Towards a better understanding of the genetics of lean meat growth – from UNE20P to UNE23P

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Brief introduction to project UNE20P

The aim of this project was to optimise selection indices for efficient lean meat growth. Traditionally, genetic improvement of lean meat growth and feed efficiency has been based on *ad libitum* feeding. However, selection for lean meat growth and feed conversion ratio under *ad libitum* feeding has led to a reduction in feed intake in modern genotypes to the extent that feed intake is often not sufficient to meet the animal's requirement for maximum protein deposition. Results from selection experiments have indicated that it might be beneficial to select pigs under restricted feeding for efficient lean meat growth (McPhee *et al*., 1988; Cameron and Curran, 1995). These selection experiments were conducted under research conditions where pigs were single penned and feed intake of the individual pig was well monitored. However, in commercial conditions pigs are group penned and in order to record feed intake in these commercial conditions electronic feeders have to be used.

The aims of this project were:

To test the hypothesis that performance traits are genetically a different trait under restricted feeding than under *ad libitum* feeding and that it is beneficial to select pigs under restricted feeding for lean meat growth.

To answer the question, is there a genetic basis reducing the difference in growth and carcase traits observed between boars and gilts?

To investigate genotype by nutrition interaction for meat quality traits

To analyse additional carcase traits which had not been analysed before.

The design of project UNE20P and interim results were presented at the last pig genetics workshop (Hermesch, 1998). The aim of the current paper is to briefly summarise the main conclusions from UNE20P and to introduce a new project (UNE23P). The aim of UNE23P is to incorporate growth models into selection procedures for lean meat growth.

Description of data recording and data analysis

1. General description of total data set

Performance recording for UNE20P started in February 1996 and finished in September 1998. During this time approximately 9600 animals were performance recorded. However, performance data from the first 1500 animals could not be used for analyses since feed intake levels were substantially lower and animals were tested over a different weight range (see Hermesch, 1998 for details). The data set included boars and gilts from two breeds, Large White and Landrace. Carcase and meat quality traits recorded in the abattoir were available for 5500 animals.

Animals were performance recorded for feed intake and growth rate from 80 to 110 kg live weight using electronic feeders. Electronic feeders were used to measure feed intake under commercial conditions with 30 animals per group. The two feeding levels included *ad libitum* and restricted feeding. Feed intake in the restricted group was reduced to 90% of the *ad libitum* group.

2. General description of analysis

Variance components were estimated for production, carcase and meat quality traits. In order to investigate any genotype by feeding regime interaction each performance trait was defined as a different trait in each feeding regime. A genetic correlation of less than one means that a genotype by feeding regime interaction exists. In the same way, a genotype by sex interaction was investigated by defining each trait as a different trait in each sex, boars and gilts, and obtaining genetic correlations between traits.

Selection indices can remain the same for both sexes

Genetic correlations between traits recorded in gilts and boars were not significantly different from one for the majority of traits. Only growth rate recorded during test and lifetime average daily gain had reduced genetic correlations of 0.77 (±0.08) and 0.83 (±0.06), respectively. Further genotype by sex interaction was found for back leg weight (rg: 0.76 (±0.10), which is highly correlated with growth rate. However, the magnitude of these genotype by sex interactions is not large enough to define these traits as different traits in each sex.

- Currently performance traits recorded in each sex are regarded as the same trait, which has been confirmed as the correct genetic evaluation procedure.

Meat quality traits

Meat quality traits were genetically the same trait in both feeding regimes and both sexes. It is therefore not necessary to develop different selection indices for meat quality traits for different feeding regimes or for each sex. However, antagonistic relationships between meat quality traits describing pale, soft and exudative (PSE) meat and backfat measurements were confirmed. The high emphasis on backfat and feed conversion ratio as it is currently used in industry continues to select pigs that are more prone to develop PSE meat.

- Genetic parameters for meat quality traits do not differ between feeding regimes and between both sexes.

Analysis of new traits

The new traits analysed in this project included backfat at start of test (80 kg live weight), backfat above the tail, dressing percentage and ham weight including bone weight. Genetic parameters for these traits showed that it is not worthwhile to include any of these traits in breeding programs additionally to traits used already. Both backfat measurements were highly correlated with backfat at the P2 site but had lower heritabilities. Dressing percentage was only lowly heritable but was favourably correlated with ham weight in boars. Finally, ham weight including the bone was highly correlated with weight of the whole back leg. Once weight of the whole back leg is available it is not worthwhile recording weight of the ham including the bone weight. In contrast, slash boning the ham and obtaining ham weight provides further information about lean meat growth.
It is not necessary to include any of the newly analysed traits in selection procedures.

Selection for lean meat growth: *ad libitum* or restricted feeding?

Improvement of feed conversion ratio, defined as feed intake over weight gain, can be achieved in two ways; reducing feed intake or increasing weight gain. Fowler *et al.* (1976) showed that genetic improvement in efficient lean meat growth under *ad libitum* feeding results from a decrease in fat deposition by reducing voluntary feed intake. Although reduction in voluntary feed intake might be beneficial in the short-term, reduction in feed intake might limit protein deposition in the long term. As a consequence, Fowler et al. (1976) suggested testing pigs under restricted feeding and mentioned the method of Kielanowski (1968) as the preferred method. This method implies that pigs are brought to a similar live weight at start of test and then fed for a fixed period of time on a scale, which increases with time. Such a scheme does not allow any expression of feed intake and virtually all selection pressure is put on increasing lean tissue gain.

For a better understanding of the biological implications of different selection strategies a selection experiment was conducted to compare four breeding objectives (Webb and Curran, 1986). In the final comparison of selection lines, animals were compared under *ad libitum* feeding (Cameron and Curran, 1995). No differences between selection lines were found in the Landrace population. However, Large White pigs from the selection line based on restricted feeding had a higher growth rate and a higher feed intake under *ad libitum* feeding than animals which were derived from the selection lines based on lean growth rate and lean feed conversion ratio under *ad libitum* feeding. These results confirmed earlier findings by McPhee et al. (1988) whose selection experiment consisted of one selection line selected for lean meat growth under restricted feeding. The authors concluded that selection for lean meat growth under restricted feeding better exposed to selection the favourable genetic relationship between growth rate and backfat which is associated with the partitioning of feed energy into lean and fat deposition.

- Restricted feeding has been suggested as the preferred method of performance recording when selecting pigs for efficient lean meat growth.

Ad libitum feed intake in commercial conditions

The use of restricted feeding in practical pig breeding herds requires the development of a performance recording procedure suitable for commercial conditions. The development of electronic feeders at Bunge Meat Industries (BMI) allows the measurement of feed intake in group penned pigs. Each pen accommodating 30 pigs is equipped with three electronic feeders. This allows three pigs to eat at the same time.

On average, feed intake was 2.44 kg and 2.46 kg in gilts and boars under *ad libitum* feeding. This feed intake under *ad libitum* feeding was lower than the feed intake observed in a previous project (UNE.17P) of 2.60 kg where boars were single penned in a test station.

- The housing system based on group penning and the use of electronic feeders reduced feed intake in comparison to the test station environment.

Standardising test conditions

The amount of food available for the restricted group was increased each week on test ranging from 2.1 in the first week to 2.8 kg in the fifth week on test. The average feed intake for the restricted group was 2.22 kg in both sexes. Pigs were performance tested between 80 to 110 kg live weight. However, it was not possible to standardise weight at test entry and pigs entering test had large differences in live weight. Since the level of feed intake was constant for all pigs the actual level of restriction differed for individual pigs and was larger for heavier pigs. These pigs have higher maintenance requirements and less energy remains for growth.

- Further improvement of performance recording procedures has to aim at reducing variation in live weight of pigs on test.

Heritability estimates

Feed intake under *ad libitum* feeding was moderately heritable (Table 1). The estimate agrees well with estimates provided by Hall *et al*. (1999) who also recorded feed intake in group penned pigs. Therefore, electronic feeders provide the opportunity to measure feed intake in commercial environments. This reduces the risk of genotype by environment interaction, as is the case when feed intake is recorded in single pens used in test stations. The heritability estimate for feed intake under restricted feeding was not zero (Table 2) indicating that some pigs were not restricted in their feed intake. McPhee *et al*. (1988) also reported that not all pigs restricted in feed allowance were able to eat the allocated amount. The coefficient of variation for feed intake under restricted feeding was much lower (CV: 0.02) than in the present study (CV: 0.10). In the study by McPhee *et al*. (1988), feed intake was monitored for each individual pig (Cam

McPhee pers. communication) which is not possible in commercial pig breeding companies.

Growth rate during the test period (ADG) had a low heritability estimate due to high environmental variation. It has been discussed before (UNE.20P Progress Report, 1998) that the short test period is one cause of this low heritability estimate. Random differences in weight measurements at beginning and end of test have a proportionally larger influence on average daily gain during test in a short test period than in a long test period. The low heritability estimate of feed conversion ratio results from the high environmental variation in growth rate.

Table 1. Number of records (N), heritability estimates (h^2) (with standard errors, se), litter effect estimate (c^2 with standard error, se) along with variance components for performance traits recorded under ***ad libitum* feeding**

Trait	N	h^2 (se)	c^2 (se)	σ^2_a *	σ^2_c	σ^2_e
FDINT *	3950	0.25(0.03)	0.03 (0.02)	0.024	0.003	0.069
ADG	3950	0.08 (0.02)	0.07 (0.02)	1435	1267	14299
FCR	3941	0.10 (0.02)	0.08 (0.02)	0.020	0.015	0.168
LP2	3950	0.46 (0.03)	0.04 (0.02)	2.92	0.27	3.12

* Abbreviations:

FDINT: Daily feed intake during test
ADG: Average daily gain during test
FCR: Feed conversion ratio
LP2: Backfat at P2 recorded with real time ultrasound on the live animal

* σ^2_a: additive genetic variance, σ^2_c: litter effect variance; σ^2_e: environmental variance

Table 2. Number of records (N), heritability estimates (h^2) (with standard errors, se), litter effect estimate (c^2 with standard error, se) along with variance components for performance traits recorded under **restricted feeding**

Trait	N	h^2 (se)	c^2 (se)	σ^2_a *	σ^2_c	σ^2_e
FDINT *	3623	0.14 (0.03)	0.04 (0.02)	0.004	0.001	0.020
ADG	3623	0.09 (0.02)	0.06 (0.02)	1271	810	11406
FCR	3909	0.11 (0.02)	0.06 (0.02)	0.023	0.013	0.179
LP2	3623	0.47 (0.04)	0.01 (0.02)	2.52	0.06	2.83

for Abbreviations see Table 1.

Heritability estimates did not differ among feeding regimes for growth rate, feed conversion ratio and backfat measurements. Variance components were reduced under restricted feeding for growth rate and backfat which was due to lower means and variation in performance traits under restricted feeding. Both McPhee *et al*. (1988) and Cameron and Curran (1995) also found lower variance components for performance traits under restricted feeding. Heritability estimates were lower for restricted feeding in the study by Cameron and Curran (1995) for growth rate and backfat. In contrast, McPhee *et al.* (1988) found higher heritability estimates for these two traits under restricted feeding.

- Electronic feeders provide the opportunity to measure feed intake in commercial environments

- Feed restriction did not eliminate all variation in feed intake. Some pigs were not restricted in their feed intake.
- Growth rate and feed conversion ratio have low heritability estimates. Random differences in weight measurements at start and finish of test are believed to be the reason for this low heritability.
- Heritability estimates did not differ between feeding regimes. Variance components were lower for growth rate and backfat recorded under restricted feeding as a result of lower means.

Estimates of genetic correlations

1. Genetic correlations for each feeding regime

The reduction in feed intake caused some changes in genetic correlations between traits. Firstly, the genetic correlation between feed intake (FDINT) and growth rate (ADG2) was reduced in the restricted feeding group (rg: 0.41 versus rg: 0.64). Growth rate under *ad libitum* feeding depends partly on the feed intake capacity of the pig. By restricting feed intake this component of growth rate was reduced which is reflected in a lower genetic correlation between these two traits. Consequently, the genetic correlations between growth rate, feed intake and feed conversion ratio (FCR) differed between feeding regimes. Under *ad libitum* feeding feed conversion ratio was more strongly related to feed intake (rg: 0.68) but less strongly related to growth rate (rg: -0.17) (Table 3.). Under restricted feeding feed conversion ratio and growth rate are expected to be the same trait (but with opposite signs). Although these two traits were highly correlated (rg: -0.86) these two traits were not genetically the same since it was not possible to reduce all variation in feed intake. Backfat and growth rate had a lower, more favourable, genetic correlation under restricted feeding (rg: -0.18) than under ad libitum feeding (rg: -0.03).

Table 3: Genetic correlations between feed intake (FDINT), growth rate (ADG), feed conversion ratio (FCR) and backfat at P2 site (LP2) recorded under *ad libitum* (above diagonal) and restricted feeding (below diagonal)

Trait	FDINT	ADG	FCR	LP2
FDINT		0.64 (0.07)	0.68 (0.08)	0.45 (0.06)
ADG	0.41 (0.12)		-0.17 (0.15)	-0.03 (0.09)
FCR	0.14 (0.14)	-0.86 (0.04)		0.58 (0.07)
LP2	0.50 (0.08)	-0.18 (0.10)	0.60 (0.09)	

* estimate at the border of the parameter space, standard error could not be obtained

These genetic correlations support the hypothesis by Fowler et al. (1976) that improvement of lean feed conversion ratio under *ad libitum* feeding would result in the short term from reduction in voluntary feed intake and not increased growth rate. This result was also found in the Edinburgh selection experiment (Cameron and Curran, 1994). Selection for lean feed conversion ratio under *ad libitum* feeding resulted in no response in growth rate but backfat and feed intake were reduced in both populations.

Genetic correlations between growth rate and backfat measurements were more favourable under restricted feeding than under *ad libitum* feeding. The shift of genetic correlations between these two traits was not as profound as in the study of McPhee *et al*. (1988) where the genetic correlation changed from 0.35 under *ad libitum* feeding to -0.22 under restricted feeding. This might be explained by the lower level of restriction in this study in comparison to the experiment by McPhee *et al*. (1988) where animals were restricted to 80% of the *ad libitum* feed intake. Cameron and Curran (1994) also reported moderate positive genetic correlations between growth rate and backfat for each *ad libitum* selection line in the Large White and Landrace populations whereas genetic correlations were -0.10 and -0.02 for the two restricted feeding lines. The genetic correlation between growth rate and backfat could therefore be regarded as an indicator of the level of restriction in feed intake. A stronger restriction in feed intake causes a reduction in the genetic correlation between growth rate and backfat. For example, the genetic correlation between growth rate and backfat at P2 site was 0.30 in UNE.17P (Hermesch, 1996) where feed intake was 0.2 kg higher than in the current *ad libitum* group. In comparison, the *ad libitum* group with a daily feed intake of 2.44 kg in the current project had a genetic correlation of -0.03 while the restricted feeding group which had a daily feed intake of 2.22 kg showed a genetic correlation of -0.18 between growth rate and backfat.

2. Genetic correlations across both feeding regimes

Genetic correlations between performance traits differed for each feeding regime. In order to answer the question whether this level of restriction is sufficient to cause a genotype by feeding regime interaction, the genetic correlation between the same trait defined as a different trait in both environments has to be estimated. When these genetic correlations are significantly lower than one a genotype by environment interaction exists. In this study genotype by feeding regime (GxFR) interactions were found for feed intake (rg: 0.85) and feed conversion ratio (rg: 0.71) (Table 4). No GxFR interactions were found for growth rate and backfat measurements.

Table 4: Genetic correlations across feeding regimes between feed intake (FDINT) growth rate (ADG), feed conversion ratio (FCR) and backfat at P2 site (LP2) recorded under ad libitum feeding (ad lib.) and restricted feeding (restr.)

Trait		**FDINT ad lib.**	**ADG ad. lib**	**FCR ad lib.**	**LP2 ad lib.**
FDINT	**(restr.)**	<u>0.85</u> (0.06)	0.72 (0.10)	0.43 (0.12)	0.54 (0.07)
ADG	**(restr.)**	0.54 (0.10)	<u>1.00</u> (*)	-0.59 (0.11)	0.02 (0.10)
FCR	**(restr.)**	-0.12 (0.11)	-0.82 (0.09)	<u>0.71</u> (0.09)	0.59 (0.10)
LP2	**(restr.)**	0.21 (0.07)	-0.15 (0.10)	0.50 (0.09)	<u>0.99</u> (0.02)

- Selection for feed conversion ratio under *ad libitum* feeding results mainly from a reduction in feed intake while growth rate is not increased.
- Restricting feed intake reduces the genetic correlation between growth rate and backfat. This genetic correlation is expected to be lower (more favourable) if it is possible to reduce variation in feed intake under restricted feeding.

- Only feed conversion ratio and feed intake were genetically different traits under both feeding regimes. No genotype by environment interactions were found for growth rate and backfat.

What does this all mean?

It has been shown that restricting feed causes genetic parameters between traits to change. Implications of these changes in genetic parameters on genetic improvement of performance traits are demonstrated by a simple index. Only one animal (mass selection) was included in this index. This animal had records for growth rate and backfat, as is the case in most PIGBLUP herds. These two traits were either recorded under *ad libitum* feeding or under restricted feeding. This index assumes that the breeding objective is based on *ad libitum* feeding since this is the feeding regime used by producers. Two breeding objective were compared. The first index included growth rate, backfat and feed conversion ratio with the main emphasis on backfat and feed conversion ratio. The second breeding objective included backfat and growth rate with a stronger emphasis on growth rate. In general, results from selection index calculations depend on the underlying genetic parameters and the number of traits recorded on different animals. The aim of this simple index is to demonstrate underlying principles. A more comprehensive selection index comparing the two feeding regimes was derived by Hermesch (1999) in the final report of this project.

Responses in individual traits show that a larger response is achieved in growth rate under restricted feeding while *ad libitum* feeding leads to a larger response in backfat (Table 5). The larger response in backfat under *ad libitum* feeding is accompanied by a reduction in feed intake. Restricted feeding does not lead to a reduction in feed intake. The overall breeding objective (BO) is derived by multiplying the response in individual traits with the respective economic weight. For the first breeding objective with a stronger emphasis on backfat and feed conversion ratio *ad libitum* feeding is the preferred selection procedure. Restricted feeding is superior in the second breeding objective which places no emphasis on feed conversion ratio but uses a larger economic weight for growth rate.

Table 5. Genetic response in individual traits and breeding objective (BO) along with accuracy of index for ad libitum and restricted feeding

Trait	Breeding objective I			Breeding objective II		
		Genetic response			Genetic response	
	ec. wt	*Ad libitum*	Restricted	**ec. wt**	*Ad libitum*	Restricted
ADG (g)	**0.05**	1.78	6.83	**0.10**	3.90	7.33
LP2 (mm)	**-1.5**	-1.24	-1.000	**-1.5**	-1.13	-0.970
FCR	**-28**	-0.0606	-0.0608	**0**	-0.0585	-0.0611
FDINT (kg)	**0**	-0.0400	-0.0033	**0**	-0.0281	-0.0004
BO		3.64	3.54		2.09	2.19
accuracy		0.59	0.58		0.62	0.65

Note: the underlying positive definite matrix can be obtained from the author. The index was derived using the program SIP (Wagenaar *et al*., 1995).

- Selection under restricted feeding provides larger response in growth rate.
- Response in backfat is larger under *ad libitum* feeding which is achieved by reducing feed intake.
- *Ad libitum* feeding is the superior selection procedure for breeding objectives that have a high emphasis on backfat and feed conversion ratio.
- Restricted feeding is the superior selection procedure for breeding objectives that aim at minimising reduction in feed intake and maximising lean meat growth.

Implications for PIGBLUP users

Evaluation of genetic improvement in growth rate, backfat and feed conversion ratio is based on *ad libitum* feeding and the set up for these traits will remain the same in PIGBLUP. In order to implement restricted feeding in PIGBLUP, the main performance traits, growth rate and backfat recorded under restricted feeding need to be included as additional traits. PIGBLUP allows analysing seven performance traits simultaneously and the majority of users do not require all seven traits in their evaluation procedures. For these users it is possible to include performance traits recorded under restricted feeding in those trait allocations that are not used. These traits are usually the three carcase traits backfat and muscle depth and lean meat percentage. Any breeder interested in accommodating PIGBLUP for restricted feeding may consult the author for the required changes in trait limits and genetic parameters.

Taking it further – introducing UNE23P

1. Aim of project UNE23P

For a breeding objective including growth rate and backfat, feed intake or feed conversion ratio will always have a negative economic weight. In order to overcome this emphasis on reducing feed intake some breeding companies have not included feed intake but put a stronger emphasis on growth rate. However, nutritionists argue that feed intake in modern genotypes which have been selected for increased leanness is not sufficient to meet their maximum potential for lean meat growth. In these genotypes a higher feed intake increases growth rate until a plateau is reached. (see Figure 1). The underlying growth model which explains this relationship is the linear-plateau model which was described in detail during the last pig genetics workshop (Hermesch, 1998). The aim of this project UNE23P is to estimate heritabilities for parameters of this growth model and to obtain genetic correlations with other performance traits. The project is an attempt to combine nutritional and genetic principles for improvement of lean meat growth.

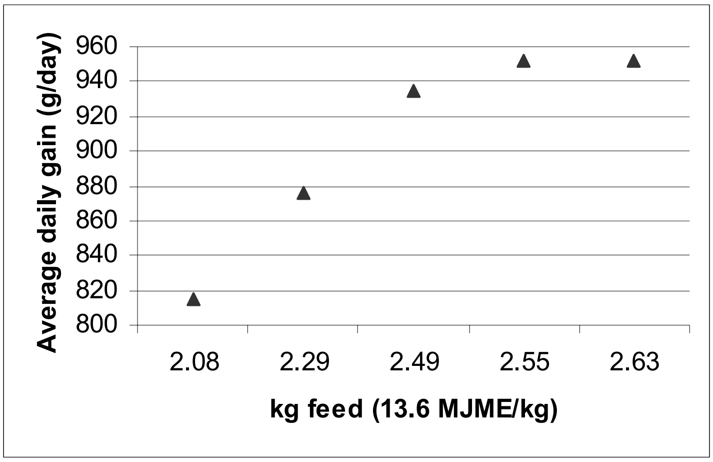

Figure 1: Average daily gain for different levels of feed intake for a BMI population as published by Henman *et al*. (1999).

2. Description of project UNE23P

Until November 2000, 3200 boars from three terminal sire lines will be performance tested in groups of 30 pigs from 80 to 110 kg live weight using electronic feeders. During the first two weeks pigs are given *ad libitum* food to allow them to adapt to the new feeding device (Table 6). Pigs are then allocated to three feeding levels. The level of feed intake during test is shown for these three feeding levels in Table 6. The aim of the design is to test three boars per litter with one boar allocated to each feeding regime. This will provide the best genetic linkage possible between groups. A further aim is to relate feed intake to the weight of the animal. Therefore, animals are weighed four times; after week two, during weeks five and seven, and after week nine. In addition, electronic scales have been installed in February 2000 to obtain weight measurements automatically.

Table 6. Changes in average daily feed intake during test period for different feeding groups included in project

		Group 1	Group 2	Group 3
Week 1	Pre-test	3.000	3.000	3.000
Week 2	Pre-test	3.000	3.000	3.000
Week 3	On-trial	1.900	1.615	2.185
Week 4	On-trial	2.000	1.700	2.300
Week 5	On-trial	2.200	1.870	2.530
Week 6	On-trial	2.400	2.040	2.760
Week 7	On-trial	2.600	2.210	2.990
Week 8	On-trial	2.700	2.295	3.105
WEEK 9	ON-TRIAL	2.800	2.380	3.220
Average daily feed intake (kg)		2.371	2.016	2.727
Percentage of group value		100%	85%	115%
Observed feed intake (790 pigs)		2.16 (0.26*)	1.96 (0.16)	2.34 (0.31)
Percentage of group value		100%	91%	108%

3. What is next?

The genetic analyses planned require a minimum amount of variation in daily feed intake for each group. Individual feed intake data has been obtained from BMI to investigate feed intake patterns and to eliminate errors in recording feed intake. It is hoped that these editing procedures will reduce the current variation in feed intake observed. Furthermore, data recorded by individual scales will be analysed to evaluate the use of automatic scales to record the animal's weight. The aim of this project is to obtain genetic parameters for parameters of the linear plateau model. The underlying principles of this growth model are used in AUSPIG. Therefore, this project may provide a bridge between software packages like AUSPIG and PIGBLUP.

General conclusions

- Electronic feeders provide the opportunity to measure feed intake in commercial environments. However, variation in feed intake was considerable for the restricted group. Analysis of individual feed intake data will attempt to reduce this observed variation in feed intake.
- Ad libitum feeding maximises genetic improvement in backfat and feed conversion ratio by reducing feed intake. Selection for efficient lean meat growth under restricted feeding will not reduce feed intake.
- A new project is under way which aims to combine nutritional and genetic principles for better improvement of lean meat growth.

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