7	0.0070	2.71	0.0669		
sl * sn	50.7	0.8	0.3898	1.2	0.2826	3.6	0.0685
sl * fs	53.5	0.9	0.3610	0.9	0.3585	1.1	0.3041
sn * fs	57.8	2.5	0.1228	0.2	0.6841	5.6	0.0248
• sl * hs	53.2	0.2	0.6237				
• sn * hs	56.5	6.1	0.0163				
• fs * hs	58.3	0.5	0.4735				
sl * sn * fs	53.8	0.1	0.7515	3.3	0.0763	2.7	0.1099
• sn * fs * hs	57.7	1.5	0.2277				
• sl * sn * hs	52.3	1.2	0.2821				
• sl * fs * hs	53.4	0.2	0.6310				
• sl * sn * fs * hs	52.3	2.3	0.1348				
• Σ of (sl * sn * fs * hs) -effects		64.1					
Covariates							
Time 25 kg to market	633	35.1	<.0001	19.3	<.0001	11.0	0.0011
Time 25 kg to market * sn	637	16.1	<.0001			11.4	0.0009
Weight	5233	7.6	0.0060	4.8	0.0286	5.0	0.0258
Weight * weight	5231	9.8	0.0017	5.5	0.0187	6.4	0.0112
Energy	92.5	3.2	0.0761	3.2	0.1207	2.1	0.1553
Energy * fs				1.5	0.2569		
Protein	104	2.3	0.1290	2.2	0.1546	0.1	0.7820
Protein * fs	102	8.6	0.0043			8.3	0.0058
Temperature				0.1	0.7341	0.1	0.7188
Temperature * sn				2.3	0.1356	3.3	0.0713
Temperature * temperature				0.0	0.8898	0.6	0.4312
Temperature * temperature * sn				2.7	0.1047	4.4	0.0384
Sum of F-values		1044.4		371.7		601.7	

[a] The degrees of freedom (df), computed with the Satterthwaite approximation, are given for the Main model (n=5295 records).

• housing related effects.

Table 14 lists the variance, ratio, and number of farms per group of the random effect farm, and the residual related values. The criterion fat-free lean depends on non-slaughterhouse effects rather than the other two criteria fat score and pH. Hence, the grouping of the random effect farm was computed within the effects season, housing and feeding system. The chi-square test showed a P-value <0.001 compared to the model without grouping, and the model featured a better (=smaller) AIC by 42 units (0.2 %). In spite of the significance the ratios were small (not of importance) with values of 4 to 27 % of the residual variance of 6.92. The groups were very homogeneous in summer with a variance of 0.66 to 1.0, and featured a somewhat larger variation in winter with a variance of 0.27 to 1.84. The maximum of 1.84 and minimum of 0.27 occurred in CON- and ALT-farms, respectively, both in winter and in combination with whey feeding systems.

Table 14: Variance of the random effect farm and the residual (fat-free lean)

Random effect farm grouped in:									
Season	Summer				Winter				
Feeding system	Whey feed		Complete feed		Whey feed		Complete feed		Residual
Housing system	CON	ALT	CON	ALT	CON	ALT	CON	ALT	
Main model									
Number of farms	24	12	12	31	19	15	8	27	
Variance ± SE	1.00 ± 0.4	0.69 ± 0.4	0.95 ± 0.6	0.66 ± 0.2	1.84 ± 0.8	0.27 ± 0.2	0.66 ± 0.5	1.22 ± 0.4	6.92 ± 0.1
Ratio in % of residual[a]	14	10	14	9	27	4	10	18	

[a] Variance*100 diveded by the residual variance (and rounded); example: 1.00*100/6.92=14.45, rounded to14.

5.2.2.2. Housing effect

The eight housing comparisons of the response variable fat-free lean are given in Table 15, comparisons 1 to 8. For an overview of the eight comparisons encircled ls-means highlight comparisons with a trend (arbitrarily at P<0.3) when CON>ALT, quadratic frames (as in the other two criteria) would emphasise distinctive higher ALT levels, which were not existing in this criterion.

In general, the comparisons featured a housing dependent pattern, particularly in summer. The CON-pigs exhibited in seven of the eight comparisons higher ls-means than the ALT-pigs, and in the eighth comparison (number 6) it was contrary. In summer, the higher ls-means of CON-pigs were significant in three comparisons, with P-values of 0.012, 0.0004 and 0.028 in comparison 1, 2 and 4, respectively, and the fourth comparison (number 3) was nearly significant at P=0.098. In winter, no comparison was significant; however, two comparisons featured a trend for higher levels of CON-pigs at P-values of 0.180 and 0.217 in the comparisons 5 and 8, respectively, while the remaining two comparisons were nearly balanced with P>0.68.

Table 15: LS-Means of housing comparisons (fat-free lean)

Main model		Slaughterhouse 1				Slaughterhouse 2			
		Comparison	LS-Means[a]	SE	P-value[b]	Comparison	LS-Means	SE	P-value
Summer	*Whey Feed*								
	CON	1)	55.6	0.39	**0.012**	2)	55.7	0.35	**<0.001**
	ALT		54.2	0.40			53.4	0.50	
	Complete Feed								
	CON	3)	55.9	0.51	0.098	4)	56.1	0.44	**0.038**
	ALT		55.0	0.26			55.0	0.35	
Winter	*Whey Feed*								
	CON	5)	56.2	0.52	0.180	6)	55.8	0.41	0.687
	ALT		55.5	0.27			56.0	0.32	
	Complete Feed								
	CON	7)	56.0	0.70	0.760	8)	56.5	0.43	0.217
	ALT		55.8	0.33			55.8	0.44	

[a] LS-Means are computed with the REML approach; [b] P-values are unadjusted and bold marked when <0.05.

- Frames provide an overwiew at a glance for comparisons at P<0.3; quadrate: ALT>CON, circle: ALT<CON.

5.2.2.3. Temperature effect

The regressions of the covariate ambient temperature (linear and quadratic) resulted in two curves per housing system (Fig. 12) expressing the seasonal relationships. The significances (P_F-values) of the linear terms in interaction with season ($T \times sn$) were 0.136 and 0.071, and that of the quadratic terms ($T^2 \times sn$) 0.108 and 0.038 in the CON and ALT, respectively. The curves show relatively weak season-dependent trends in both housing systems.

Conventional housing system: In winter, a trend towards higher fat-free lean was observed with rising temperatures without regard to the apart-situated observations at T<15 °C. The latter contrary to an expected trend featured a higher level of fat-free lean, which cannot be explained (same market groups as in the criterion fat score[13]). In summer, higher temperatures went along with lower ls-means.

Alternative housing system: In winter, lower fat-free lean proportions were prevalent beyond the temperature range of 6 to 16 °C than within this range. In summer, no trend was observed in the upper temperature range, whereas in the lower range a slight tendency towards higher ls-means could be seen.

[13] Presumably the temperature records were not correct.

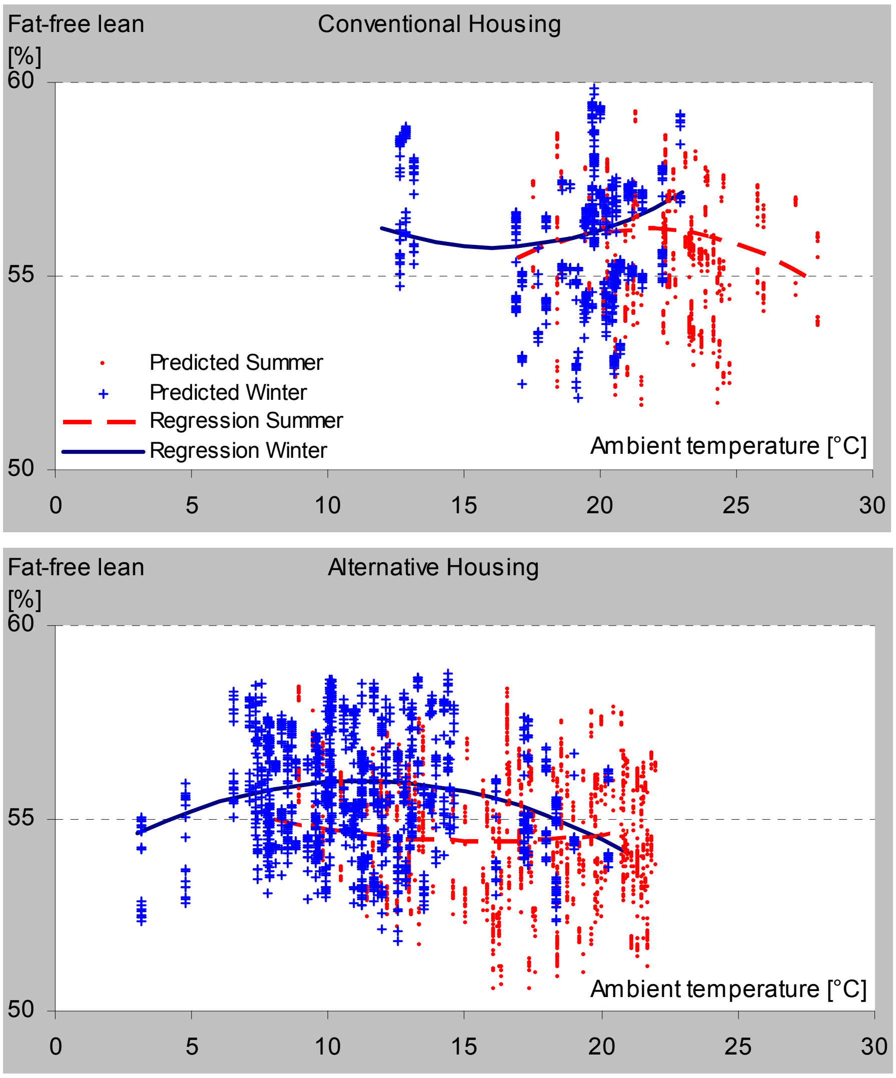


Fig. 12: Regression curves of the variables fat-free lean and ambient temperature

The P-values of the interaction effect of the covariate fat-free lean was: CON_{linear} 0.136, $CON_{quadratic}$ 0.105; ALT_{linear} 0.071, $ALT_{quadratic}$ 0.038. One cross/dot represents one record (=pig). A confounding of the fixed effect season and the covariate T can be excluded because the main temperature range covered both seasons. If temperature levels would not have been clearly different in summer and winter then a possible temperature effect could also be a season effect (and vice versa).

5.2.3. Discussion (fat-free lean)

5.2.3.1. Housing effect

Two articles were published recently analysing comparable housing systems. Lebret et al. (2002) found no rearing influence on muscle percentage (fat-free lean), while in another experiment Lebret et al. (2003) reported a significantly higher lean meat content (fat-free lean) for pigs reared in a conventional housing system. In the present study, a similar situation was observed, namely both higher and equal levels of fat-free lean in the second period (winter). In summer, the CON-pigs featured consistently higher levels. Besides possible climatic impacts, another reason for higher fat-free lean in winter (the second recording period) has to be taken into account: the data collecting fell into a period of an ongoing switch from conventional to alternative housing systems (1997 <10 %, 2001 >40 % ALT-pigs, see Fig. 1), which brought about new management challenges to the farmers (feeding, housing, etc.), even more so to those with whey than the easier-to-manage complete feeding system. The majority (92 %) of market groups from ALT-farms featured an averaged fat-free lean percentage higher in winter than in summer, with a minimum and maximum difference of -2.5 and +7.4 %, respectively (plus means winter > summer, minus vice versa), whereas only 55 % of CON market groups were higher in winter, with a minimum and maximum difference of -1.3 and +4.1 %, respectively. These figures corroborate a presumed improved management in ALT-farms in the second recording period (winter).

Other investigations of indoor- and outdoor-raised pigs included free-range pigs on pasture and outdoor pens (circa 7 m^2/pig) over soil/straw e.g. in Holland (Van der Wal et al., 1993), in the U.S.A. (Gentry et al., 2002), in Sweden (Enfält et al., 1997; Stern et al., 2003), or cabins for shelter and straw beds against the cold (0.5 m^2/pig) in the western Canadian climate in Alberta (Sather et al., 1997). These kinds of pig-raising refer rather to semi-intensive or extensive systems (organic farming), while the present alternative housing is considered as an intensive system with a limited outdoor area of 0.45 to 0.65 m^2 /pig usually on concrete floors. From the climatologic point of view very extreme conditions were reported by Sather et al. (1997) with temperatures in Winter (January to April) clearly below 0 °C during the growing and above the freezing point during the finishing period, compared with a 20 °C climate of indoor pigs. The temperature in their summer period of 15 to 5-10 °C in the growing to the finishing period, respectively, (June to October) were comparable with the present conditions in the winter period. Interestingly, their housing comparisons within season revealed a higher fat-free lean of the “free range” pigs in both seasons (differences amounted to significantly +1 % in summer, and 0.5 % in winter), however, with about 14 days more time required to the market life weight of 105 kg. In the present study, the effective time to market was equal in CON and ALT at only little different carcass weights (in summer 83.1 and 83.2 kg, in winter 83.3 and 83.9 kg for CON- and ALT-pigs, respectively). The predicted fat-free lean proportion was higher in summer for the CON-pigs in all four comparisons ($P<0.10$), whereas in winter two comparisons (number 6 and 7) featured almost equal levels, and higher values were seen for the CON-pigs in the other two comparisons (number 5 and 8). It can be concluded that the fat-free lean proportion is not necessarily negatively affected when fattening pigs are kept under outdoor conditions although the exact comparison of these two works is because of different approaches not given. Stern et al. (2003) reported in a two years comparison as well higher fat-free lean values in the second year of pigs kept on a pasture in an experimental design with n>70 (not described whether it was in summer or in winter). The higher energy supply in the second year in their trial can be seen as an improved management measure as it is assumed in the present study and discussed earlier. The rearing comparison by Enfält et al. (1997) in August to October revealed as well, though not significantly, higher fat-free lean values (+ 0.5 %, n=51) for the free-range pigs, and the trial by Gentry et al. (2002) in a semi-arid climate at 1,000 m altitude in Texas (U.S.A.) showed again leaner pigs and a larger loineye area of the outdoor pigs (difference significant in summer and not significant in winter, n=40). On the other hand, Van der Wal et al. (1993) published from Holland a significantly lower lean meat percentage and concomitantly more fat of scharrel (="free range") pigs (littered pens provided with access to an open dunging area) compared to conventional indoor raised pigs. However, in an earlier trial by Van der Wal (1991) scharrel pigs (n=39) featured higher lean meat percentages than conventional pigs. No difference of fat-free lean of free-range (300 m^2/pig) and conventionally raised pigs (n=12 each) was reported by Bridi et al. (1998) in Brazil.

The variation (standard deviation = square root of variance) of farms grouped within season, feeding and housing system, was small as compared the fat score and pH models. The maximum ($CON_{Whey\text{-}Feed}$ $\sqrt{1.84}$ =1.36) and minimum ($ALT_{Whey\text{-}Feed}$ $\sqrt{0.27}$ =0.52) resulted in winter and reflect the fact that the variation of the CON-farms was somewhat higher than that of the ALT-farms. In a parallel-study, Schnider (2002) investigated health aspects in the same farms. He reported a remarkably higher proportion of CON-farms (>50 %) with bad air quality in winter, as compared to a <10 % of ALT-farms based on an olfactory classification into three categories: good, medium and bad. Whether this was a factor of variability among the CON-farms in winter cannot be quantified. Bad air quality should, however, be considered as a negative factor. Steinwidder (1999) reported a reduced feed conversion ratio and growth rate when air quality was bad (noxious gases), but not lower fat-free lean. In the present study, the relatively large difference of farm variability (high in CON, low in ALT in winter and whey feeding systems) could be a sign of such an influence.

In the context of outdoor feeding (at given varying ambient temperature) the aspect of cold versus warm (or lukewarm) liquid soup is an aspect to be considered. Holmes (1971) reported a better growth rate of 11 % at 16 °C and of 5 % at 22 °C air temperature when the liquid whey meal was heated to 40 °C compared to a 15 °C whey meal. In both cases (at an ambient temperature of 16 and 22 °C) the pigs fed the cool whey diet required more dry matter per kg live weight gain and grew at a slower rate than those with warm whey. In that experiment the pigs were fed thrice daily (as it was usual in the present study as well) and the author supposed that the entire growth benefit was due to the "heat of warming the cool whey" to body temperature (Holmes, 1971). This effect can be understood, considering that any diet colder than body temperature will be warmed up in the gut to the level of the actual body temperature, an energy-consuming process, which was estimated to be 7 to 12 % of the pig's total heat loss (Holmes, 1970). In this article the author reported negative physiological effects (inducement of thermoregulatory responses such as strong shivering, reduced respiratory rate, etc.) in pigs, depending on the air temperature when feeding cold (10 °C), as compared with warm whey (30 to 40 °C). The temperature of liquid food is a significant parameter in their thermal environment (Holmes, 1970).

5.2.3.2. Temperature effect

The ambient temperature effect, which was not regarded in the comparisons of the housing effects (see 4.3), has been analysed for each housing system separately. In general, virtually no interrelationships were found. This can be ascribed to the extraordinarily mild winter described in 4.3 and Table 12 section F, where the temperature remained rarely at a long-term low level, which would alter fat-free lean proportion substantially (e.g. Mount, 1979; Verstegen et al., 1985; Lefaucher et al., 1991). Looking at the alternative housing system, one can see that pigs of two market groups at the lower end (at 3 and 5 °C in Fig. 12 lower plot) featured lower predictive fat-free lean percentages than the majority in the winter period, which was quasi-indifferent within the range of 6 to 15 °C. In the conventional housing system, the temperature curve featured a positive slope for the range of 17 to 23 °C in winter (crosses) and in summer (circles/dots) (Fig. 12 upper plot). Above this limit until 28 °C, where only summer records were observed, the curve switched to a negative slope. No temperature average of the finishing period exceeded the level of 28 °C, the CT_{upper} (Holmes and Close, 1977). However, few farms featured a relatively high average near 28 °C, which implicates periods were frequently higher than the CT_{upper}.

In the author's opinion, describing and reasoning the temperature situation in the present study is more delicate when done indoors than outdoors (yet more accentuated for the criterion fat score, particularly with respect to ventilation aspects and the noticeable varying air quality (Schnider, 2002). However, the regression curves were consistent with expected trends from the literature, except for the four market groups (68 pigs) kept at a T of 13 °C originating from two whey-feeding farms. They featured, in spite of the low temperature level, a comparable high fat-free lean percentage, which cannot be explained (as it was not either for their fat scores and 18:1 levels). An error (reading) of the temperature could be the cause. Lower fat-free lean proportions in the lower and upper temperature ranges, assuming that feeding regimes in practice were not adapted to different ambient temperature levels, could to some degree reflect the suboptimal environmental conditions regarding growth. Below the calculated CT_{low} of 23 to 24 °C, energy expenditure starts to increase independently of the growing or finishing stage, amounting to an additional averaged feed requirement of 19 g/day per °C for the range of 12 to 24 °C (Quiniou et al., 2001). From the point of view of "high temperatures", energy retention diminishes with rising T due to decreasing voluntary feed intake (Holmes and Close, 1977; Le Dividich et al., 1998), by 48 and 77 g/day per °C for 45 and 75 kg BW, respectively, in the temperature range of 19 to 29 °C (Quiniou et al., 2000 and 2001).

5.3. Results pH of M.l.d.

5.3.1. Descriptive statistics

5.3.1.1. Covariates (fasting-, transport- and lairage time)

The descriptive data of fasting, transport and lairage time are given in Fig 13 with columns (averages) and vertical bars representing minima and maxima displayed for each housing system, season and slaughterhouse. The table App. V contains the detailed values (including standard deviation and coefficient of variance) subdividing additionally between the feeding classes.

Fasting time: The covariate describes the time of the last feed intake until loading on the lorry. The overall average was 10.1 hours. The averages among the housing systems were similar (Fig. 13), whereas between the feeding systems (Table App. V) partly a large variation was observed (cv 4.6 to 66.7 %). However, the four CON-subclasses with whey feeding systems (mainly cheese dairies) featured a consistently low variation (cv ≤15.5 %). The corresponding minimum and maximum in the latter were 7.5 and 14.3 hours, respectively, while within all farms, a lowest feed withdrawal of 0 and a highest of 21 hours was recorded.

Transport time: The transport time was slaughterhouse related (Fig. 13) reflecting the trading area of the abattoirs. Geographically, the rurally situated slaughterhouse 2 is closer to pig farms than the urban border-near located slaughterhouse 1, which was reflected by the shorter durations. Transports were particularly short in slaughterhouse 2 with approximately 1.1 and 1.7 hours for CON- and ALT-pigs, respectively, but exhibited partly a noticeably higher variation. The averages in slaughterhouse 1 amounted to 3.4 and 2.3 hours for CON-pigs in summer and winter, respectively, and for the ALT-pigs to 2.8 hours in both seasons.

Lairage time: The averages of lairage time were between 1.1 and 1.9 hours, with consistently lower values but a higher variation except in one case in slaughterhouse 2. The minimum was at 0.1 and the maximum at 4.5 hours. The coefficients of variance covered a large range (17 to 83 %) as it was characteristic for all three criteria.

Time postmortem for the criterion pH-2 h p.m.: The effective averaged time measuring the pH-2 h p.m. was 2.36[14] and 2.20 hours in slaughterhouse 1, and 2.23 and 2.27 hours in slaughterhouse 2, each in summer and winter, respectively, resulting in averaged time displacements relative to 2 h p.m. of 12 to 21 minutes in the subclasses.

For description of the variable fat-free lean, see 5.2.1.

[14] Minutes in decimal units

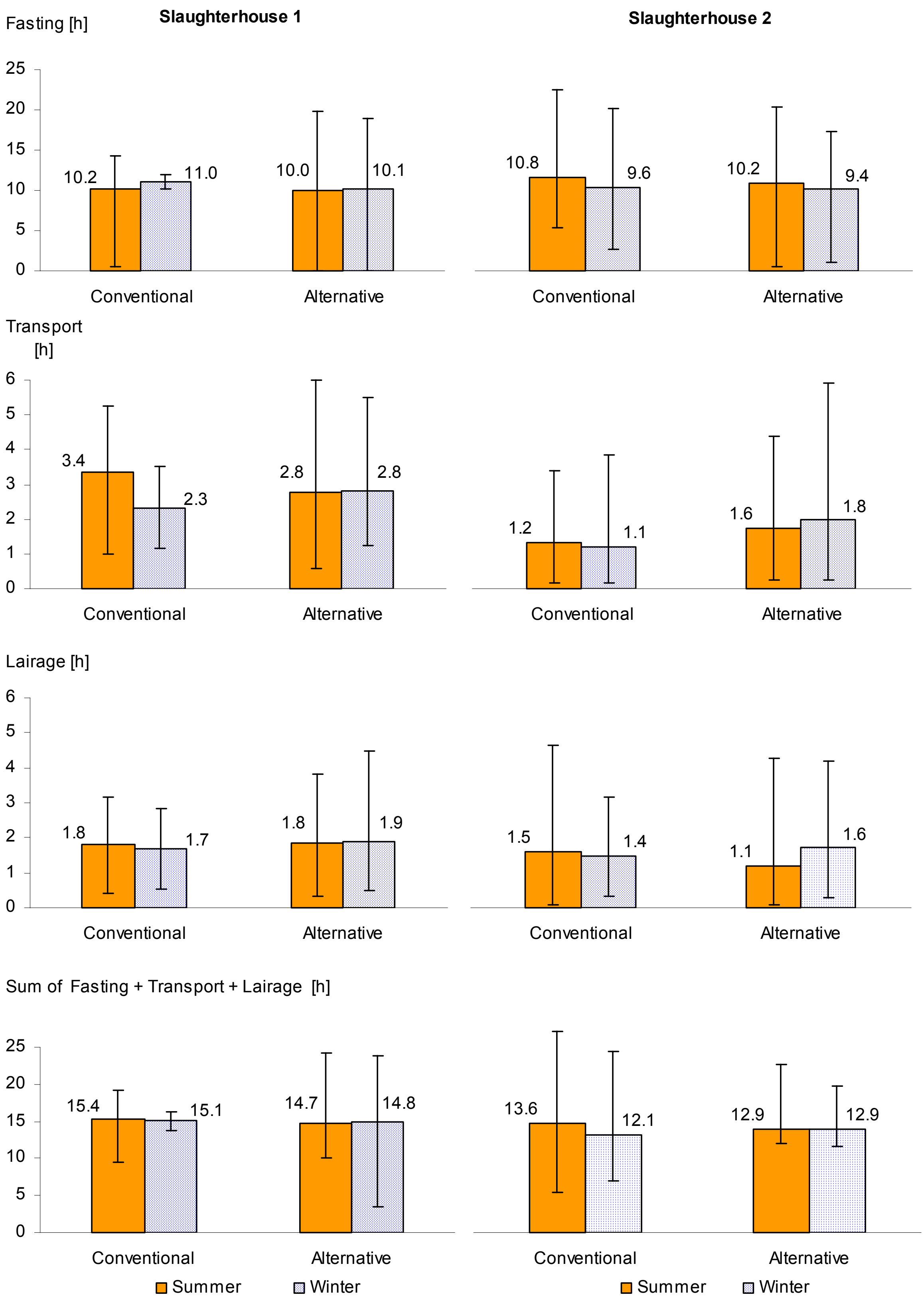


Fig. 13: Fasting, transport and lairage time (pH), column diagrams

Averages in columns, minima and maxima are visualised with vertical bars; no distinction of feeding classes (for distinction of feeding classes see table App. V).

5.3.1.2. Response variable pH

The values of the pH averages, standard deviation, minimum and maximum, are given in Table 16 section A to E.

Comparing the housing systems within slaughterhouse (section A) reveals that the consistently higher pH values for ALT-pigs were more distinctive in slaughterhouse 2, with differences of +0.06, +0.04 and +0.03 units, as compared to +0.02, +0.02 and ±0.0 units in slaughterhouse 1 at 35 min, 2 and 24 h postmortem, respectively.

The differences within slaughterhouse and season (section B) revealed one outstanding low average of 5.33±0.10 (pH-24 h slaughterhouse 2), whereas the other averages featured a better accordance. The differences in the early postmortem stages were more accentuated in slaughterhouse 1, whereas the ultimate stage showed a greater difference in slaughterhouse 2.

The differences between slaughterhouse 1 and 2 (section C) were small (0.02 and 0.03 units at 35 min and 24 h p.m., respectively) except for the pH-2 h postmortem. At 2 h postmortem the difference was relatively large differences (0.16 pH units) and accompanied by another characteristic owing to slaughterhouse 1, namely, a higher proportion of records at the lower end (tail) of the pH distribution (to be described in detail below).

Regarding the housing systems (section D), the initial and ultimate pH (at 35 min and 24 h p.m.) of CON-pigs was 0.03 units higher than that of ALT-pigs; the comparison of pH-2 h p.m. is more accurately done within the slaughterhouses, respecting thus potentially process-related differences mentioned in chapter 4.4.1.

The overall averages (section E) amounted to 6.43±0.22, 6.06±0.29 and 5.38±0.09 for 35 min, 2 and 24 h p.m., respectively.

The records of the pH-2 h p.m. in slaughterhouse 1 accumulated to a second peak (Fig. 14, dark surface of left middle plot), a phenomenon not seen in any other distribution. The numeric description of this fact is given in Table 17 (framed row “Δ 1-2” =Δ slaughterhouse 1 minus 2). An increasing or decreasing difference among the four given quantiles (in the upper or lower tail) designates an incongruent distribution between the slaughterhouses. This was particularly visible in the lower tail (arrows to the left) of the pH-2 h, and to a much smaller extent at 35 min and 24 h postmortem. In the upper end, there was at all three postmortem stages a congruent or nearly congruent situation (similar pH development between the slaughterhouses). A second characteristic to be read from the “Δ 1-2”-rows are the inverse differences (switching from plus to minus) in the ultimate pH indicating a qualitatively different situation than in the early postmortem stages.

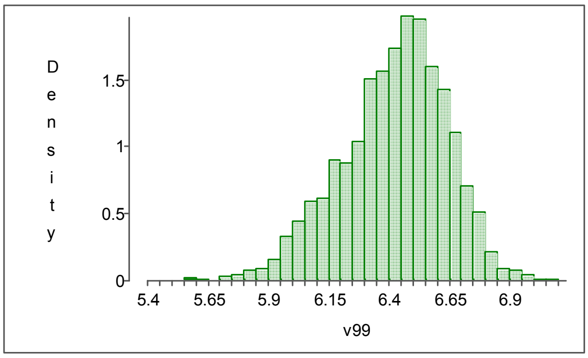
Table 16: Descriptive results (pH)

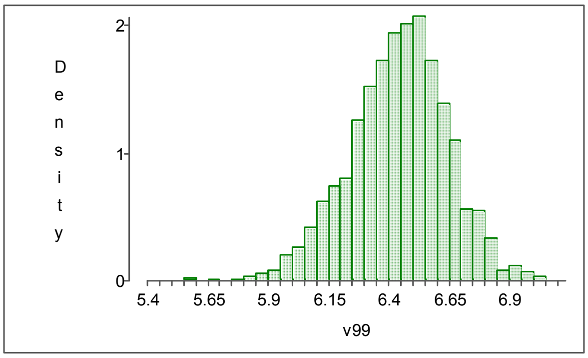
			Model	Mean	SD	Min	Max	n
A)	**Slaughterhouse * housing system**							
	1	CON	pH-35 min	6.40	0.22	5.64	7.11	622
			pH-2 h	5.98	0.29	5.23	6.64	621
			pH-24 h	5.39	0.08	5.17	5.67	523
		ALT	pH-35 min	6.42	0.23	5.42	7.13	1970
			pH-2 h	6.00	0.30	5.27	6.83	1938
			pH-24 h	5.39	0.08	5.11	5.76	1614
	2	CON	pH-35 min	6.41	0.20	5.59	7.02	1145
			pH-2 h	6.13	0.25	5.29	6.80	1140
			pH-24 h	5.34	0.10	5.00	5.74	840
		ALT	pH-35 min	6.47	0.21	5.55	7.15	994
			pH-2 h	6.17	0.26	5.31	6.91	983
			pH-24 h	5.37	0.09	5.08	5.73	948
B)	**Slaughterhouse * season**							
	1	Summer	pH-35 min	6.40	0.22	5.42	7.10	1458
			pH-2 h	5.98	0.29	5.30	6.83	1454
			pH-24 h	5.39	0.08	5.11	5.76	1263
		Winter	pH-35 min	6.44	0.23	5.58	7.13	1134
			pH-2 h	6.01	0.29	5.23	6.74	1105
			pH-24 h	5.40	0.07	5.23	5.67	874
	2	Summer	pH-35 min	6.43	0.21	5.70	7.04	997
			pH-2 h	6.15	0.26	5.32	6.91	986
			pH-24 h	5.33	0.10	5.00	5.74	932
		Winter	pH-35 min	6.44	0.21	5.55	7.15	1142
			pH-2 h	6.15	0.25	5.29	6.83	1137
			pH-24 h	5.39	0.08	5.15	5.65	856
C)	**Slaughterhouse**							
	1		pH-35 min	6.42	0.22	5.42	7.13	2592
			pH-2 h	5.99	0.29	5.23	6.83	2559
			pH-24 h	5.39	0.08	5.11	5.76	2137
	2		pH-35 min	6.44	0.21	5.55	7.15	2139
			pH-2 h	6.15	0.25	5.29	6.91	2123
			pH-24 h	5.36	0.10	5.00	5.74	1788
D)	**Housing system**							
	CON		pH-35 min	6.41	0.21	5.59	7.11	1767
			pH-2 h	6.08	0.27	5.23	6.80	1761
			pH-24 h	5.36	0.10	5.00	5.74	1363
	ALT		pH-35 min	6.44	0.22	5.42	7.15	2964
			pH-2 h	6.06	0.29	5.27	6.91	2921
			pH-24 h	5.39	0.08	5.08	5.76	2562
E)	**Grand total**		pH-35 min	6.43	0.22	5.42	7.15	4731
			pH-2 h	6.06	0.29	5.23	6.91	4682
			pH-24 h	5.38	0.09	5.00	5.76	3925

- A more detailed table including the feeding systems is given in App. VI.

Slaughterhouse 1 Slaughterhouse 2

v99=pH-35 min p.m. (x-axis: 0.05 units)

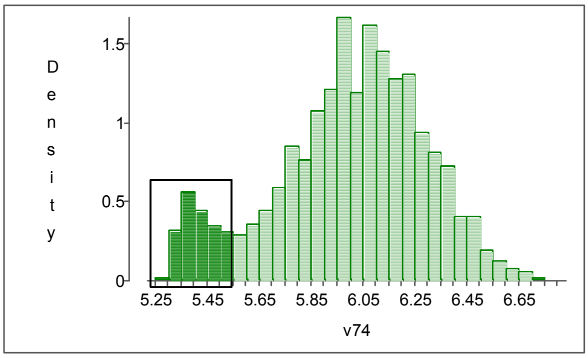


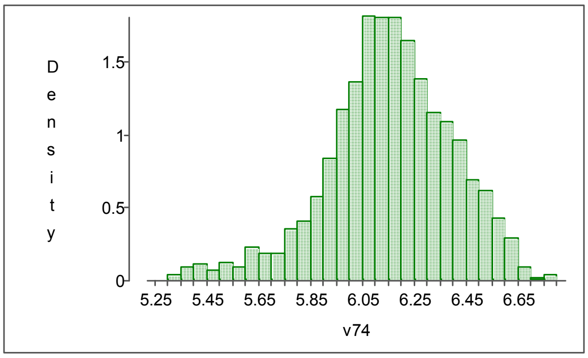


Average: 6.42, Min: 5.42, Max: 7.13

Average: 6.44, Min: 5.55, Max: 7.15

v74=pH-2 h p.m. (x-axis: 0.05 units)

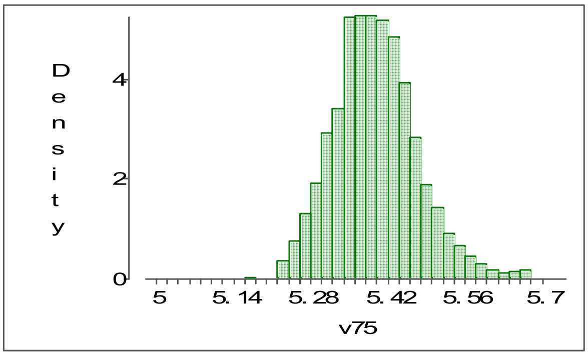


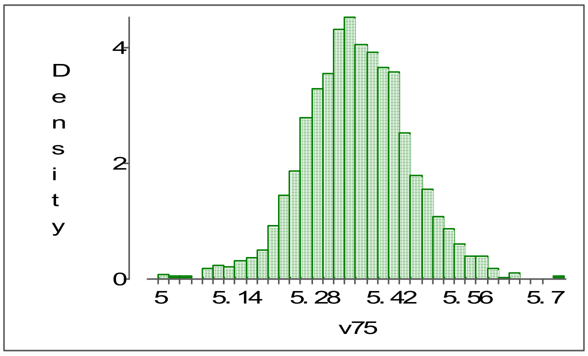


Average: 5.99, Min: 5.23, Max: 6.83

Average: 6.15, Min: 5.29, Max: 6.91

v75=pH-24 h p.m. (x-axis: 0.02 units)





Average: 5.39, Min: 5.11, Max: 5.76

Average: 5.36, Min: 5.00, Max: 5.74

Fig. 14: Density diagrams of pH records between slaughterhouses

Dark-framed marked surface at pH 2 h p.m. were neither PSE nor housing related but a characteristic of the slaughterhouse 1. The more detailed plots comparing the dark surface between the housing systems is given in the figure App. VII, and revealed two similar densities of both housings.

Table 17: Quantiles and differences of pH records between the slaughterhouses

Model	Slaughter-house	Mean	1%	5%	10%	Q1 (25%)	Median (50%)	Q3 (75%)	90%	95%	99%
			pH-limit of quantiles								
			lower end					upper end			
pH-35 min	1	6.42	5.82	6.02	6.11	6.28	6.44	6.57	6.68	6.75	6.88
	2	6.44	5.90	6.08	6.16	6.31	6.45	6.58	6.68	6.76	6.91
	Δ 1-2	-0.02	-0.08	-0.06	-0.05	-0.03	-0.01	-0.01	0.00	-0.01	-0.03
pH-2 h	1	5.99	5.32	5.40	5.54	5.83	6.02	6.20	6.35	6.44	6.59
	2	6.15	5.41	5.69	5.84	6.01	6.16	6.32	6.46	6.54	6.66
	Δ 1-2	-0.16	-0.09	-0.29	-0.30	-0.18	-0.14	-0.12	-0.11	-0.10	-0.07
pH-24 h	1	5.39	5.23	5.27	5.30	5.34	5.39	5.44	5.49	5.53	5.63
	2	5.36	5.21	5.20	5.24	5.30	5.36	5.42	5.49	5.52	5.59
	Δ 1-2	0.03	0.02	0.07	0.06	0.04	0.03	0.02	0.00	0.01	0.04

Δ 1-2: pH-difference of slaughterhouse 1 minus 2 at each quantile; the differences at 2 h p.m are framed.

Summarised, the anomalous differences between slaughterhouses concerned mainly the lower end of the pH-2 h being indicated at 35 min but disappearing and switched at 24 h postmortem.

5.3.1.3. PH among breeds, PSE- and DFD-meat frequency

Table 18 lists the number of pigs within a breed, and their pH averages in each slaughter-house. The standard deviations and PSE frequencies were not slaughterhouse-specific. The breeds 1, 2, 5, and 6 were balanced or nearly balanced between the slaughterhouses, whereas the breed 3 (Duroc) and particularly the breed 4 (Duca) were not. The pH differences among the breeds were more distinctive than in the housing comparisons of the housing systems. The levels of pH-35 min and pH-2 h p.m. went along with each other, such as breeds with lower pH-35 min featured also lower pH-2 h. Relatively lower pH-35 min and pH-2 h levels were observed in the breed Duca, where the sires (Duca boar) of the offspring were PiétrainxDuroc crossings, resulting in pigs of 25 % Piétrain (and Duroc) blood. Their pH value, compared to the averages listed in the foregoing Table 16 section C, were remarkably lower by 0.11 and 0.17 in slaughterhouse 1, and in slaughterhouse 2 by 0.09 and 0.21 for pH-35 min and pH-2 h, respectively.

The PSE-meat frequency is determined in predominantly anaerobic muscles at 45 min post-mortem, i.e., in the M.l.d., SM, and BF. Values in the M.l.d. below 5.8 to 5.9 are indicative of a faster-than-normal glycolysis determined as PSE-meat (Honikel and Kim, 1985; Barton Gade et al., 1995). The PSE-meat proportions among breeds amounted to 0.5 to 1.1 % and 1.0 to 1.9 %, except for the breed Duca, which featured a little higher incidence of 3.8 and 6.8 %, according to the mentioned limits of pH 5.8 or 5.9, respectively.

The incidence of DFD-meat is determined at the ultimate pH stage. PH values of the M.l.d. readings above 6.1 to 6.2 are classified as DFD, and values within the range of 5.9 to 6.1 are "slightly" DFD-meat (Honikel and Schwägele, 1998; Barton Gade et al., 1995). Based on these limits, DFD-meat was not observed, and "slightly" DFD-meat occurred in six cases, equal to 0.15 %.

The PSE-meat frequency between the housing systems was low and nearly equal with 0.7 and 0.9 % or 1.6 and 1.9 % for the limits of Honikel and Kim (1985) and Barton Gade et al.(1995), respectively.

Table 18: PH averages of breeds and PSE-meat proportions

			Number of pigs		pH observed		SD (larger)	PSE-frequency[a]			
								Number		%	
Breed		Slaughterhouse →	1	2	1	2	1+2	1+2		1+2	
								H	B	H	B
1	Large White	pH-35 min	955	920	6.46	6.44	0.21	10	19	0.5	1
	>75%	pH-2 h	950	912	6.04	6.16	0.27				
		pH-24 h	790	728	5.40	5.35	0.10				
2	Large White x Landrace	pH-35 min	236	266	6.36	6.48	0.22	3	8	0.6	3
		pH-2 h	236	265	5.94	6.20	0.28				
	50%	pH-24 h	226	247	5.38	5.38	0.09				
3	Duroc	pH-35 min	88	182	6.40	6.47	0.22	3	5	1.1	2.7
	50%	pH-2 h	86	182	6.00	6.16	0.28				
		pH-24 h	62	134	5.39	5.38	0.09				
4	Duca[b]	pH-35 min	306	32	6.31	6.35	0.26	13	23	3.8	6.8
	50%	pH-2 h	295	32	5.82	5.94	0.34				
		pH-24 h	214	22	5.39	5.28	0.09				
5	Hampshire	pH-35 min	64	80	6.49	6.49	0.20	0	1	-	0.7
	50%	pH-2 h	64	80	6.06	6.16	0.26				
		pH-24 h	64	80	5.40	5.40	0.08				
6	Undefined	pH-35 min	943	659	6.42	6.40	0.21	9	31	0.6	1.9
		pH-2 h	928	652	6.01	6.12	0.28				
		pH-24 h	786	597	5.40	5.37	0.09				
		Total in housing (slaughterhouse 1+2):						PSE-frequency			
				n		pH 35 min		n		%	
		CON		**1767**		**6.41**		**12**	**28**	**0.7**	**1.6**
		ALT		**2964**		**6.44**		**28**	**56**	**0.9**	**1.9**

[a] PSE limits: 5.84(H) and 5.94(B) at 35 min p.m.; refers to 5.80 (H=Honikel & Kim 1985) and 5.90 (B=Barton Gade et al., 1995) at 45 min p.m.

[b] Duca: sire line of Duroc x Piétrain.

5.3.2. Results (pH)

5.3.2.1. Residual analysis, model fit, F- and P-values

The residual analyses of the three pH-models revealed that in the early postmortem models no exclusion of records was needed, and in the ultimate postmortem model, 25 records from the upper end of the residual tail (bold/framed dots in Fig. 15) were considered for exclusion from the editing model. These records all represented a (in this study relatively) high ultimate pH-level of ≥5.63 (see the figure in App VIII).

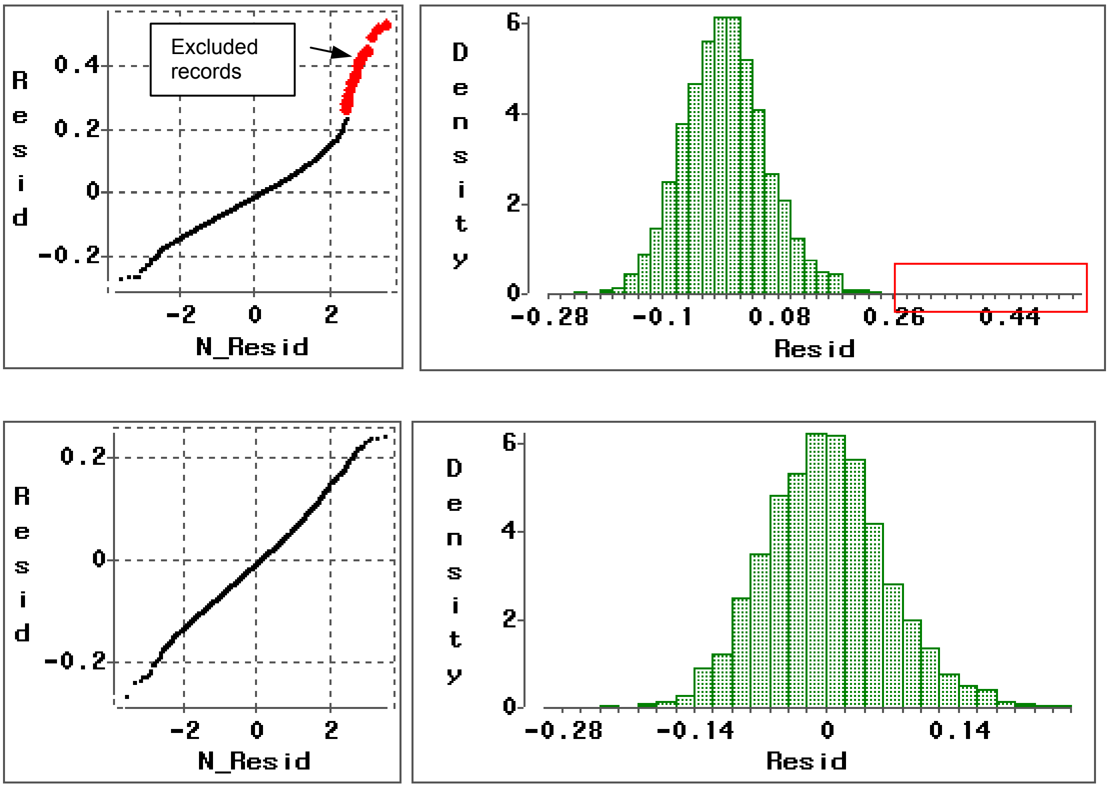


Fig. 15: QQ- and normal distribution plots of residuals (pH)

Representative for all three pH models, the plots of the pH-24 h p.m. are shown. The 25 bold marked excluded records featured a level pH ≥5.63; they are no more visible as columns at the framed end to the right of the density distribution (above) reaching a maximum of x=0.57; scale of x-axis: 0.02 pH units.

The residual of the ultimate pH model before and after exclusion (=editing dataset) was 0.0060±0.0001 and 0.0047±0.0001, respectively (Table 20). The minima were at -0.27 and -0.26, the maxima at 0.54 and 0.25, each before and after exclusion, respectively. The exclusion resulted in a better (=smaller) residual and a balanced maxima and minima relative to the presumed mean located at zero. The exclusion concerned particularly the two fasting related covariates (main effect and interaction effect) featuring together about 1 % variance proportion before compared to 18 % after the exclusion.

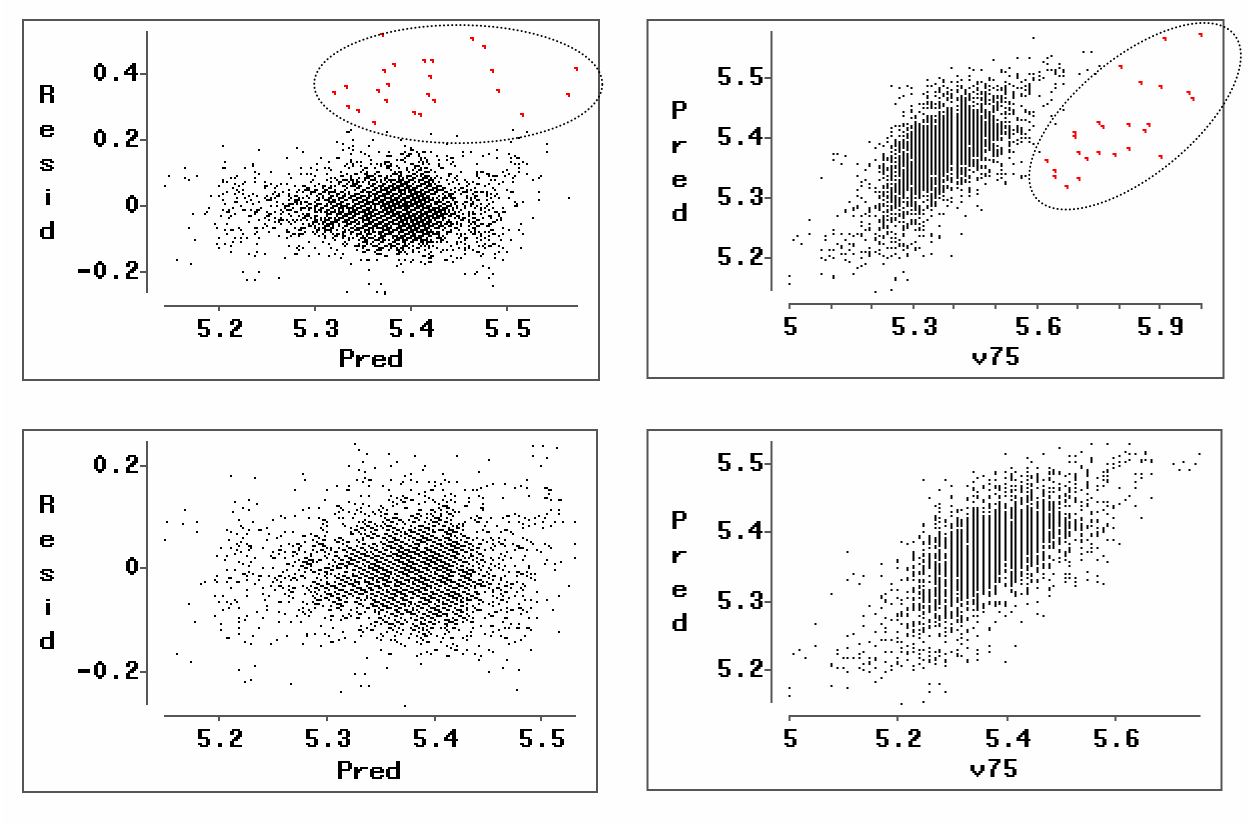


Fig. 16: Residual- and correlation plot of predicted v. observed values (pH)

v75= observed values, representative for all three pH models, the plots of the pH 24 h p.m. are shown: before (above) and after (below) exclusion of 25 records (isolated and bold-red marked); correlations$_{Pred.-Obs.}$ = 0.61 and 0.66 before and after exclusion, respectively (right plots); n_{edited}=3,925.

The pH-2 h model featured a (even though little) higher correlation predicted-observed (r=0.449, residual=0.067) than the model pH-35 min (r=0.407, residual 0.041) indicating a slightly better model fit at 2 h (AIC=1,019.0) than at pH-35 min (AIC of 1,326.2). This was not necessarily expected when looking at the constellation of the data showing a larger standard deviation (=larger variation) of the pH 2 h (SD=0.29) compared to that of pH-35 min p.m. (SD=0.22). The correlation remained higher when calculating the pH 2 h model without the model-specific variable[15] "time at pH-2 h" (r=0.444, AIC=1,036.2) but consequently less explained variance. The variance amounted (sum of the F-values) to 64.6 and 46.5 with and without the variable "time at pH 2 h", respectively, while that of the pH-35 min model was 62.9. The minima and maxima of the model pH-35 min were -0.88 and 0.71, and of the model pH-2 h -0.83 and 0.82, respectively.

[15] featuring then the identical model configuration.

Table 19: F- and P-values of model effects (pH)

Model effects	pH-35 min			pH-2 h		pH-24 h	
	df[a]	F-value	P-value	F-value	P-value	F-value	P-value
Class effects							
Slaughterhouse (sl)	282	3.3	0.0717	1.3	0.3609	13.8	0.0002
Breed (b)	230	5.6	<.0001	13.3	<.0001	0.8	0.5433
Sex (x)	4670	0.1	0.7096	0.0	0.9869	9.8	0.0017
Season (sn)	244	0.0	0.8629	0.6	0.5310	13.3	0.0003
Feeding system	88.7	1.3	0.2651	1.3	0.3582	0.2	0.6605
• Housing system (hs)	90.5	3.0	0.0894	4.3	0.0978	0.4	0.5154
sn * x						8.4	0.0038
sl * b	230	2.7	0.0217	5.1	0.0073	3.4	0.0051
sn * fs	88.9	0.3	0.5841	2.6	0.1982	0.3	0.5823
sl * sn	91.5	0.1	0.7300	0.3	0.6821	9.2	0.0030
sl * fs	91.5	1.5	0.2314	0.2	0.7325	2.0	0.1631
• sl * hs	90.4	0.3	0.5983	0.4	0.6354	26.2	<.0001
• sn * hs	87.9	0.3	0.5752	0.1	0.8197	6.8	0.0102
• fs * hs	92.6	5.4	0.0225	5.2	0.0708	0.8	0.3673
sn * sl * fs	91.1	1.8	0.1788	1.0	0.4308	4.5	0.0389
• sn * sl * hs	88	2.5	0.1203	1.7	0.2987	2.3	0.1373
• sl * fs * hs	93.5	0.1	0.7148	0.2	0.7566	6.5	0.0131
• sn * fs * hs	86.7	1.8	0.1882	3.3	0.1459	0.0	0.9477
• sl * sn * fs * hs	87.6	0.1	0.7296	1.1	0.3953	0.8	0.3787
Covariates							
Fat-free lean	4658	15.0	0.0001	7.1	0.0079	11.1	0.0009
Fasting	179	1.0	0.3090	1.1	0.3000	42.3	<.0001
Fasting * sn	190	1.5	0.2204	0.8	0.3711	42.8	<.0001
Transport	277	0.4	0.5417	0.8	0.3727	44.1	<.0001
Transport * sl	300	9.8	0.0019	7.6	0.0062	3.2	0.0727
• Transport * hs						5.9	0.0157
• Transport * sl * hs						66.3	<.0001
Lairage	1367	0.02	0.8791	0.35	0.5532	1.8	0.1747
Lairage * sl	1045	2.62	0.1059	0.07	0.7897	20.2	<.0001
Lairage * sn	1426	2.39	0.1223	0.51	0.4758	7.4	0.0067
• Lairage * hs						19.4	<.0001
Lairage * sl * sn						22.2	<.0001
• Lairage * sn * hs						24.2	<.0001
Time at pH-2 h				16.5	<.0001		
Time at pH-2 h * sl				2.6	0.1042		
pH-35 min						35.9	<.0001
pH-35 min * x						9.7	0.0019
pH-35 min * sl						11.5	0.0007
Sum of F-values		62.9		79.4		477.5	

[a] The degrees of freedom (df), computede with the Sattertwaite approximation, are given for the model p-35 min only (n=4731 records).

• housing related effects.

The sum of the F-values of the pH-24 h model reflected the crucial difference between the early and ultimate pH models featuring a sum of the F-values of 477.5 (Table 19). Although the three models are not fully alike it can basically be said that in both early postmortem stages (at 35 min and 2 hours), the fixed effects and the covariate fat-free lean accounted for relatively more variation of the total explained variance compared to the ultimate stage model. The covariates fasting and lairage time were more important at the ultimate pH (P mostly <0.01), whereas the covariate transport time was in all three models similarly important (P 0.07 to <0.01).

The random effect farm (Table 20) was grouped within the effects slaughterhouse and season in all three models (P<0.001). The ratios in percent represent the relation to the residual variance. Ratios in the early p.m. stages were small, with values of 7 to 22 % (comparably small to those of the criterion fat-free lean). This corresponds to variances of 0.0018 to 0.0099. The ratios (and the variances) were distinctively higher in the ultimate pH stage. Slaughterhouse 2 on the one hand, and the summer period on the other hand, showed higher ratios (larger variances) than their complements with values in slaughterhouse 1 of 87 and 30 %, and in slaughterhouse 2 of 177 and 130 %, each in summer and winter, respectively. The variances within groups featured similar values of 0.0014 to 0.0084. The pH ratios were higher than those of the fat-free lean but smaller than those of the fat score.

Table 20: Variance of the random effect farm and the residual (pH)

	Random effect farm grouped within:				
Slaughterhouse	1		2		Residual
Season	Summer	Winter	Summer	Winter	
pH-35 min					
Number of farms	43	33	35	31	
Variance ± SE	0.0030 ± 0.001	0.0050 ± 0.002	0.0035 ± 0.002	0.0091 ± 0.003	0.0406 ± 0.001
Ratio in % of residual[a]	7	12	9	22	
pH-2 hours					
Number of farms as above					
Variance ± SE	0.0066 ± 0.002	0.0098 ± 0.003	0.0018 ± 0.001	0.0060 ± 0.003	0.0673 ± 0.001
Ratio in % of residual[a]	10	15	3	9	
pH-24 hours					
Number of farms	41	31	35	24	
Variance ± SE	0.0041 ± 0.0011	0.0014 ± 0.0005	0.0083 ± 0.0024	0.0061 ± 0.0022	0.0047 ± 0.0001
Ratio in % of residual[b]	90	30	180	130	

[a] Variance*100 diveded by the residual variance (and rounded); example: 0.0030*100/0.0406=7.4, rounded=7.

[b] Variance*100 diveded by the residual variance (and rounded to the nearest ten); example: 0.0041*100/0.0047=87, rounded=90.

5.3.2.2. Housing effect

The effect housing systems analysed within the categories feeding system, season, and slaughterhouse, brought along eight analogous housing comparisons for each postmortem stage resulting in 24 figure pairs (Table 22 comparisons 1 to 24). The detailed comparisons were, in general, more distinctive in slaughterhouse 2 than in slaughterhouse 1. In slaughterhouse 2, the CON-pigs featured in summer consistently a faster decline at significance levels of $P_{Whey\text{-}Feed}$=0.175 (comparison 2) and $P_{Complete\text{-}Feed}$=0.020 (comparison 4) at 35 min, and at significance levels of $P_{Whey\text{-}Feed}$=0.217 (comparison 10) and $P_{Complete\text{-}Feed}$=0.023 (comparison 12) at 2 h postmortem. In winter the significance was less distinctive (P>0.30 for the comparisons 6, 8, 14 and 16) and inverse for the $CON_{Whey\text{-}Feed}$-pigs (=slower decline than ALT-pigs, comparisons 6 and 14). In slaughterhouse 1 there was in winter a similar situation as in slaughterhouse 2. The CON-pigs in complete feeding systems exhibited in both early postmortem stages a faster decline (P=0.074 and P=0.137 at 35 min and 2 h p.m., respectively, comparisons 7 and 15), whereas in farms with whey feeding systems the ALT-pigs featured lower levels (P around 0.45, comparisons 5 and 13). In summer no relevant differences between the housing systems were prevalent (P>0.660 to 0.921).

The situation in the ultimate pH stage was less uniformly. In slaughterhouse 2 the CON-pigs (comparison 18) featured the lowest predicted level of 5.29 ($\Delta_{to\ ALT}$ -0.09 units, P=0.104) compared to the ls-means of ALT-pigs of 5.38. The comparison 23 also exhibited lower pH values of CON-pigs (P=0.288) but the compared ls-means featured a difference of only 0.03 units. Two comparisons featured an inverse ultimate pH constellation as the development in the early postmortem stages was. In both cases it concerned pig from complete feeding systems in slaughterhouse 2 where the ALT-pigs exhibited lower predictions of 5.33 ($\Delta_{to\ CON}$ -0.07, P=0.221, comparison 24) in summer, and of 5.33 ($\Delta_{to\ CON}$ -0.05 units, P=0.358, comparison 20) in winter. The highest ls-means of CON-pigs of 5.44 ($\Delta_{to\ ALT}$ +0.05, P=0.147, comparison 17) was predicted, interestingly analogous to the lowest ls-means, in pigs of farms with the same feeding system and in the same season (with whey feeding systems, in summer) but in slaughterhouse 1. The three comparisons 19, 21 and 22 showed balanced or near-balanced ls-means, which was roughly yet prevailing in the early postmortem stages (comparisons 3, 5, 6, and 11, 13, 14 at pH 35 min and 2 h p.m., respectively).

Table 21: LS-Means of housing comparisons (pH)

		Slaughterhouse 1				Slaughterhouse 2			
		Comparison	LS-Means[a]	SE	P-value[b]	Comparison	LS-Means	SE	P-value
pH-35 min (early p.m. stage)									
Summer	*Whey Feed*								
	CON	1)	6.42	0.027	0.661	2)	6.42	0.027	0.175
	ALT		6.40	0.029			6.48	0.035	
	Complete Feed								
	CON	3)	6.37	0.038	0.573	4)	6.37	0.030	**0.020**
	ALT		6.39	0.020			6.46	0.026	
Winter	*Whey Feed*								
	CON	5)	6.47	0.039	0.434	6)	6.46	0.028	0.375
	ALT		6.44	0.028			6.41	0.040	
	Complete Feed								
	CON	7)	6.35	0.058	**0.074**	8)	6.44	0.047	0.429
	ALT		6.46	0.023			6.50	0.036	
pH-2 hours (early p.m. stage)									
Summer	*Whey Feed*								
	CON	9)	6.01	0.037	0.835	10)	6.14	0.027	0.217
	ALT		6.02	0.041			6.19	0.033	
	Complete Feed								
	CON	11)	5.97	0.054	0.921	12)	6.07	0.030	**0.023**
	ALT		5.98	0.028			6.15	0.024	
Winter	*Whey Feed*								
	CON	13)	6.01	0.054	0.463	14)	6.13	0.031	0.612
	ALT		5.96	0.038			6.11	0.041	
	Complete Feed								
	CON	15)	5.90	0.080	0.137	16)	6.12	0.048	0.319
	ALT		6.03	0.032			6.18	0.036	
pH-24 hours (ultimate p.m. stage)									
Summer	*Whey Feed*								
	CON	17)	5.44	0.025	0.147	18)	5.29	0.028	0.104
	ALT		5.39	0.026			5.37	0.042	
	Complete Feed								
	CON	19)	5.35	0.039	0.541	20)	5.41	0.034	0.358
	ALT		5.38	0.016			5.36	0.031	
Winter	*Whey Feed*								
	CON	21)	5.39	0.019	0.620	22)	5.39	0.030	0.875
	ALT		5.40	0.014			5.39	0.033	
	Complete Feed								
	CON	23)	5.37	0.029	0.288	24)	5.40	0.047	0.211
	ALT		5.40	0.012			5.33	0.031	

- Frames provide an overwiew for comparisons at P<0.3; quadrate: ALT>CON / Winter>Summer, circle: ALT<CON / Winter<Summer.

[a] LS-Means are computed with the REML approach; [b] P-values are unadjusted and bold marked when <0.05.

5.3.3. Discussion (pH)

5.3.3.1. Descriptive statistics

PH of breeds

The incidence of PSE-meat was, except for the Duca breed, at a negligibly low level of 0.5 to 1.1 %. This is in accordance with the consistently falling and now vanishing genetic PSE frequency of the progeny population at the Swiss Pig Performance Testing Station and mirrors the results of the field halothane tests during the last decades, reaching about 2.5 % in 1992 (Schwörer et al., 1993) and 0 to 0.5 % in 1998 (Schwörer et al., 1999). The somewhat higher proportion of 3.8 % noticed for the breed Duca was expected in the light of the 25 % Piétrain blood of the Duca offspring, which are known for genetic stress susceptibility caused by a recessive gene (Webb and Simpson, 1986; MacLennan, et al., 1990; Terlouw, 2002). Nevertheless, also heterozygous animals show a higher stress nature than non-carriers (NN) (De Smet et al., 1996; Terlouw, 2002). It can be assumed that, compared to the overall average, the somewhat lower averages of the 7.1 % Duca pigs of 6.31 (-0.12) and 5.82 (-0.24) at pH 35 min and 2 h p.m., respectively, reflected the influence of the genetic situation. V. Lengerken et al. (1998) reported pH-45 min averages for the year 1993 at Halle (Germany) of 6.43, 5.91 and 5.58, and De Smet et al. (1996) published ls-means of 6.25, 6.09 and 5.76 in Belgian slaughter pigs for homozygous (non-carriers), heterozygous and homozygous (carriers) genotypes, respectively. Warriss (1982a) reported proportions of 39 and 71 % of Landrace and Piétrain, respectively, featuring a pH-45 min lower than 6.1, whereas <2 % of Large White fell below this limit.

The overall average at 35 min p.m. of 6.43 was expected to be higher than averages in the literature of the more commonly recorded pH-45 min that was proved true when comparing it to reported means by Schwörer (2004a) of 6.15 to 6.24 for the years 2000 to 2002 and 6.27 to 6.35 for the year 2003 in Swiss breeds LW, LWxLR, LR and Duroc. In the present study records at 35 min p.m. ranged from 5.42 to 7.15 which was comparable to a range of e.g. 5.3 to 7.3 (n=433) reported by Warriss (1982a) at 45 min postmortem. The variation is fairly different among studies when comparing the present standard deviation of 0.22 with those of Van der Wal et al. (1993 and 1995) each of 0.33 for n=78 and n=1,969 pigs, and with that in another work by Van der Wal et al. (1997) of 0.17 to 0.22 (n<100 in several cases, and in one case n=260).

PH of slaughterhouse

Contrary to the pH-35 min and the ultimate pH, the second early-postmortem monitoring revealed a discrepancy between the slaughterhouses of 0.16 with levels of 5.99 and 6.15 in slaughterhouse 1 and 2, respectively. A certain influence can be imagined from the relatively larger proportion of Duca pigs featuring ¼ Piétrain blood delivered to slaughterhouse 2 (about 90 % of the Duca pigs went to slaughterhouse 1 equal to 295 pigs). They represented, on the other hand, only 11.8 % of the total monitored pigs in slaughterhouse 1, and the pH levels with and without these Duca pigs were at 5.99 and 6.02, respectively, the latter value is not documented elsewhere. Hence further explanations would be needed explaining the slaughterhouse differences of 0.16 units at pH-2 h p.m., and the measured difference of 2 °C (see 4.4.2) of the carcass core temperature was within the expected range and therefore not a crucial factor in this context (Honikel, 2004).

Looking at the pH-2 h level, a general slightly upward adjustment of 0.1 to 0.15 pH units should be considered in order to compensate a pH-lowering effect caused by the measuring in the same incision as in the foregoing pH-35 min (Honikel, 2004).

Not only early postmortem pH levels are known to vary remarkably among abattoirs (Kallweith et al., 1988; Honikel, 1998), but also differences of 0.1 to 0.3 units in ultimate pH are reported (Gispert et al., 2000). The present averages between the slaughterhouses differed irrelevantly little at 35 min and 24 h while diverging most at 2 h p.m., and furthermore the variation at 2 h p.m. was higher in slaughterhouse 1 (sd 0.29, Δ_{sd} +0.04 compared to slaughterhouse 2), while the variation of the ultimate pH was higher in slaughterhouse 2 (sd 0.10, Δ_{sd} +0.02 compared to slaughterhouse 1). It seems that in slaughterhouse 1 (without blast cooler) the wider spreading of individual pH-levels until 2 h postmortem and the narrower distributed ultimate pH compared with the development in slaughterhouse 2 (with blast cooler) were to some degree slaughter process-related.

The overall pH-24 h average of 5.38 (sd 0.09, n=3,925) was remarkably low situated, compared to averages of 5.4 to 5.6 (Honikel, 1998; Lawrie, 1998), or 5.7±0.26 in a survey with about 3,000 records (Gispert et al., 2000). Low ultimate pH values were published in other works. Fernandez et al. (1992) reported levels in the M.l.d. comparable to the present ones; however, they attributed levels of 5.39 to 5.43 to the 50 % Hampshire blood in their crossbreed animals, and Stern et al. (2003) published values of 5.34 (n=62) and 5.32 (n=71) for indoor and outdoor 50 % Hampshire crossbreed pigs, respectively. In the present study the 144 Hampshire crossbreed animals (=3.6 %) exhibited in both slaughterhouses an average of 5.40, which is equal or higher (but not lower) as compared to the other breeds. On the other hand, high ultimate pH levels were reported by Chadwick and Kempster (1983) in a British survey with ls-means of 5.91±0.18 measured in 14 abattoirs in the M.l.d. of >5,000 records. A relatively high frequency (1 %) of extremely low measurements of <5.15 has been observed in the present study (Honikel, 2004). The corresponding standard deviations (0.8 and 0.10 in slaughterhouse 1 and 2, respectively) were about one third to nearly three times smaller than reported variations elsewhere (Chadwick and Kempster, 1983; Van der Wal et al., 1995 and 1997; Gispert et al., 2000). The variation of the ultimate pH between studies was less contrasted than the averages were. The distribution in the present study (5.00 to

5.76) was similar to the distribution of 5.1 to 5.9 (Warriss, 1982a), but smaller than the range of 5.2 to 6.6 (Chadwick and Kempster, 1983).

The difference of the ultimate pH (0.03 units) between slaughterhouses was small. In view of the comparatively narrow standard deviations described above, the lower level (5.36) in slaughterhouse 2 can presumably be associated with shorter transport durations. When analysing it between seasons, one sees that this assumption becomes more evident. The lowest ultimate pH average of 5.33 (Table 16 section B) was observed in slaughterhouse 2 in summer, and this subclass featured both remarkably shorter transport durations and lairage times (Fig. 13) as compared to the winter and as well to the corresponding values of slaughterhouse 1. Pigs rested for a too short period or not at all, and in connection with short transport ways, are likely to exhibit lower pH-24 h levels and other disadvantageous quality traits, which are alleviated when allowing a rest of 1 to 3 hours (Santos et al., 1997; Warriss et al., 1998; Pérez et al., 2002).

Time of fasting in CON and ALT

Furthermore, the majority of the pig farms (70 and 80 % of CON and ALT-farms, respectively) did not change feeding practise the day before delivery. They fed a regular second ration from 4 to 8 pm. All transports took place from midnight to morning, with immediate slaughtering in the early morning (begin at 3:30 to 5:00 am in slaughterhouse 2, and at 6:00 am in slaughterhouse 1) until forenoon to noon. Bringing forward the evening meal (before 4 pm) was practised in 12 and 15 %, while a late evening (after 8 pm) or early morning meal before delivery was reported of 8 and 15 %, each in CON and ALT-farms, respectively (Fig. 17 left). The corresponding total fasting times (until stunning) classified into 5 categories (Fig. 17 middle) revealed housing-typical differences. About 41 % of CON-pigs were slaughtered within a 12 hours fast, as compared to 14 % of ALT-pigs; corresponding less CON-pigs were fasted >12 hours (59 %), whereas 86 % of ALT-pigs featured a total feed withdrawal of >12 hours. Tarrant (1989) reported that 22 % of pig producers provided their pigs a final meal on the morning of delivery, while 54 % fed them the evening before and 24 % missed this evening-before-delivery meal. Gispert et al. (2000) published from a survey carried out in 5 abattoirs during a summer and winter period in Spain relatively large variations of fasting times (3 to 34 hours at averages of 12 to 20 hours) and transport durations (<0.5 to >6 at averages of <2 to 4 hours) as well as lairage times (<1 to >15 at averages of 4 to 12 hours). The present extremes and averages (see Fig 13) were in general somewhat smaller, with ranges of 0 to 21 hours and averages of 13 to 15 hours for fasting times, of 0.2 to 6 hours and averages of 1.2 to 3.3 hours for transport times, and of 0.1 to 4.5 hours and averages of <0.25 to 1.9 hours for lairage times. Particularly, the lairage times were remarkably lower in the present study when compared to those from Spain.

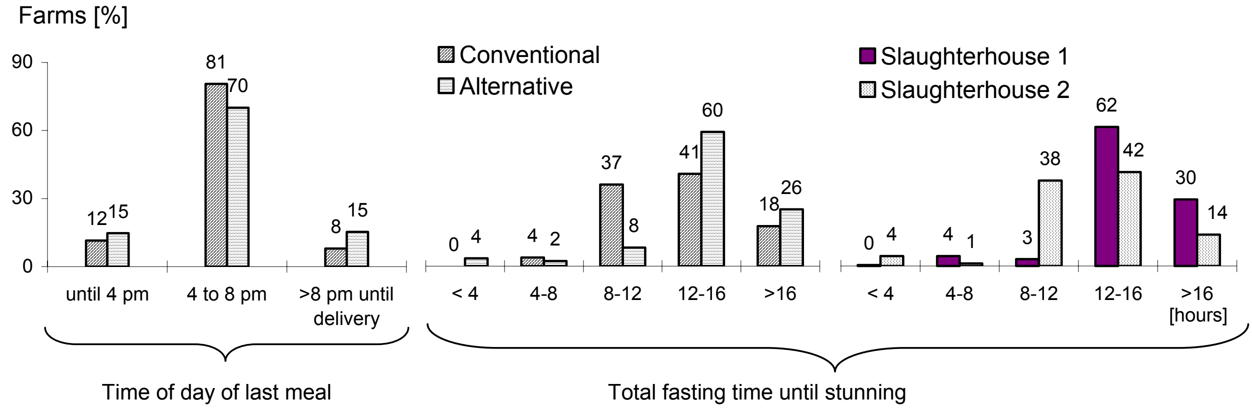


Fig. 17: Last feeding- before delivery and total fasting time (pH), column diagrams

Time point of the last feeding the day before delivery (left); proportion of pigs classified into five fasting times (<4, 4-8, 8-12, 12-16, and >16 hours) referring to the housing system (middle), and the slaughterhouse (right).

Time of transport between CON and ALT, and between slaughterhouses

Transport durations depended naturally on the geographic conditions of the slaughterhouses. Slaughterhouse 2 is situated in a rural area characterised with traditionally pig production both in farms and dairy-affiliated pig units, whereas slaughterhouse 1 is located in an urban area at the border to Germany. The transport ways were hence naturally longer for home-market pigs in slaughterhouse 1, which had consequences for the slaughterhouse-related total fasting times. In the urban slaughterhouse 1, 92 % of the pigs (62 % with 12 to 16 hours, 30 % with >16 hours) had a total fasting time of >12 hours whereas in the rural slaughterhouse 2, only 56 % (42 % with 12 to 16 hours, 14 % with >16 hours) were fasted >12 hours (Fig. 17 right). Slaughterhouse dependent fasting times due to considerably different transport distances were reported in a survey by Gispert et al. (2000), with averages of <1.5 to 4 hours among five slaughter plants in Spain.

5.3.3.2. Housing effect

Few papers report comparisons between conventional and alternative housings with limited outdoor access (see also 5.1.3 second paragraph). The decline speed and ultimate pH levels of alternatively raised pigs are controversially discussed presumably largely due to the different types of such housing systems. In the author’s opinion, also due to discrepancies between controlled (optimised) conditions within factorial designs, normally with few animals on the one hand, and the various and partly uncontrollable and/or disregarded effects in the practice, on the other hand. A few articles reported indoor comparisons between confined and enriched pen arrangements. In a trial by Petersen et al. (1997b) pH-45 min decline of pigs kept grouped in an enlarged pen area (comparable to the alternative housing conditions of the present study except the missing outside area) was significantly slower than that of pigs kept confined individually with daily training, and the latter again slower than confined individually-kept, non-trained pigs (each group n=4). In the present study, six out of 16 early postmortem comparisons (number 2, 4, and 7 at 35 min, and number 10, 12, and 15 at 2 h p.m.) showed a P-value ≤0.220, and a seventh comparison (number 16) exhibited a P-value of 0.320, all of them with higher ls-means at the ALT-pigs. The inverse constellation (CON>ALT) was not present in this clearness; the most distinctive higher pH level of CON-pigs (comparison 6) featured a significance of P=0.375. Whether the obvious greater proportion of ALT-pigs featuring a higher early postmortem pH was due to a "training effect" promoting a higher proportion of red muscle cells (i.e. oxidative muscle cells), which would show a lower glycolytic potential at slaughter (Fernandez et al., 1995) and a higher early postmortem pH level (Larzul et al., 1997) as was concluded in the investigation by Petersen et al. (1997b), cannot be quantified in the present study, but such an effect is imaginable to some degree. However, other investigations comparing as well several meat quality traits of pigs kept in indoor pens either moderately enriched or confined (=conventional) revealed no obvious differences (Geverink et al., 1999; Beattie et al., 2000a) or negative impacts (including a, though not significantly but lower, ultimate pH of 5.38, paler meat, more drip loss) for the regularly exercised pigs (Enfält et al., 1993). A work by Lewis et al. (1989) showed no difference in the ultimate pH level of daily-trained pigs. Perhaps in these experiments the training of the pigs was not comparable to outdoor (training) conditions as it is present in a free accessible outdoor area (including the given climatic conditions).

To the author's knowledge, one of the only studies analysing comparable housing systems published Lebret et al. (2003). Their results showed a higher level of pH-45 min p.m. in the M.l.d. of pigs (n=62) with outdoor access (comparable to the alternative housing systems in this study) of 6.42 compared to conventionally raised pigs (n=52) with 6.37. While their difference of 0.06 units (at a similar residual standard deviation of 0.20) was not significant (P>0.10), one housing comparison of the present ALT-pigs featured a significantly higher pH value than the CON-pigs of +0.10 (P ≤0.020) at 35 min and of +0.08 (P ≤0.023) at 2 h postmortem (comparisons 4 and 12), and a second comparison displayed similarly higher pH levels of ALT-pigs of +0.11 (P=0.074) at 35 min (comparison 7) and +0.13 (P=0.137) units at 2 h p.m. (comparison 15). – The ultimate pH levels between the housing systems of their work were quasi-equal in the M.l.d., but significantly lower for the outdoor pigs in the muscles BF and SM, all of them white muscles featuring a higher content of glycogen than red ones (Fernandez et al., 1995). In the present study both higher and lower pH levels were prevalent.

When comparing the present results with further works, which included an indoor and a free-range outdoor system, rather the general difference of the systems (i.e. climatic effects, enhanced explorative facilities such as wallowing, huts, etc.) should be focused on than detailed (small) floor and litter specifications. The statements in the literature are controversial relative to meat quality parameters. Enfält et al. (1996) reported generally lower quality traits, including significantly lower ultimate pH levels of 5.44 for outdoor as compared to 5.50 for indoor pigs (n=51 each category), and Stern et al. (2003) found a significantly lower ultimate pH level of 5.32 (-0.02 units, n=71) and more reddish meat in outdoor pigs. Several works (n=12 to 40) reported similar or equal pH values between outdoor and indoor pigs at either the early or the ultimate postmortem stage (Warriss et al., 1983; Sather et al., 1997; Bridi et al., 1998; Gentry et al., 2002).

The inconsistent results of the present study particularly regarding the ultimate pH levels could partly be seen under the aspect of not distinguished (=summarised in the effect slaughterhouse) meat quality-determining effects around slaughtering, e.g. weekday, lairage type, stockperson (Warriss, 1994), stunning (Troeger and Woltersdorf, 1989), and post-slaughtering effects (Honikel, 1987a; D'Souza et al., 1998), which could have masked to some extent the present (investigated) effects. The last handling before stunning can indeed foil a proper, low-stress handling in the lairage (e.g. Van der Wal et al., 1997 and 1999).

6. Conclusions

Fat score

CON-pigs featured in whey feeding systems higher fat scores than ALT-pigs, which was, however, significant only in the winter period. These CON-pigs also exhibited significantly higher fat scores than in the precedent summer period. Contrarily, ALT-pigs showed a higher fat score in complete feeding systems in the winter period than CON-pigs. The mere temperature effect was not enough pronounced to show a clear trend except at T <10 °C in the ALT-housing in winter where higher fat scores are to be expected. The results show that the ALT-housing per se does not entail a fat score rising effect under Swiss climatic conditions. The CON requires a generally higher minimal ambient temperature than the ALT. A temperature level below 20 to 22 °C for pigs in CON-housings in the finishing period, especially during the winter period, is considered too cold. It could enhance the endogen 18:1 synthesis and eventually the fat score as well as it was experienced presumably in some cases in CON-pigs at an averaged 18.5 °C ambient temperature level over the last 60 fattening days.

Fat-free lean

Fat-free lean between several CON and ALT comparisons were highly significant in the first period (summer) with higher lean percentages in CON-pigs irrespective of the effect feeding system. However, this was not repeated in the second period (winter) where the differences were small or disappearing. A temperature effect did virtually not play an important role except for those pigs experiencing a long-term period below ca. 8 °C where lean proportion was lower. The remarkably lower lean percentage of pigs in the first period raised in ALT-farms can to some extent presumably be ascribed to lacking experience of the farmers in management aspects such as housing and feeding, culling to market, etc.. Many of these farmers were adapting the new housing system by the time of data collection. It may be assumed that the trend of the second period indicates that the effect housing system was at least not the only factor responsible for the lower lean percentages in the first period. Further studies, i.e., a data collection of a new recording period, would be needed to confirm this conclusion.

PH of Musculus longissimus dorsi (M.l.d.)

Eight housing comparisons showed a mixed pattern. While in the early p.m. stages (at 35 min and 2 h) the CON-pigs tended partly to exhibit a lower pH level, in the ultimate stage this was not consistently repeated anymore. Few comparisons featured qualitatively the same difference while others a contrary development. The differences were in general small (≤0.13 and ≤0.07 pH units in the early and ultimate stage p.m., respectively) and only in the early p.m. stages significant in rare cases. The housing systems do not relevantly influence the pH development postmortem. A late evening supply of whey (and other feed) must be questioned for pigs slaughtered the following night/morning, as it is common in Switzerland (no overnight stay). One consequence is that the ultimate pH drops too low when coinciding with a short transport way and immediate stunning at the slaughterhouse (e.g. first delivered pigs) as it was observed in the CON-pigs of one subclass. Transport ways were slaughterhouse dependent and featured in general short to normal duration.

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8. Appendix

App. I: Detailed feed variables (Weender analysis)

		Unit[a]	Whey feeding system					Complete feeding system				
			Average	SD	CV-%	Min	Max	Average	SD	CV-%	Min	Max
Conventional Housing (CON)												
Summer	Pufa / energy	g/MJ	0.65	0.15	22.3	0.35	0.95	0.82	0.15	18.7	0.46	0.97
	18:1 / energy	g/MJ	1.35	0.56	41.7	0.21	2.73	0.78	0.30	38.4	0.30	1.23
	Energy[b]	MJ	15.8	0.6	3.6	14.7	17.3	15.3	0.2	1.4	14.9	15.6
	Protein in diet	g	192	17	9	165	228	187	13	7	170	215
	Total Fat	g	61.5	27.0	43.9	14.5	136.9	39.6	11.2	28.3	19.6	55.3
	Pufa	g	10.3	2.5	24.6	5.4	16.3	12.5	2.3	18.7	7.1	14.8
	Oleic acid (18:1)	g	21.6	9.7	45.0	3.2	47.2	11.9	4.7	39.5	4.5	19.2
	Pufa in fat	%	18.9	6.7	35.4	11.0	43.5	33.3	8.8	26.5	21.7	49.7
	18:1 in fat	%	34.6	4.2	12.2	18.2	39.7	28.9	4.9	17.1	21.4	35.7
Winter	Pufa / energy	g/MJ	0.57	0.15	26.5	0.19	0.87	0.75	0.08	10.4	0.62	0.86
	18:1 / energy	g/MJ	1.19	0.40	33.9	0.68	2.21	0.57	0.28	48.9	0.32	1.00
	Energy	MJ	15.7	0.4	2.5	14.8	16.6	15.2	0.2	1.2	14.9	15.5
	Protein in diet	g	199	22	11	165	232	188	15	8	170	214
	Total Fat	g	55.3	17.8	32.1	32.8	100.4	31.4	10.0	32.0	21.1	48.6
	Pufa	g	9.9	2.4	27.1	2.9	13.4	11.3	1.2	10.7	9.2	13.1
	Oleic acid (18:1)	g	18.9	6.9	36.5	10.7	36.6	8.7	4.3	49.7	4.8	15.4
	Pufa in fat	%	17.3	5.7	33.1	5.2	29.5	38.9	10.7	27.6	25.3	51.2
	18:1 in fat	%	33.6	2.8	8.4	29.1	38.8	25.9	6.0	23.0	16.5	33.3
Alternative Housing (ALT)												
Summer	Pufa / energy	g/MJ	0.74	0.20	27.0	0.44	1.18	0.86	0.18	21.2	0.46	1.42
	18:1 / energy	g/MJ	1.18	0.58	49.2	0.53	2.67	1.02	0.40	39.5	0.30	2.05
	Energy	MJ	15.9	0.6	3.7	15.2	17.1	15.4	0.4	2.4	14.7	16.2
	Protein in diet	g	187	13	9	157	221	187	13	7	167	232
	Total Fat	g	55.9	23.6	42.2	32.4	115.2	50.1	14.1	28.2	18.0	83.2
	Pufa	g	11.7	3.1	26.8	6.9	18.0	13.3	2.9	21.5	6.8	22.4
	Oleic acid (18:1)	g	19.0	10.2	53.8	8.2	45.6	15.9	6.5	41.2	4.5	33.2
	Pufa in fat	%	23.1	9.3	40.3	12.8	49.6	28.5	8.8	30.9	13.0	45.0
	18:1 in fat	%	33.7	4.1	12.2	26.5	40.1	31.4	5.0	16.0	20.7	41.8
Winter	Pufa / energy	g/MJ	0.59	0.12	20.7	0.31	0.75	0.71	0.18	25.6	0.28	1.41
	18:1 / energy	g/MJ	0.88	0.42	47.7	0.23	2.16	0.75	0.35	47.4	0.23	1.62
	Energy	MJ	15.6	0.3	2.3	15.0	16.4	15.3	0.4	2.4	14.1	16.0
	Protein in diet	g	188	16	9	148	215	189	13	7	165	228
	Total Fat	g	42.4	18.3	43.3	15.0	95.7	38.8	12.6	32.6	12.9	73.0
	Pufa	g	9.1	1.9	21.3	4.9	12.3	10.9	2.8	25.9	4.0	21.7
	Oleic acid (18:1)	g	13.9	7.0	50.4	3.6	35.5	11.5	5.5	48.3	3.5	25.9
	Pufa in fat	%	23.4	5.6	23.9	12.8	32.6	30.4	10.1	33.1	17.3	54.7
	18:1 in fat	%	32.5	4.0	12.3	25.2	37.8	29.3	6.6	22.7	11.3	38.4

[a] Units are based on 1 kg dry matter (DM).
[b] digestible energy

App. II: Descriptive results of dietary oleic acid (18:1)

Dietary oleic acid (18:1) in g/MJ DE									
Season		Comparison	Average / SD	Min	Max	CV-%	Overall		n farms
Summer	*Whey Feed*								
Summer	CON	1)	1.35 ± 0.56	0.21	2.73	41.7			23
Summer	ALT	1)	1.18 ± 0.58	0.53	2.67	49.2			13
Summer	*Complete Feed*						CON Average	1.10	
Summer	CON	2)	0.78 ± 0.30	0.30	1.23	38.4	ALT Average	0.92	10
Summer	ALT	2)	1.02 ± 0.40	0.30	2.05	39.5			31
Winter	*Whey Feed*								
Winter	CON	3)	1.19 ± 0.40	0.68	2.21	33.9	Total		17
Winter	ALT	3)	0.88 ± 0.42	0.23	2.16	47.7	Average	0.99	17
Winter	*Complete Feed*						Min	0.23	
Winter	CON	4)	0.57 ± 0.28	0.32	1.00	48.9	Max	2.73	8
Winter	ALT	4)	0.75 ± 0.35	0.23	1.62	47.4			33

App. III: Differences of dietary PUFA and 18:1 between season, housing-, and feeding systems

Part 1: in g/MJ energy	Whey feeding		Complete feeding		Difference[A] in % of: Whey → Complete f.	
A)	PUFA	18:1	PUFA	18:1	PUFA	18:1
CON in summer	0.65	1.35	0.82	0.78	+26	-42
CON in winter	0.57	1.19	0.75	0.57	+31	-52
ALT in summer	0.74	1.18	0.86	1.02	+17	-13
ALT in winter	0.59	0.88	0.71	0.75	+22	-16
B)	Summer		Winter		Summer → Winter	
CON with Whey feeding	0.65	1.35	0.57	1.19	-12	-12
CON with Complete feeding	0.82	0.78	0.75	0.57	-9	-26
ALT with Whey feeding	0.74	1.18	0.59	0.88	-21	-25
ALT with Complete feeding	0.86	1.02	0.71	0.75	-17	-27
C)	CON		ALT		CON → ALT	
Whey feeding in summer	0.65	1.35	0.74	1.18	+14	-13
Complete feeding in summer	0.82	0.78	0.86	1.02	+6	+31
Whey feeding in winter	0.57	1.19	0.59	0.88	+3	-26
Complete feeding in winter	0.75	0.57	0.71	0.75	-4	+30

Part 2: in % of total fat	Whey feeding		Complete feeding		Difference in % of: Whey → Complete f.	
A)	PUFA	18:1	PUFA	18:1	PUFA	18:1
CON in summer	18.9	34.6	33.3	28.9	+76	-17
CON in winter	17.3	33.6	38.9	25.9	+125	-23
ALT in summer	23.1	33.7	28.5	31.4	+23	-7
ALT in winter	23.4	32.5	30.4	29.3	+30	-10
B)	Summer		Winter		Summer → Winter	
CON with Whey feeding	18.9	34.6	17.3	33.6	-8	-3
CON with Complete feeding	33.3	28.9	38.9	25.9	+17	-10
ALT with Whey feeding	23.1	33.7	23.4	32.5	+1	-4
ALT with Complete feeding	28.5	31.4	30.4	29.3	+7	-7
C)	CON		ALT		CON → ALT	
Whey feeding in summer	18.9	34.6	23.1	33.7	+22	-3
Complete feeding in summer	33.3	28.9	28.5	31.4	-14	+9
Whey feeding in winter	17.3	33.6	23.4	32.5	+35	-3
Complete feeding in winter	38.9	25.9	30.4	29.3	-22	+13

[A] Example of the first line in table: Whey → Complete f. = +26 %, i.e. in summer the CON-farms with complete-feeding-systems featured 26 % more PUFA (g/MJ) than those with whey feeding systems.

App. IV: LS-Means and comparisons of the 18:1 model

Model of oleic acid (18:1)			Comparison	LS-Means [a]	SE	P-value [b]
Housing comparisons						
Summer	*Whey Feed*	CON	1)	43.3	0.28	0.870
		ALT		43.4	0.39	
	Complete Feed	CON	2)	43.1	0.38	**0.019**
		ALT		42.0	0.25	
Winter	*Whey Feed*	CON	3)	43.8	0.33	0.332
		ALT		43.3	0.36	
	Complete Feed	CON	4)	43.2	0.50	0.764
		ALT		43.0	0.28	
Season comparisons						
Conventional	*Whey Feed*	Summer	5)	43.3	0.28	0.262
		Winter		43.8	0.33	
	Complete Feed	Summer	6)	43.1	0.38	0.908
		Winter		43.2	0.50	
Alternative	*Whey Feed*	Summer	7)	43.4	0.39	0.854
		Winter		43.3	0.36	
	Complete Feed	Summer	8)	42.0	0.25	**0.008**
		Winter		43.0	0.28	

[a] LS-Means are computed with the REML approach; [b] P-values are unadjusted and bold marked when <0.05.

- Frames provide an overwiew for comparisons when P<0.3; quadrate: ALT>CON/Winter>Summer, circle: ALT<CON/Winter<Summer.

App. V: Descriptive results of fasting, transport and lairage time (pH)

Unit in hours			Comparison	Slaughterhouse 1 Average/SD	Min	Max	CV-%	Comp.	Slaughterhouse 2 Average/SD	Min	Max	CV-%	Overall	Slaughterhouse 1	Slaughterhouse 2
A) Fasting time (on farm)														n market groups at initial pH	
Summer	*Whey Feed*														
		CON	1)	11.0 ± 1.7	9.0	14.3	15	2)	9.1 ± 1.1	7.5	12.3	12		13	23
		ALT		11.4 ± 2.1	7.0	14.0	18		8.3 ± 5.2	0.6	15.5	63		10	11
	Complete Feed												CON Average 10.4		
		CON	3)	7.8 ± 5.2	0.5	12.0	67	4)	13.4 ± 5.5	5.0	21.0	41	ALT Average 10.0	4	16
		ALT		9.7 ± 3.4	0.0	19.8	35		11.4 ± 4.6	1.6	19.0	40		40	17
Winter	*Whey Feed*														
		CON	5)	10.8 ± 0.5	10.2	11.5	5	6)	9.7 ± 1.4	7.8	12.3	14	Total	7	20
		ALT		9.3 ± 2.6	4.0	13.3	28		7.0 ± 3.3	1.0	10.5	47	Average 10.1	16	10
	Complete Feed												Min 0.0		
		CON	7)	12.0 ± 0.0	12.0	12.0	0	8)	9.3 ± 6.0	2.5	18.8	65	Max 21.0	2	6
		ALT		10.6 ± 3.9	0.0	19.0	37		11.3 ± 2.7	6.3	16.3	24		28	13
B) Transport time															
Summer	*Whey Feed*														
		CON	1)	3.5 ± 1.3	1.5	5.3	37	2)	0.8 ± 0.6	0.2	2.3	75		do.	
		ALT		2.0 ± 1.0	1.0	4.0	50		2.0 ± 1.3	0.3	3.8	65			
	Complete Feed												CON Average 1.7		
		CON	3)	3.0 ± 1.7	1.0	5.0	57	4)	1.9 ± 0.9	0.8	3.2	47	ALT Average 2.4		
		ALT		3.0 ± 1.2	0.6	6.0	40		1.4 ± 1.2	0.3	4.1	86			
Winter	*Whey Feed*														
		CON	5)	2.5 ± 0.9	1.2	3.5	36	6)	0.9 ± 1.0	0.2	3.6	111	Total		
		ALT		3.0 ± 1.4	1.3	5.5	47		2.7 ± 1.8	0.2	5.5	67	Average 2.2		
	Complete Feed												Min 0.2		
		CON	7)	1.7 ± 0.2	1.5	1.8	12	8)	1.9 ± 0.8	0.5	2.7	42	Max 6.0		
		ALT		2.8 ± 1.0	1.3	5.3	36		1.2 ± 1.4	0.3	5.5	117			
C) Lairage time															
Summer	*Whey Feed*														
		CON	1)	1.8 ± 0.7	0.4	3.2	39	2)	1.5 ± 1.0	0.2	4.3	67		do.	
		ALT		1.7 ± 0.7	0.6	2.7	41		0.9 ± 0.4	0.4	1.6	44			
	Complete Feed												CON Average 1.5		
		CON	3)	1.8 ± 0.8	0.7	2.7	44	4)	1.4 ± 1.0	0.1	3.5	71	ALT Average 1.7		
		ALT		1.9 ± 0.7	0.3	3.8	37		1.2 ± 1.0	0.1	4.0	83			
Winter	*Whey Feed*														
		CON	5)	1.7 ± 0.7	0.5	2.8	41	6)	1.5 ± 0.5	0.3	2.9	33	Total		
		ALT		1.8 ± 0.6	0.5	2.9	33		1.5 ± 1.0	0.3	3.4	67	Average 1.6		
	Complete Feed												Min 0.1		
		CON	7)	1.7 ± 0.3	1.5	2.0	18	8)	1.1 ± 0.5	0.7	1.9	45	Max 4.3		
		ALT		1.9 ± 0.8	0.9	4.5	42		1.6 ± 0.9	0.5	3.9	56			

D) Effective time at pH-2 h p.m. (averaged)

		hours	Δ minutes (absolute) relative to 2 hours p.m.
Summer	Sl'house 1	2.36 ± 0.31	+21
	Sl'house 2	2.23 ± 0.16	+13
Winter	Sl'house 1	2.20 ± 0.14	+12
	Sl'house 2	2.27 ± 0.17	+16

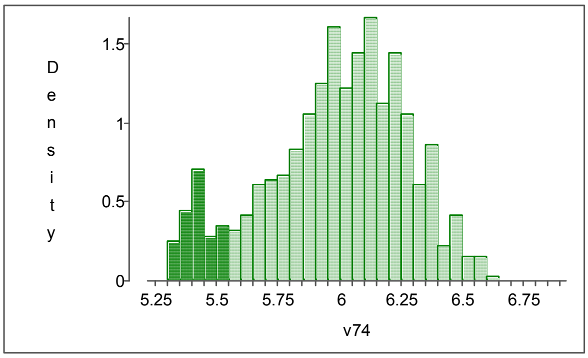
App. VI: PH-values observed in slaughterhouse, season, feeding and housing system

Slaughter-house	Season	Feeding system	Housing system	Model	Average	SD	Min	Max	n
1	Summer	Whey feed	CON	pH-35 min	6.41	0.22	5.75	6.94	306
				pH-2 h	6.00	0.29	5.31	6.64	306
				pH-24 h	5.40	0.09	5.17	5.67	232
			ALT	pH-35 min	6.43	0.21	5.60	6.99	261
				pH-2 h	6.02	0.28	5.31	6.71	261
				pH-24 h	5.38	0.07	5.17	5.58	261
		Complete feed	CON	pH-35 min	6.35	0.21	5.66	6.80	112
				pH-2 h	5.96	0.27	5.40	6.49	112
				pH-24 h	5.39	0.08	5.25	5.65	89
			ALT	pH-35 min	6.40	0.22	5.42	7.10	779
				pH-2 h	5.97	0.30	5.30	6.83	775
				pH-24 h	5.39	0.09	5.11	5.76	681
	Winter	Whey feed	CON	pH-35 min	6.44	0.25	5.64	7.11	138
				pH-2 h	5.98	0.32	5.23	6.57	137
				pH-24 h	5.38	0.06	5.26	5.59	136
			ALT	pH-35 min	6.45	0.22	5.59	7.13	340
				pH-2 h	6.01	0.29	5.27	6.74	332
				pH-24 h	5.40	0.06	5.23	5.62	276
		Complete feed	CON	pH-35 min	6.39	0.19	5.92	6.85	66
				pH-2 h	5.96	0.26	5.36	6.54	66
				pH-24 h	5.39	0.06	5.26	5.54	66
			ALT	pH-35 min	6.44	0.24	5.58	7.10	590
				pH-2 h	6.02	0.29	5.29	6.72	570
				pH-24 h	5.41	0.07	5.23	5.67	396
2	Summer	Whey feed	CON	pH-35 min	6.40	0.18	5.87	6.84	348
				pH-2 h	6.13	0.25	5.36	6.80	348
				pH-24 h	5.28	0.08	5.01	5.54	324
			ALT	pH-35 min	6.48	0.21	5.83	7.00	162
				pH-2 h	6.21	0.26	5.35	6.79	162
				pH-24 h	5.34	0.08	5.08	5.57	157
		Complete feed	CON	pH-35 min	6.36	0.20	5.83	7.02	182
				pH-2 h	6.09	0.25	5.35	6.66	182
				pH-24 h	5.36	0.12	5.00	5.74	164
			ALT	pH-35 min	6.48	0.22	5.70	7.04	305
				pH-2 h	6.18	0.26	5.32	6.91	294
				pH-24 h	5.37	0.09	5.12	5.73	287
	Winter	Whey feed	CON	pH-35 min	6.43	0.21	5.59	6.99	482
				pH-2 h	6.14	0.25	5.29	6.75	477
				pH-24 h	5.38	0.08	5.18	5.61	268
			ALT	pH-35 min	6.40	0.20	5.55	7.15	253
				pH-2 h	6.12	0.24	5.31	6.62	253
				pH-24 h	5.39	0.09	5.15	5.65	250
		Complete feed	CON	pH-35 min	6.44	0.18	5.84	6.91	133
				pH-2 h	6.13	0.24	5.46	6.68	133
				pH-24 h	5.40	0.07	5.26	5.61	84
			ALT	pH-35 min	6.50	0.21	5.90	6.95	274
				pH-2 h	6.19	0.26	5.39	6.83	274
				pH-24 h	5.38	0.09	5.20	5.60	254

App. VII: Distribution diagrams of pH-2 h p.m. between housings and slaughterhouses

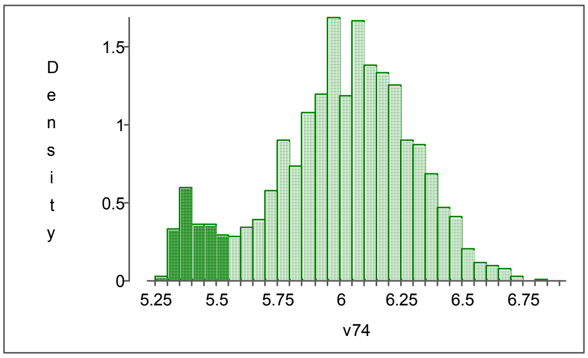
Slaughterhouse 1

CON



Average: 5.98, Min: 5.23, Max: 6.64

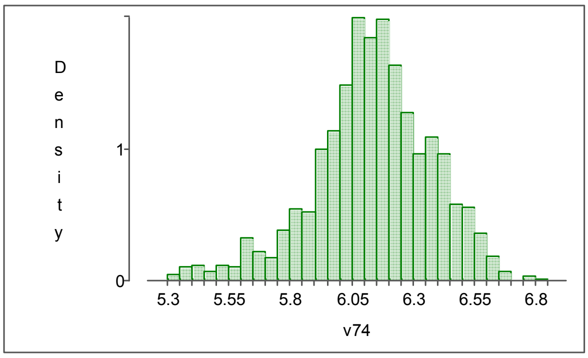
ALT



Average: 6.00, Min: 5.27, Max: 6.83

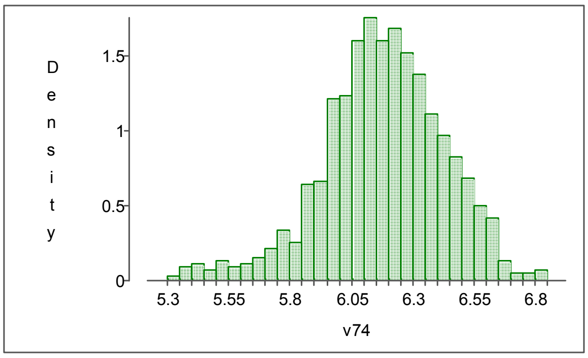
Slaughterhouse 2

CON



Average: 6.13, Min: 5.29, Max: 6.80

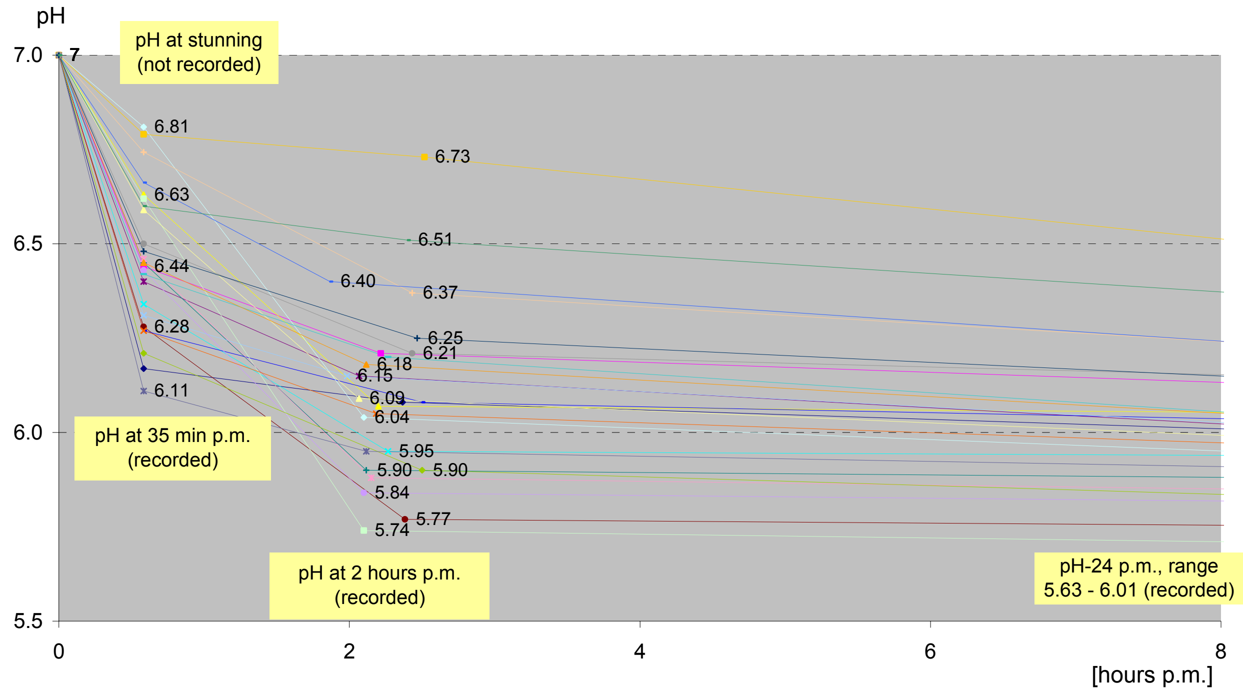
ALT



Average: 6.17, Min: 5.31, Max: 6.91

The division of the pH-2 h (=v74) recordings show that the small peak at the lower end in slaughterhouse 1 was present in both housing systems and is hence not a housing typical characteristic but slaughterhouse related. No such peak was observed in slaughterhouse 2. One possible reason for this difference between the slaughterhouses could be the chilling of the carcasses via the blast cooler in slaughterhouse 2 (-10 °C for about 80 minutes before pH-2 h p.m.) whereas in slaughterhouse 1 the carcasses were cooled without blast cooler (see also Fig. 14).

App. VIII: Individual courses of 25 highest pH-ultimate records



Curriculum Vitae of Hans Ulrich Bärlocher

2000-2005	Ph.D. thesis at Agroscope FAT, Tänikon, Ettenhausen (TG), and at Swiss Federal Institute of Technology (ETH), Department of Animal Science, Zürich, Switzerland.
2002	Four-months stay at the University of Illinois, Urbana-Champaign, Illinois, U.S.A., at the Animal Science lab of Prof. Dr. James E. Pettigrew in connection with the Ph.D. thesis.
1999-2000	Employment at the company Provimi-Kliba, Cossonay-Gare (VD), Switzerland, domain alimentation in the poultry department.
1993-1999	University degree (Dipl. Ing. Agr. ETH) at the Swiss Federal Institute of Technology, Zürich, distinction Animal Science. Diploma thesis: Genetic analysis (polymerase chain reaction of micro satellites of DNA) of New World Camelids.
1997	Language formations at Malaga, Spain, and Quito, Ecuador, including a four-months stay in Manglaralto, Ecuador, Finca Santa Maria del Fiat, a student development program of animal husbandry (pig housing).
1995	Six-months stay as supervisor for goat development project at Dhoni Farm, Palakkad, Kerala, India, for the Indo-Swiss Development Project (DEZA-SDC, Swiss Agency for Development and Cooperation).
1989-1993	Evening high school and graduation (Type C) at the ISME (Interstaatliche Maturitätschule für Erwachsene) at St. Gallen, Switzerland. Language formations at Paris and Hyères, France, and Siena, Italy.
1987-1991	AI part-time employment, as well as training and employment for embryo transfer in cows at the AET (Arbeitsgemeinschaft für Embryotransfer) at Avenches (VD), and Bütschwil (SG), Switzerland.
1985-1987	Full-time employment as cattle breeder (AI-station Bütschwil, SG), areas Kanton Glarus (GL) and St. Gallen (SG), Switzerland.
1984	Artificial cattle insemination (AI) training at Neustadt/Aisch, Bavaria, Germany, including AI cattle breeder diploma.
1983-1984	Several employments at farms with and without cattle in Switzerland.
1982-1983	1-year employment on a Canadian dairy farm in Brampton, Ontario.
1979-1981	Swiss vocational winter-school for farmers including diploma at the Agricultural School of Rheinhof, Salez (SG), Switzerland.
1979	Military service (heavy truck driver).
1977-1979	Farm training apprenticeship and school with Swiss Farmer diploma at Vaumarcus, Corcelles, and Cernier (NE) (the French part of Switzerland).
1967-1977	Primary and secondary school at Berg (SG) and Gais (AR), Switzerland.
1960, September 15	Born in Scherzingen (TG), Citizen of St. Gallen (SG), Switzerland, evangelic protestant.