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Effect of feeding corn distiller's dried grains with solubles (DDGS) on the growth and other parameters of swine

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Abstract

We examined the effect of using Distiller's Dried Grains with Solubles (DDGS) as a feed ingredient on the growth performance, carcass quality and other parameters of finishing pigs.

There were a total of 5 groups in the study, a control group of pigs that were fed a DDGS-free feed from a body weight of 30 kg up to shipping, 3 treatment groups fed different levels (10, 15, or 20% of feed) of DDGS from 30 kg to 70 kg live body weight followed by the same feed as controls from 70 kg up to shipping, and 1 group fed with feed containing 10% DDGS throughout, from 30 kg to shipping.

Fifty LWD pigs (25 females and 25 castrated males) of about 3 months of age were used, and 10 animals were assigned to each group, and the males and females were reared separately in groups.

Weight gain, feed intake and feed conversion ratio were measured during the study period, and the health status of the animals was monitored routinely. Each animal was slaughtered when its live weight reached 110 kg and the carcass weight, dressing percent, backfat thickness, meat color and fat color were noted, and the carcass meat graded.

The results showed no significant difference between the DDGS-fed groups and the control group in growth performance and carcass performance at shipping.

1. Objective

To investigate the effect of mixing DDGS in the feed of finishing pigs on their growth, meat quality and other parameters.

2. Materials and methods

1) Test substance

DDGS manufactured in the USA and supplied by the US Grains Council was used for the study.

2) Test animals

Fifty LWD pigs (25 females and 25 castrated males, aged 72-82 days, and weighing 27.6-37.7 kg) that were reared in a pig farm in Ibaraki Prefecture were procured. Before the experiment, they were subjected to preliminary rearing for 7 days to check their health status and acclimate them to the experimental environment.

3) Treatment groups

A total of 5 groups were used in the study, a control group of pigs that were fed a DDGS-free feed from a body weight of 30 kg up to shipping, 3 treatment groups (10-0%, 15-0%, and 20-0% group) fed different levels (10, 15, or 20% of feed) of DDGS from 30 kg to 70 kg body weight and the same feed as controls from 70 kg up to shipping, and 1 group (10-10% group) fed with feed containing 10% of DDGS throughout, from body weight 30 kg up to shipping.

Animals of each sex were divided into 5 groups with approximately the same live body weight distribution and each of the female group and the castrated male group were assigned to each treatment group. They were then reared until they weighed 110 kg.

Table 1 lists the feeds given to pigs for each of 3 body weight stages (30-50 kg, 50-70 kg and more than 70 kg). The nutritional value was the same for the control feed and the feeds containing different amounts of DDGS. The feeds were designed to meet the nutritional requirements specified in Japanese Feeding Standard for Swine (2005)¹⁾. We used the data provided by the US Grains Council for the normal components, amino acid composition, and non-phytin phosphorus content of the DDGS for designing the feeds.

4) Rearing management

The pigs were reared in groups in concrete-floored pigpens (2.7 x 3.6 m) with the floors covered with sawdust. The animals were not vaccinated.

The feeds for the different body weight stages were changed on the first day of the 4th and 7th week.

5) Endpoints

(1) Growth performance

The body weight of each animal was measured at weekly intervals from the start of the study. The feed intake between every two consecutive days of weighing was also measured for each group, and the daily weight gain, daily feed intake, feed conversion ratio and days required to reach shipping weight were calculated. In determining the days required to reach shipping weight, the number of days required beyond the 7th week was calculated by extrapolation from the estimated daily weight gain, as the weight measurements were made at weekly intervals.

(2) Health status

The health status of individual animals was checked daily, in the morning and evening.

(3) Carcass performance

The animals were slaughtered individually when each animal's body weight became 110 kg. The carcass weight, dressing percent, backfat thickness (on mid-back, over the shoulder, on loin, and mean) were measured, the L*, a*, b* values of the meat and fat were determined with a chroma meter (CR-400, KONICA MINOLTA), and the carcass meat was graded.

6) Statistical analysis

The growth performance was analyzed by two-way analysis of variance⁵⁾ with the feed given and sex as the factors. One-way analysis of variance was carried out for each sex on the carcass performance, taking the type of feed as the factor. As for grading of carcasses, scores were assigned (High: 5, Medium: 3, and Fair: 1) and analysis of variance was carried out.

7) Study period

The study was conducted during May 18 to September 15, 2006.

8) Study location

Feed Research Center, Japan Scientific Feeds Association, 821 Yoshikura, Narita, Chiba Prefecture.

Table 1 Mixing proportions of feeds studied (%)

Ingredients	For the 30-50 kg stage				For the 50-70 kg stage				For the 70 kg to shipping weight stage	
	Control	DDGS10%	DDGS15%	DDGS20%	Control	DDGS10%	DDGS15%	DDGS20%	Control	DDGS10%
DDGS	—	10.000	15.000	20.000	—	10.000	15.000	20.000	—	10.000
Corn	54.280	49.400	46.958	44.520	57.570	52.645	50.181	47.720	51.690	47.690
Milo	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000
Soybean cake	17.200	11.975	9.363	6.750	14.700	9.500	6.900	4.300	11.000	5.000
Wheat bran	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	15.000	15.000
Fish meal (CP 65%)	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	—	—
Calcium carbonate	0.860	1.005	1.078	1.150	0.880	1.030	1.105	1.180	0.950	1.150
Dicalcium phosphate	0.640	0.450	0.355	0.260	0.410	0.205	0.103	—	0.450	0.150
Animal fat	1.000	1.050	1.075	1.100	0.500	0.600	0.650	0.700	—	—
Common salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
B vitamins ¹⁾	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Vitamins A, D & E ²⁾	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Trace minerals ³⁾	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
DL-Methionine	0.010	0.005	0.003	—	—	—	—	—	—	—
L-Lysine hydrochloride	0.100	0.180	0.220	0.260	0.040	0.115	0.153	0.190	0.01	0.110
L-Tryptophan	—	0.015	0.023	0.030	—	0.005	0.008	0.010	—	—
L-Threonine	0.010	0.020	0.025	0.030	—	—	—	—	—	—
Composition										
CP (%)	16.0 (103) ⁴⁾	16.0 (103)	16.0 (103)	16.0 (103)	15.0 (103)	15.0 (103)	15.0 (103)	15.0 (103)	13.3 (102)	13.1 (101)
TDN (%)	77.8 (104)	78.0 (104)	78.1 (104)	78.2 (104)	78.6 (105)	78.8 (105)	78.9 (105)	79.0 (105)	77.0 (103)	77.3 (103)
Calcium (%)	0.66 (110)	0.66 (110)	0.66 (110)	0.66 (110)	0.61 (111)	0.61 (111)	0.61 (111)	0.61 (111)	0.53 (106)	0.53 (106)
Non-phytin phosphorus (%)	0.30 (111)	0.32 (119)	0.33 (122)	0.33 (122)	0.26 (113)	0.27 (117)	0.28 (122)	0.28 (122)	0.21 (105)	0.21 (105)
Arginine (%)	0.97 (346)	0.88 (314)	0.84 (300)	0.79 (282)	0.90 (375)	0.81 (338)	0.77 (321)	0.72 (300)	0.80 (444)	0.68 (378)
Histidine (%)	0.41 (152)	0.41 (152)	0.41 (152)	0.40 (148)	0.36 (140)	0.39 (170)	0.38 (165)	0.38 (165)	0.35 (194)	0.34 (189)
Isoleucine (%)	0.65 (127)	0.63 (124)	0.61 (120)	0.60 (118)	0.60 (140)	0.58 (135)	0.57 (133)	0.56 (130)	0.51 (150)	0.47 (138)
Leucine (%)	1.46 (172)	1.55 (182)	1.60 (188)	1.64 (193)	1.40 (194)	1.49 (207)	1.54 (214)	1.58 (219)	1.23 (220)	1.30 (232)
Effective lysine (%)	0.79 (110)	0.79 (110)	0.79 (110)	0.79 (110)	0.67 (110)	0.67 (110)	0.67 (110)	0.67 (110)	0.50 (105)	0.50 (105)
Effective methionine + cystine (%)	0.49 (111)	0.45 (102)	0.43 (98)	0.41 (93)	0.46 (124)	0.42 (114)	0.41 (111)	0.39 (105)	0.40 (138)	0.36 (124)
Phenylalanine + tyrosine (%)	1.30 (160)	1.19 (147)	1.14 (141)	1.08 (133)	1.22 (120)	1.11 (163)	1.06 (156)	1.01 (149)	1.06 (200)	0.92 (174)
Effective threonine (%)	0.52 (111)	0.52 (111)	0.52 (111)	0.52 (111)	0.48 (120)	0.47 (118)	0.47 (118)	0.46 (115)	0.40 (129)	0.38 (123)
Tryptophan (%)	0.19 (119)	0.19 (119)	0.19 (119)	0.19 (119)	0.17 (121)	0.17 (121)	0.16 (114)	0.16 (114)	0.16 (145)	0.14 (127)
Valine (%)	0.76 (131)	0.76 (131)	0.76 (131)	0.77 (133)	0.72 (147)	0.72 (147)	0.72 (147)	0.72 (147)	0.63 (166)	0.62 (163)

Notes ¹⁾ Thiamine nitrate 1.0, riboflavin 7.0, pyridoxine hydrochloride 0.5, nicotinic acid amide 6.0, D-pantothenic acid calcium 10.9, and choline chloride 57.6, all in g/kg ²⁾ Vitamin A 10,000, vitamin D₃ 2,000, both in IU/g; dl- α -tocopherol acetate 10 mg/g. ³⁾ Mn 50, Fe 50, Cu 10, Zn 60, and I 1, all in g/kg ⁴⁾ Number in parenthesis are the percentages of the daily requirement prescribed in the Japanese Feeding Standard for Swine (2005).

3. Results

1) Growth performance

The growth curves of the different groups are shown in Figs. 1 and 2. Growth during the 7th week from the start of the study onwards generally tended to be a slightly slower because of the summer heat, but there were no marked differences among the groups.

The daily weight gain, estimated days required to reach 110 kg body weight, feed intake, and feed conversion ratio are shown in Table 2. There were no significant differences among the groups. These parameters also showed no clear relationships with the mixing proportions of DDGS or the duration of feeding the mixed feed.

A total of 5 pigs, 2 castrated males and 3 females, were culled during the study period. Their details are given in Table 3. These animals were excluded from the start of the study in the analysis of daily weight gain and other parameters.

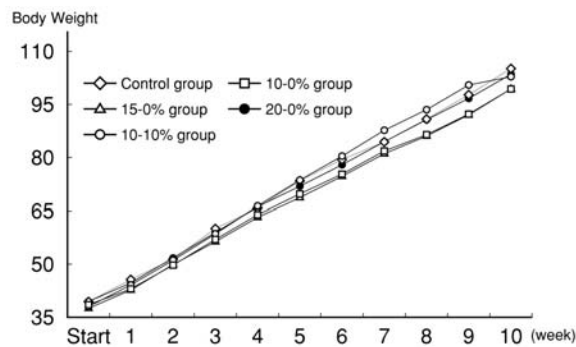


Fig 1 Growth curves (castrated males)

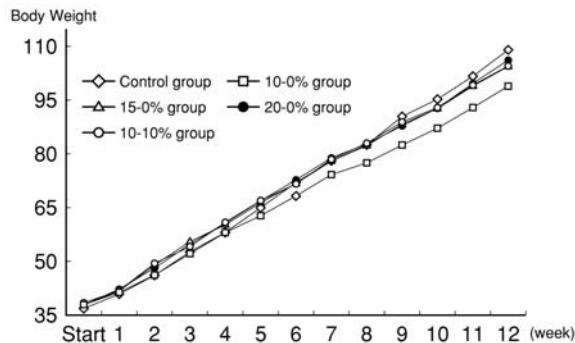


Fig. 2 Growth curves (females)

Table 2 Growth performance

	Sex	Control group	10-0% group	15-0% group	20-0% group	10-10% group	Mean
Daily weight gain (kg)							
Start-3 weeks	Castrated male	0.98	0.82	0.87	0.92	0.95	0.91
	Female	0.78	0.70	0.82	0.77	0.78	0.77
4-6 weeks	Castrated male	0.91	0.86	0.87	0.91	1.03	0.92
	Female	0.92	0.74	0.81	0.85	0.81	0.83
7 weeks-shipping	Castrated male	0.90	0.91	0.96	0.92	0.87	0.91
	Female	0.83	0.73	0.78	0.80	0.79	0.79
Start-shipping	Castrated male	0.92	0.87	0.92	0.92	0.93	0.91
	Female	0.84	0.72	0.79	0.80	0.79	0.79
Estimated days needed to reach shipping weight							
	Castrated male	78	81	79	77	77	78
	Female	88	101	91	91	91	92
Daily feed intake (kg)							
Start-3 weeks	Castrated male	2.39	2.12	2.09	2.26	2.20	2.21
	Female	1.88	1.69	1.95	1.90	1.89	1.86
4-6 weeks	Castrated male	2.71	2.70	2.71	2.87	3.13	2.82
	Female	2.46	2.21	2.34	2.45	2.34	2.36
7 weeks-shipping	Castrated male	3.03	3.04	3.16	3.13	2.98	3.07
	Female	2.78	2.49	2.55	2.75	2.60	2.63
Start-shipping	Castrated male	2.81	2.75	2.81	2.85	2.83	2.81
	Female	2.52	2.29	2.38	2.52	2.42	2.43
Feed conversion ratio							
Start-3 weeks	Castrated male	2.44	2.59	2.40	2.46	2.32	2.44
	Female	2.41	2.41	2.38	2.47	2.42	2.42
4-6 weeks	Castrated male	2.98	3.14	3.11	3.15	3.04	3.08
	Female	2.67	2.99	2.89	2.88	2.89	2.86
7 weeks-shipping	Castrated male	3.37	3.34	3.29	3.40	3.43	3.37
	Female	3.35	3.41	3.27	3.44	3.29	3.35
Start-shipping	Castrated male	3.05	3.16	3.05	3.10	3.04	3.08
	Female	3.00	3.18	3.01	3.15	3.06	3.08

Table 3 Details of culled pigs

Group	Sex (ID No.)	Particulars
Control group	Castrated male (No.60)	Developed arthritis of the left hock 4 weeks into the study, and culled at completion of 4 th week.
	Female (No.100)	Seen coughing 3 weeks into the study. Culled at completion of 8 th week because of stagnation in growth.
15-0 % group	Female (No.82)	Showed growth stagnation from 2 nd week of the study. Culled at completion of 7 th week.
20-0 % group	Female (No.104)	Showed growth stagnation from 5 th week of the study. Culled at completion of 7 th week.
10-10 % group	Castrated male (No.76)	Showed growth stagnation from 4 th week of the study. Culled at completion of 7 th week (pleural pneumonia).

2) Carcass performance

Table 4 shows carcass performance data. Among both the castrated males and the females, there was no significant difference between the groups in the carcass weight, dressing percent, backfat thickness, and carcass quality score. There were also no definite trends in relation to the percentage of DDGS mixed in the feed or the duration of feeding it.

Among castrated males, the b* value of meat color in the 20-0% group was significantly higher than in the 10-0% group. In fat color, the a* value was significantly higher in the 10-0% group than in the control group. However, there were no definite trends in relation to the percentage of DDGS mixed in the feed and the period of feeding it.

Table 4 Carcass performance

		Control group	10-0 % group	15-0 % group	20-0 % group	10-10 % group	
Carcass weight (kg)	Castrated male	73.9±3.9	73.3±1.8	71.8±3.6	71.9±2.7	74.3±1.7	
	Female	70.5±2.1	72.7±1.8	71.3±2.4	72.5±2.5	71.6±2.2	
Dressing percent (%)	Castrated male	69.2±3.0	68.9±0.6	67.5±1.8	68.4±2.9	69.3±0.9	
	Female	66.6±1.6	68.3±0.6	66.4±2.5	67.7±1.8	67.1±1.0	
Backfat thickness (cm)	Castrated male	4.25±0.39	4.65±0.30	4.20±0.53	4.33±0.97	4.27±0.42	
	mid-back Female	3.72±0.17	3.81±0.66	3.71±0.60	3.92±0.05	3.83±0.15	
Shoulder	Castrated male	2.07±0.28	2.47±0.47	2.32±0.28	2.23±0.38	2.27±0.15	
	Female	2.14±0.32	1.64±0.35	1.84±0.52	1.94±0.50	1.87±0.38	
Loin	Castrated male	3.03±0.26	3.23±0.45	3.23±0.60	3.33±0.24	3.52±0.22	
	Female	3.27±0.45	2.71±0.37	3.20±0.25	3.20±0.30	3.21±0.46	
Mean	Castrated male	3.12±0.23	3.45±0.26	3.25±0.43	3.30±0.51	3.35±0.22	
	Female	3.04±0.24	2.72±0.40	2.92±0.36	3.02±0.23	2.97±0.31	
Meat	L*	Castrated male	53.34±2.90	53.85±4.65	53.26±3.02	60.12±7.59	54.69±3.65
	Female	54.16±4.72	51.17±8.16	51.69±3.32	49.06±2.20	55.11±6.64	
a*	Castrated male	5.97±0.86	5.08±1.10	5.67±1.58	7.36±2.06	4.60±1.98	
	Female	5.28±0.78	6.01±1.53	6.81±1.80	5.50±0.84	6.52±1.11	
b*	Castrated male	5.61 ^{ab} ±0.66	5.12 ^a ±1.03	5.52 ^{ab} ±0.62	7.63 ^b ±1.27	5.82 ^{ab} ±1.47	
	Female	5.14±1.33	5.73±2.49	5.67±1.84	4.74±0.77	6.18±1.71	
Fat	L*	Castrated male	73.90±7.45	76.99±3.63	76.75±3.13	76.69±4.41	74.43±4.64
	Female	74.06±2.94	73.27±4.41	72.24±4.45	73.25±4.87	76.56±4.14	
a*	Castrated male	3.35±1.72	3.03±0.54	2.18±0.61	2.98±0.70	3.36±0.78	
	Female	2.82 ^{ab} ±1.18	4.12 ^a ±0.57	2.47 ^b ±0.42	2.55 ^b ±0.33	3.05 ^{ab} ±0.76	
b*	Castrated male	6.52±1.29	6.07±1.02	6.04±1.20	6.80±0.94	6.83±1.01	
	Female	5.62 ^b ±0.93	7.89 ^a ±0.84	6.63 ^{ab} ±0.84	6.02 ^{ab} ±0.93	7.59 ^{ab} ±1.27	
Carcass score	Castrated male	4.5±1.0	3.0±2.0	4.6±0.9	3.4±1.7	5.0±0.0	
	Female	4.5±1.0	3.4±1.7	2.5±1.0	4.0±1.2	4.2±1.1	

Notes: Carcass score: Calculated after assigning scores of 5, 3, or 1 for high, medium and fair quality.

Means marked with different letters a and b were significantly different (p<0.05).

4. Discussion

DDGS is a byproduct of ethanol fermentation. Production of ethanol from corn is expanding in the US. Therefore, the production of DDGS is expected to increase.

In the present study, we investigated the effects of feeding DDGS on the growth performance and carcass performance of finishing pigs, by mixing 10-20% of DDGS with the feed of pigs weighing 30-70 kg, and feeding mixed feed containing 10% DDGS to pigs from 30 kg bodyweight up to shipping.

In both the feeding modes, i.e., 10-20% DDGS during the 30-70 kg stage and 10% DDGS during the 30 kg-shipping stage, there was no effect of DDGS on the growth and feed intake of the pigs. This was a natural result because the control and DDGS mixed feeds were designed to be identical in nutritional value in this study.

On the other hand, DDGS contains high amounts of xanthophyll originating from its raw material, the corn. There was some concern that this xanthophyll would affect the fat color when DDGS is fed at the late stage of finishing. However, the color of the meat and fat were not affected even when feed containing 10% DDGS was fed throughout, up to shipping.

We may conclude from the above results that the use of DDGS in swine feeds up to the time of shipping would not adversely affect productivity or meat quality.

In the present study, the test feeds were designed by partially replacing corn and soybean cake with DDGS, under the assumption that 34% and 53%⁶⁾ of the phosphorus in corn and soybean cake and 90% of the phosphorus in DDGS³⁾ were non-phytin phosphorus. Because of this, when 20% DDGS mixed feed was given during the 30-50 kg stage, the content of dicalcium phosphate mixed was reduced to 0.26% against 0.64% in the control. Similarly, in the feed for the 50-70 kg stage, it was reduced to 0% in the DDGS mixed feed against 0.410% in the control. For the 10% DDGS feed for the 70 kg onwards stage, it was only 0.15% against 0.45% in the control. In spite of this, there was no effect on the growth of the test animals, as discussed above. The results suggest that the phosphorus contained in the DDGS was effectively utilized by the

animals and feeding DDGS was an effective way of reducing the environmental impact of DDGS.

5. References

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Appended table 1-1 Change in body weight of castrated males (kg)

Groups	ID No.	Start	1 st week	2 nd week	3 rd week	4 th week	5 th week	6 th week	7 th week	8 th week	9 th week	10 th week	11 th week	12 th week	13 th week
Control	77	36.2	41.5	46.9	55.7	61.5	67.7	73.9	78.3	86.3	93.4	101.0	108.1	113.2	110.4
	61	39.9	46.1	50.5	58.4	64.0	70.4	74.9	78.8	85.3	91.2	96.9	103.5	109.0	
	63	37.5	43.6	49.6	56.3	64.5	71.3	77.2	84.4	91.6	98.9	106.1	113.7		
	60	36.1	40.3	46.1	50.3	42.5	Culled								
	58	43.8	51.5	59.0	69.1	75.7	83.0	89.5	95.7	100.8	106.5	114.7			
	Mean	39.4	45.7	51.5	59.9	66.4	73.1	78.9	84.3	91.0	97.5	104.7	108.4	111.1	
10-0%	62	33.9	40.5	47.0	54.4	60.9	66.6	73.7	80.9	83.1	91.9	98.7	105.6	110.4	110.9
	66	37.9	41.6	47.1	53.1	58.9	64.6	71.2	76.9	82.9	90.2	96.4	103.4	110.0	
	64	43.8	47.5	54.0	60.5	66.6	75.3	80.3	87.4	93.4	97.1	107.8	117.2		
	83	40.6	45.5	50.2	57.3	62.9	68.8	75.0	80.3	89.0	91.4	100.5	107.1	114.3	
	79	41.9	46.7	52.3	58.2	63.4	68.6	73.9	80.1	82.0	88.6	94.2	101.5	108.8	
	Mean	39.6	44.4	50.1	56.7	62.5	68.8	74.8	81.1	86.1	91.8	99.5	107.0	110.9	
15-0%	59	36.6	41.8	47.5	54.5	62.5	68.7	76.6	81.0	87.8	95.7	103.5	111.3	110.0	
	56	36.8	38.9	45.2	52.2	57.4	65.2	68.9	75.1	77.7	83.6	91.8	97.7		103.8
	78	38.5	46.8	54.4	60.2	69.7	68.7	72.0	75.9	79.4	85.2	95.2	102.3		110.0
	75	39.0	43.9	50.1	56.6	63.6	71.0	77.0	84.9	90.2	96.2	104.5	113.7		
	67	41.1	44.1	51.7	60.5	66.1	74.5	81.2	89.9	94.7	100.5	108.7	117.4		
	Mean	38.4	43.1	49.8	56.8	63.9	69.6	75.1	81.4	86.0	92.2	100.7	108.5		106.9
20-0%	74	39.7	46.4	52.6	59.4	65.4	71.6	77.6	84.2	91.2	97.4	104.1	110.2	110.7	
	69	35.6	41.6	49.1	55.9	64.1	70.1	78.5	84.2	89.2	97.6	105.1	114.0		
	71	38.5	43.9	49.6	56.4	62.6	69.5	75.0	82.8	88.4	94.4	101.5	105.5		111.4
	68	39.7	41.7	49.0	55.9	61.8	66.7	72.0	77.8	83.8	88.7	95.1	101.9		110.0
	70	44.8	51.2	58.7	67.6	75.2	81.1	87.1	93.7	100.4	105.4	111.4			
	Mean	39.7	45.0	51.8	59.0	65.8	71.8	78.0	84.5	90.6	96.7	103.4	107.9		110.7
10-10%	76	36.7	41.6	47.3	54.5	56.7	60.7	66.4	66.4	Culled				114.3	
	57	34.3	39.8	45.4	52.4	59.6	67.7	74.8	82.2	88.1	94.3	93.8	100.5		107.1
	55	43.4	48.8	57.5	65.7	72.7	79.3	85.2	91.6	96.8	103.0	106.6	111.2		
	72	34.6	40.6	46.4	54.0	60.8	69.2	76.8	84.7	89.8	98.3	101.8	110.7		
	65	41.8	47.5	55.2	62.2	70.7	78.2	83.4	93.1	99.9	106.0	110.2			
	Mean	38.5	44.2	51.1	58.6	66.0	73.6	80.1	87.9	93.7	100.4	107.5	107.1		114.3

Appended table 1-2 Change in body weight of females (kg)

Groups	ID No.	Start	1 st week	2 nd week	3 rd week	4 th week	5 th week	6 th week	7 th week	8 th week	9 th week	10 th week	11 th week	12 th week	13 th week	14 th week	15 th week	16 th week
Control	95	35.0	39.0	43.7	50.0	56.0	63.4	73.2	75.5	81.8	87.3	93.2	99.5	106.1	106.4	110.0		
	102	38.6	43.2	47.7	54.3	59.4	64.0	72.9	77.9	78.8	89.5	91.0	97.6	105.9	110.1			
	88	34.5	39.6	46.7	55.0	60.0	66.8	73.4	79.7	84.8	92.6	97.6	103.7	110.9				
	94	38.7	42.2	47.2	52.6	57.7	65.6	69.9	79.2	84.6	91.1	98.4	104.6	112.6				
	100	38.4	45.1	50.5	57.9	58.9	66.4	73.4	76.1	69.3	Culled							
	Mean	36.7	41.0	46.3	53.0	58.3	65.0	72.4	78.1	82.5	90.1	95.1	101.4	108.9	108.3	110.0		
10-0%	96	34.5	39.2	44.7	51.2	56.4	62.2	66.9	72.6	77.6	80.7	86.3	92.6	100.0	101.3	108.4	115.6	
	97	37.5	41.1	45.8	51.9	58.5	62.1	66.8	74.4	75.2	79.4	84.6	89.9	95.3	100.1	102.6	108.9	110.2
	87	40.0	43.1	48.2	54.3	58.7	62.9	67.8	72.0	74.8	80.1	83.5	89.1	92.8	96.4	101.7	106.2	110.5
	99	40.9	44.8	49.2	54.9	59.2	65.2	71.4	78.8	82.2	88.3	93.7	97.5	105.3	110.0			
	91	37.2	40.2	44.6	50.9	56.3	61.7	67.8	73.0	76.4	82.5	87.5	94.7	101.6	104.8	114.6		
	Mean	38.0	41.7	46.5	52.6	57.8	62.8	68.1	74.2	77.2	82.2	87.1	92.8	99.0	102.5	106.8	110.2	110.4
15-0%	82	37.5	42.2	45.4	49.1	53.0	57.3	59.7	63.6	Culled								
	93	34.4	39.0	45.6	52.3	57.6	64.6	70.4	76.0	82.5	86.5	92.4	101.2	105.3	114.8			
	107	36.2	40.2	44.4	50.6	56.3	63.1	68.9	75.7	78.8	85.0	90.9	95.8	102.8	106.4	111.7		
	101	42.1	47.8	53.9	58.8	64.1	70.3	74.9	80.0	83.4	88.9	91.9	97.2	101.6	108.5	110.3		
	84	41.1	44.4	51.7	60.6	64.2	70.4	75.7	80.6	86.6	89.8	96.4	103.0	108.2	114.9			
	Mean	38.5	42.9	48.9	55.6	60.6	67.1	72.5	78.1	82.8	87.6	92.9	99.3	104.5	111.2	111.0		
20-0%	103	34.6	40.1	46.8	53.2	59.5	66.1	72.0	78.1	83.1	85.6	92.8	99.0	106.6	110.6			
	86	34.7	38.2	41.9	49.3	55.8	60.9	66.6	72.1	73.3	77.7	84.7	89.9	94.9	101.7	103.2	110.1	
	89	40.3	43.4	50.6	56.8	63.9	70.4	75.2	82.2	87.5	94.3	97.9	105.1	111.3				
	104	35.2	39.8	44.7	49.4	53.9	58.4	62.0	65.9	Culled								
	70	42.3	47.4	52.6	56.5	62.1	68.0	73.4	79.7	84.8	88.8	94.2	101.2	108.1	115.5			
	Mean	38.0	42.3	48.0	54.0	60.3	66.4	71.8	78.0	82.2	86.6	92.4	98.8	105.2	109.3	103.2	110.1	
10-10%	106	36.5	37.7	46.0	53.1	59.4	66.4	72.5	79.8	83.9	90.4	94.7	102.8	107.8	113.6			
	108	35.6	40.2	45.3	51.0	55.9	62.3	66.4	71.2	75.2	80.5	84.3	90.4	94.0	101.0	104.2	108.9	113.8
	92	34.5	39.6	47.9	54.3	60.9	67.1	72.7	79.8	83.6	89.2	95.5	99.8	107.7	111.2			
	80	37.6	43.0	49.6	55.3	59.4	66.2	71.2	78.8	84.8	92.2	96.5	102.9	110.0				
	105	46.4	49.6	53.7	58.7	64.9	70.1	74.5	81.8	86.4	88.0	94.5	99.1	103.6	110.5			
	Mean	38.1	42.0	48.5	54.5	60.1	66.4	71.5	78.3	82.8	88.1	93.1	99.0	104.6	109.1	104.2	108.9	113.8

Appended table 2 Daily weight gain and days required to reach the body weight of 110 kg

Groups	Castrated males						Females					
	ID No.	Daily weight gain (kg)				Days needed to reach 110 kg	ID No.	Daily weight gain (kg)				Days needed to reach 110 kg
		Start-3 rd week	4 th -6 th week	7 th week-shipping	Start-shipping			Start-3 rd week	4 th -6 th week	7 th week-shipping	Start-shipping	
Control	77	0.93	0.87	0.94	0.92	80	95	0.71	1.10	0.66	0.77	98
	61	0.88	0.79	0.72	0.77	91	102	0.75	0.89	0.76	0.79	91
	63	0.90	1.00	1.04	0.99	74	88	0.98	0.88	0.89	0.91	83
	60	—	—	—	—	—	94	0.66	0.82	1.02	0.88	81
	58	1.20	0.97	0.90	1.01	65	100	—	—	—	—	—
	Mean	0.98	0.91	0.90	0.92	78	Mean	0.78	0.92	0.83	0.84	88
10-0%	62	0.98	0.92	0.87	0.91	84	96	0.80	0.75	0.77	0.77	98
	66	0.72	0.86	0.92	0.86	84	97	0.69	0.71	0.62	0.65	112
	64	0.80	0.94	1.05	0.95	70	87	0.68	0.64	0.61	0.63	111
	83	0.80	0.84	0.94	0.88	79	99	0.67	0.79	0.79	0.76	91
	79	0.78	0.75	0.76	0.76	90	91	0.65	0.80	0.84	0.79	92
	Mean	0.82	0.86	0.91	0.87	81	Mean	0.70	0.74	0.73	0.72	101
15-0%	59	0.85	1.05	0.99	0.97	76	82	—	—	—	—	—
	56	0.73	0.80	0.84	0.80	91	93	0.85	0.86	0.91	0.88	86
	78	1.03	0.56	0.90	0.85	84	107	0.69	0.87	0.76	0.77	96
	75	0.84	0.97	1.05	0.97	73	101	0.80	0.77	0.63	0.70	98
	67	0.92	0.99	1.03	0.99	70	84	0.93	0.72	0.80	0.81	85
	Mean	0.87	0.87	0.96	0.92	79	Mean	0.82	0.81	0.78	0.79	91
20-0%	74	0.94	0.87	0.93	0.92	77	103	0.89	0.90	0.79	0.84	90
	69	0.97	1.08	1.01	1.02	73	86	0.70	0.82	0.69	0.72	105
	71	0.85	0.89	0.87	0.87	82	89	0.79	0.88	0.86	0.85	82
	68	0.77	0.77	0.90	0.84	84	104	—	—	—	—	—
	70	1.09	0.93	0.87	0.95	68	90	0.68	0.80	0.86	0.80	85
	Mean	0.92	0.91	0.92	0.92	77	Mean	0.77	0.85	0.80	0.80	91
10-10%	76	—	—	—	—	—	106	0.79	0.92	0.84	0.85	87
	57	0.86	1.07	0.81	0.88	85	108	0.73	0.73	0.68	0.70	106
	55	1.06	0.93	0.74	0.88	76	92	0.94	0.88	0.79	0.84	89
	72	0.92	1.09	0.97	0.99	76	80	0.84	0.76	0.92	0.86	84
	65	0.97	1.01	0.96	0.98	70	105	0.59	0.75	0.73	0.70	91
	Mean	0.95	1.03	0.87	0.93	77	Mean	0.78	0.81	0.79	0.79	91

Appended table 3 Daily feed intake (kg/day)

Sex	Groups	1 st week	2 nd week	3 rd week	4 th week	5 th week	6 th week	7 th week	8 th week	9 th week	10 th week	11 th week	12 th week	13 th week	14 th week	15 th week	16 th week	Start-3 rd week	4 th -6 th week	7 th week-shipping	Start-shipping
Castrated male	Conrol	2.11	2.26	2.79	2.81	2.71	2.61	2.61	3.03	3.49	3.20	3.64	3.17	2.10				2.39	2.71	3.03	2.81
	10-0%	1.91	2.03	2.43	2.43	2.81	2.84	2.93	3.06	2.77	3.47	3.64	3.49	1.90				2.12	2.70	3.04	2.75
	15-0%	1.71	1.94	2.61	2.74	2.79	2.61	2.71	3.27	2.77	3.27	3.71	3.47	2.91				2.09	2.71	3.16	2.81
	20-0%	1.93	2.26	2.59	2.86	2.84	2.91	3.11	3.04	3.14	3.31	3.19	2.99					2.26	2.87	3.13	2.85
	10-10%	1.81	2.21	2.59	3.00	3.20	3.20	3.29	3.29	2.77	2.61	2.84	2.79	3.24				2.20	3.13	2.98	2.83
Female	Conrol	1.57	1.87	2.19	2.27	2.41	2.70	2.66	2.54	2.91	2.97	3.06	3.19	2.76	2.11			1.88	2.46	2.78	2.52
	10-0%	1.43	1.56	2.07	2.17	2.20	2.27	2.54	1.99	2.24	2.50	2.60	2.70	2.59	2.97	2.70	2.06	1.69	2.21	2.49	2.29
	15-0%	1.66	1.97	2.23	2.19	2.27	2.57	2.56	2.53	2.17	2.54	2.70	2.79	2.71	2.40			1.95	2.34	2.55	2.38
	20-0%	1.66	1.89	2.16	2.24	2.50	2.60	2.67	2.53	2.34	2.59	2.89	2.99	3.16	2.39	3.19		1.90	2.45	2.75	2.52
	10-10%	1.49	2.01	2.17	2.17	2.39	2.47	2.64	2.50	2.53	2.54	2.67	2.84	2.53	2.36	2.39	3.01	1.89	2.34	2.60	2.42

Appended table 4 Feed conversion ratio

Sex	Groups	Start-3 rd week	4 th -6 th week	7 th week-shipping	Start-shipping
Castrated male	Conrol	2.44	2.98	3.37	3.05
	10-0%	2.59	3.14	3.34	3.16
	15-0%	2.40	3.11	3.29	3.05
	20-0%	2.46	3.15	3.40	3.10
	10-10%	2.32	3.04	3.43	3.04
Female	Conrol	2.41	2.67	3.35	3.00
	10-0%	2.41	2.99	3.41	3.18
	15-0%	2.38	2.89	3.27	3.01
	20-0%	2.47	2.88	3.44	3.15
	10-10%	2.42	2.89	3.29	3.06

Appended table 5-1 Carcass performance of castrated males

Groups	ID No.	Carcass weight (kg)	Dressing percent (%)	Backfat thickness (cm)				Meat color ¹⁾			Fat color ¹⁾			Carcass score ²⁾
				Shoulder	Mid-Back	Loin	Mean	L*	a*	b*	L*	a*	b*	
Control	77	70.5	66.4	4.02	2.44	2.89	3.12	52.99	6.53	6.09	72.25	5.59	7.76	5
	61	72.5	68.7	3.83	1.79	2.75	2.79	57.03	6.80	6.27	79.07	2.24	5.26	3
	63	73.0	68.1	4.59	2.12	3.12	3.28	53.37	5.65	4.95	64.06	3.80	7.49	5
	58	79.5	73.5	4.57	1.91	3.35	3.28	49.96	4.91	5.14	80.23	1.78	5.57	5
	Mean	73.9	69.2	4.25	2.07	3.03	3.12	53.34	5.97	5.61	73.90	3.35	6.52	4.5
10-0%	62	72.5	68.7	4.38	2.03	3.24	3.22	55.62	5.25	5.07	70.64	3.62	6.89	5
	66	71.0	68.1	4.63	2.18	2.83	3.21	58.95	6.47	6.37	77.89	2.78	6.77	3
	64	75.5	69.7	4.35	3.20	3.94	3.83	51.54	3.92	4.59	79.11	2.39	5.23	1
	83	74.5	68.6	5.08	2.31	2.85	3.41	47.01	4.01	3.73	77.80	3.55	6.74	5
	79	73.0	69.3	4.79	2.64	3.27	3.57	56.14	5.73	5.83	79.50	2.79	4.70	1
Mean	73.3	68.9	4.65	2.47	3.23	3.45	53.85	5.08	5.12	76.99	3.03	6.07	3.0	
15-0%	59	71.5	68.4	4.88	2.79	4.04	3.90	56.32	5.55	6.42	72.02	2.71	4.69	3
	56	71.0	68.0	3.55	2.17	3.27	3.00	54.11	8.23	5.50	79.85	1.18	5.17	5
	78	67.0	64.4	3.84	2.08	2.36	2.76	51.85	4.65	5.71	79.33	2.32	7.12	5
	75	72.5	67.4	4.21	2.26	3.15	3.21	48.75	5.79	4.75	76.01	2.61	7.43	5
	67	77.0	69.2	4.50	2.28	3.35	3.38	55.27	4.12	5.23	76.55	2.06	5.80	5
Mean	71.8	67.5	4.20	2.32	3.23	3.25	53.26	5.67	5.52	76.75	2.18	6.04	4.6	
20-0%	74	72.5	70.1	5.83	2.80	3.75	4.13	48.01	10.56	6.36	76.99	2.49	5.74	3
	69	73.0	67.9	4.78	2.20	3.31	3.43	63.80	6.38	7.89	69.04	4.12	7.90	5
	71	70.0	66.0	3.60	2.03	3.17	2.93	60.51	6.65	6.35	80.01	2.57	6.15	1
	68	68.5	65.6	3.67	1.80	3.18	2.88	68.47	8.03	9.26	78.48	3.21	7.64	3
	70	75.5	72.5	3.76	2.34	3.25	3.12	59.80	5.17	8.29	78.92	2.52	6.56	5
Mean	71.9	68.4	4.33	2.23	3.33	3.30	60.12	7.36	7.63	76.69	2.98	6.80	3.4	
10-10%	57	75.5	69.0	4.42	2.43	3.84	3.56	58.92	7.13	7.79	67.59	2.22	5.90	5
	55	75.5	70.3	4.08	2.33	3.43	3.28	56.45	3.33	5.71	75.91	3.95	7.81	5
	72	72.0	68.2	4.78	2.24	3.43	3.48	51.01	2.76	4.25	76.25	3.76	7.60	5
	65	74.0	69.7	3.80	2.07	3.36	3.08	52.38	5.17	5.53	77.95	3.51	6.01	5
Mean	74.3	69.3	4.27	2.27	3.52	3.35	54.69	4.60	5.82	74.43	3.36	6.83	5.0	

Note 1) Measured by a chroma meter; L* lightness, a* redness, b* yellowness 2) Evaluated according to the criteria of Japan Meat Grading Association and assigned scores of 5 high, 3 medium and 1 fair quality.

Appended table 5-2 Carcass performance of females

Groups	ID No.	Carcass weight (kg)	Dressing percent (%)	Backfat thickness (cm)				Meat color ¹⁾			Fat color ¹⁾			Carcass score ²⁾
				Shoulder	Mid-Back	Loin	Mean	L*	a*	b*	L*	a*	b*	
Control	95	73.5	68.8	3.85	2.22	3.23	3.10	57.09	5.41	6.32	71.81	1.97	5.06	5
	102	69.0	66.6	3.64	1.79	2.83	2.75	55.10	6.33	5.24	72.24	1.79	4.98	5
	88	70.5	66.3	3.53	2.54	3.90	3.32	57.21	4.65	5.75	73.95	4.33	6.98	5
	94	69.0	64.8	3.87	2.01	3.12	3.00	47.22	4.74	3.26	78.24	3.17	5.44	3
	Mean	70.5	66.6	3.72	2.14	3.27	3.04	54.16	5.28	5.14	74.06	2.82	5.62	4.5
10-0%	96	74.5	67.8	4.89	1.87	3.18	3.31	63.45	7.29	9.50	66.56	4.35	8.82	5
	97	72.5	68.3	3.22	1.12	2.77	2.37	41.78	4.24	3.28	73.50	3.73	7.70	1
	87	70.5	67.6	3.36	1.48	2.15	2.33	46.82	4.88	3.78	72.27	4.88	8.72	3
	99	71.5	68.7	3.78	2.00	2.79	2.86	50.01	7.82	6.60	78.33	3.41	6.99	5
	91	74.5	68.9	3.82	1.74	2.68	2.75	53.78	5.81	5.49	75.71	4.22	7.22	3
Mean	72.7	68.3	3.81	1.64	2.71	2.72	51.17	6.01	5.73	73.27	4.12	7.89	3.4	
15-0%	93	73.5	68.8	4.31	2.57	3.45	3.44	50.08	6.62	3.93	68.35	2.55	5.71	3
	107	68.0	63.0	3.50	1.43	3.00	2.64	49.12	6.24	5.74	71.96	1.91	7.38	1
	101	71.0	66.4	4.07	1.51	2.96	2.85	56.53	9.31	8.19	70.10	2.48	7.30	3
	84	72.5	67.4	2.96	1.84	3.38	2.73	51.03	5.05	4.80	78.54	2.92	6.12	3
Mean	71.3	66.4	3.71	1.84	3.20	2.92	51.69	6.81	5.67	72.24	2.47	6.63	2.5	
20-0%	103	73.0	68.6	3.90	1.79	2.88	2.86	49.28	5.28	4.30	67.69	2.71	5.51	5
	86	69.0	65.0	3.98	1.31	3.24	2.84	47.36	6.70	5.13	71.08	2.93	7.37	3
	89	73.0	68.6	3.95	2.44	3.59	3.33	47.51	4.75	3.91	75.42	2.30	5.88	5
	90	75.0	68.6	3.86	2.20	3.10	3.05	52.10	5.28	5.60	78.81	2.25	5.30	3
Mean	72.5	67.7	3.92	1.94	3.20	3.02	49.06	5.50	4.74	73.25	2.55	6.02	4.0	
10-10%	106	73.0	68.0	4.05	2.29	3.92	3.42	54.41	7.02	5.40	76.56	3.87	7.79	5
	108	74.0	67.2	3.78	1.33	2.82	2.64	44.15	4.92	3.54	69.85	3.82	9.36	3
	92	72.0	66.5	3.91	1.90	3.11	2.97	60.86	6.79	7.55	79.86	2.17	7.75	5
	80	70.5	68.2	3.72	2.15	3.37	3.08	59.66	6.02	6.97	76.44	2.72	7.25	5
	105	68.5	65.7	3.68	1.66	2.84	2.73	56.45	7.85	7.45	80.11	2.66	5.82	3
Mean	71.6	67.1	3.83	1.87	3.21	2.97	55.11	6.52	6.18	76.56	3.05	7.59	4.2	

Note 1) Measured by a chroma meter; L* lightness, a* redness, b* yellowness 2) Evaluated according to the criteria of Japan Meat Grading Association and assigned scores of 5 high, 3 medium and 1 fair quality.