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Growth Curves Fitting for Body Weight and Backfat Thickness of Swine by Sex

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성별에 따른 돼지 체중 및 등지방두께 성장곡선 추정

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Abstract

The purpose of this study was to establish proper shipping weight and backfat thickness by applying the growth model to backfat thickness, measured by means of not only body weight, but also ultrasonography, and predicting the changes by age. Three breeds, i.e. Duroc, Landrace, and Yorkshie, were analyzed, and the Gompertz, logistic, and Von Bertalanffy model were used for inference with the parameter of the growth model being sex. As a result, both body weight and backfat thickness showed different growth curve parameters and characteristics at inflection points depending on model selection and sex. As for backfat thickness, in estimating the inflection point, unlike the case of body weight, the inflection ages of the boars of the Duroc breed was earlier than that of sows, whereas the inflection ages of the sows of the Landrace and Yorkshire breeds was earlier than that of boars. More than anything else, in the analysis of the changes in backfat thickness according to body weight, as the body weight reached 145 kg, the backfat thickness showed much variation as great as 1.7-3.2 cm in each breed and sex. In addition, unlike the other breeds, the boars of the Landrace breed showed an exponential type of relationship between body weight and backfat thickness. As they grow to become 100 kg or heavier, abrupt change in backfat thickness was confirmed. If the growth of body weight and backfat thickness is understood and the genetic relationship is taken advantage of like this, it would be possible to set desired body weight and backfat thickness, and thus help effectively set the shipping time. If not only the phenotype, but also genetic parameters about growth characteristics are estimated and analyzed additionally, more effective data can be generated.

Key words: growth curve, swine, body weight, backfat thickness

Introduction

The body weight and backfat thickness of swine are the most important traits respectively among growth traits and carcass traits. Accordingly, to determine the appropriate shipping time for swine, information on overall growth changes related to both types of traits can be said to be essential. However, as animal growth does not happen at a certain time, but it takes place incessantly in and outside the body with the passage of time, it is desirable to apply the logarithmic function in the analysis so that it interpolates the time when no measurement is made as well as longitudinal records that are measured at a certain point in time or at certain intervals.

This logarithmic function was already conceived by many researchers (Black *et al.*, 1986; Bridges *et al.*, 1986; Brody, 1945; France *et al.*, 1996; Gompetz, 1825; Hill, 1913; Janoschek, 1957; Lopez *et al*, 2000; Moore, 1985; Parks, 1965; Richards, 1959; Robertson, 1908; Wan *et al.*, 1998; Von Bertalanffy, 1957) and it not only enables extraction of continuous data from discontinuous measurement data, but also makes it possible to understand the characteristics of animal growth at a glance by calculating implicit parameters

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of growth.

In consideration of this fact, this study periodically measured not only the body weight of swine, but also the backfat thickness, whose changes are difficult to check visually, through ultrasonography, and applied the nonlinear regression model to both traits to examine how the swine grows by breeds and sex, and compare the characteristics. In addition, if the optimal growth point is identified between body weight and backfat thickness through estimation of growth curve parameters, it will greatly help control the swine shipping time appropriately.

Materials and Methods

Data

The data used for estimation of growth curve parameters are the body weight and backfat thickness data of Duroc, Landrace, and Yorkshire breeding swine. The total was 170 head of pigs, and only the body weight and backfat thickness of those individuals whose measurement frequency by age exceeded 10 times were analyzed. The frequency of data of each sex by breeds is shown in Table 1. For measurement of body weight and backfat thickness, a body weight scale and an ultrasonographic machine were used respectively, and for the ultrasonography of backfat thickness, the 4^{th} rib (P1), the final rib (P2) and the final vertebra (P3) 5cm to the left or right of the center line of the swine were measured, but only the P2 measurement data was used.

Analysis

Estimation of the growth curve was based on existing models, and the Gompertz (Gompertz, 1825), logistic (Robertson, 1908), and Von Bertalanffy (von Bertalanffy, 1957) model, which make it easy to analyze the sigmoid type of growth, were used. Some (Schinckel, 1994) argue that, as various high-dimensional growth models continue to be developed, it is more effective in explaining animal growth to use a more flexible model by setting many parameters, but it has difficulty explaining potential. Rather, a model with a smaller number of parameters not only makes analysis and interpretation easy, but also is never lower in accuracy with respect to the expected values (Wellock *et al.*, 2004). In consideration of this fact, a growth model with 3 parameters and capable of estimating continuous growth, asymptote, point of inflection, and monotonic decrease in relative growth rate was used for analysis. All three models can estimate the same characteristics, but the inflection point is located in different places depending on the model. The equations and parameters of the three models, the inflection point at which the slope of the curve changes from positive to negative, and the characteristics at this point are shown in Table 2 by model.

For model-based analysis, PROC NLIN, the nonlinear regression procedure of the SAS package (version 9.1), was used. The DUD (Doesn't Use Derivative) method, i.e. the multivariate secant iterative method, a search algorithm which does not need to specify any partial derivative, was used. Parameters were obtained from each individual, and after estimation, the mean of the parameters by breeds and sex was obtained and presented. In addition, the estimated parameters were used to obtain the inflection points and the characteristics at the inflection points by means of the equation for each model. Additionally, to examine whether there is any difference in estimated parameters by model and sex, PROC ANOVA, the analysis of variance procedure of the SAS package, was used to conduct analysis of variance with the dependent variable for the fixed-effect sex being growth parameters A, b and k.

Table 1. Individuals of the breeding swine by breed and sex

	Duroc	Landrace	Yorkshire	Total
Boar	1	21	36	58
Sow	48	27	37	112
Total	49	48	73	170

Results and Discussion

Body weight

First of all, as for the result of parametric estimation of body weight, Duroc, sex growth curve parameters of the Landrace and Yorkshire breeds are shown in Table 3. Parameter (A) for mature weight estimated by breeds and sex according to the Gompertz, logistic, and Von Bertalanffy was the lowest for the logistic model, and the Von Bertalan-

Table 2. Equations, parameters and characteristics at inflection points by growth curve model

Model	Equation	Asymptotic value	Rate of maturing	Inflection point	Expectation at inflection
Gompertz	$Ae^{-be^{-kt}}$	A	k	$(1/k)\log_e b$	$(1/e)A$
Logistic	$A/(1 + be^{-kt})$	A	k	$(1/k)\log_e$	$(1/2)A$
Von Bertalanffy	$A(1 - be^{-kt})^3$	A	k	$(1/k)\log_e 3b$	$(2/3)^3A$

Table 3. Breed and sex parameters for body weight estimated by the growth curve model

Breed	Model	Parameter[1)]	Estimate±SE (boar)	Estimate±SE (sow)
Duroc	Gompertz	A^{NS}	204.0±32.14	200.1±15.930
		b^{*}	5.082±0.414	4.490±0.199
		k^{**}	0.015±0.002	0.012±0.001
	Logistic	A^{**}	137.2±4.808	149.4±5.790
		b^{**}	40.97±4.304	22.46±1.498
		k^{**}	0.036±0.002	0.024±0.001
	Von Bertalanffy	A^{NS}	327.4±123.3	251.9±31.13
		b^{NS}	0.898±0.049	0.891±0.034
		k^{NS}	0.007±0.002	0.008±0.001
Landrace	Gompertz	A^{**}	158.1±13.31	178.4±19.83
		b^{**}	4.325±0.476	4.657±0.618
		k^{**}	0.014±0.002	0.014±0.002
	Logistic	A^{**}	128.3±5.338	139.6±7.300
		b^{**}	23.08±4.687	25.13±5.430
		k^{**}	0.028±0.002	0.027±0.003
	Von Bertalanffy	A^{**}	188.9±24.13	223.0±39.75
		b^{**}	0.853±0.066	0.893±0.087
		k^{**}	0.009±.0020	0.009±0.002
Yorksire	Gompertz	A^{**}	157.1±6.409	145.3±7.061
		b^{NS}	4.672±0.236	5.441±0.539
		k^{NS}	0.015±0.001	0.018±0.002
	Logistic	A^{**}	129.4±2.864	126.4±3.587
		b^{NS}	23.10±1.835	26.69±3.702
		k^{*}	0.028±0.001	0.031±0.002
	Von Bertalanffy	A^{**}	184.3±11.13	159.6±10.44
		b^{NS}	0.922±0.038	1.085±0.095
		k^{NS}	0.010±0.001	0.014±0.001

^{NS} non-significant, $^{*}p<0.05$, $^{**}p<0.01$.

1) A, b and k are fitted parameters for mature weight, growth ratio, and maturing rate, respectively.

ffy model. Contrarily, parameter (k) for mature rate was the highest for the Von Bertalanffy model, and lower for the logistic model than for other models. Estimations by model differed seemingly because of the characteristics of the equation, and in particular, parameters A and k showed different patterns because all three models had a strong negative correlation between A and k (Cho *et al.*, 2004; Choi, 2006).

As for the analysis of the Duroc, Landrace and Yorkshire breeds by sex, the Duroc breeds showed different estimations depending on the growth models. According to the Gompertz and Bertalanffy model, the maturation weight (A) of boars was greater than that of sows, but it was not significant. According to the Gompertz model, the maturation rate (k) of boars was greater than that of sows ($p<0.01$). The logistic model showed completely different patterns than the other growth models. The maturation weight (A) of sows was greater than that of boars, whereas the maturation rate of boars was greater than that of sows ($p<0.01$). The estimated growth parameter of the Landrace breeds was similar in all three models, and parameter A for maturation body weight was greater in sows than in boars ($p<0.01$), and maturation rate (k) was similar in both sexes, but it was highly significant ($p<0.01$). This means that the body weight gain is similar in both sexes, but the body weight of sows is greater than that of boars when fully grown. As for the estimated growth curve parameter for the body weight of the Yorkshire breed, unlike the Landrace breed, the maturation body weight of boars was greater than that of sows ($p<0.01$), whereas the maturation rate (k) of sows was greater than that of boars, but the difference was significant only in the logistic model ($p<0.05$). It was estimated to be about 20 kg lowerthan the maturation body weight of sows and boars respectively, i.e. 176.17±4.17 and 201.97±6.82, reported by Cho *et al.* (2001) who applied the body weight of the Landrace breed to the Gompertz model to estimate parameters by sex, and it agreed with the above-mentioned study in that the maturation body weight of sows was greater than that of boars.

A comparison of the parameter estimates by breed shows that the Duroc breed among the three breeds has the greatest maturation body weight, and the sows of the Landrace breed is greater than that of boars. The maturation body weight of the Yorkshire breed was the smallest. As for the maturation rate, there was a difference among the breeds, but as the difference among models was so great that it is difficult to view it as a difference attributable to the difference in breed. The maturation body weight of the three breeds analyzed in this study was greater than that of the Korean native pig which Cho *et al.* (2001) used the Gompertz model to estimate: 119.69±2.63 and 131.03±3.81 for sows and boars respectively. The maturation body weight of the Duroc breed was greater than that of the Duroc×KNP hybrid reported by Cho *et al.* (2004) (179.54±6.06 and 179.84±6.33 for sows and boars respectively), and that of the Yorkshire breed was smaller.

The parameters of the estimated growth model was used to calculate the inflection point, the weight (kg) at the inflection point (age), and the body weight gain at the inflection point (kg/age) by means of the equation of each model, and they are shown in Table 4.

The inflection ages of the Yorkshire sows among the three breeds was earlier than the other breeds, and that of the Duroc sows was the latest. The boars of the Landrace breed and the Yorkshire breed showed a similar inflection ages, whereas the inflection ages of the Duroc sows was earlier than that of boars in both the Gompertz model and the Bertalanffy model, but showed completely different values estimated by the logistic model. The body weight at the inflection point was greatest for the Duroc boars, and smallest for the Yorkshire sows, but there was not much difference due to sex. The body weight at the inflection ages calculated by the Logistic model was greater for sows than for boars unlike other models. The inflection ages of the three models was a little different from each other probably because the inflection ages of each model is dependent on parameter A of the maturation body weight, and the degree of dependency is fixed at 36.8%, 50% and 29.6% for the Gompertz, logistic and Bertalanffy model respectively. The results of this study are earlier than the inflection ages of sows and boars of the Landrace breed, i.e. 4.31±0.07 and 4.56±0.11 month, reported by Cho *et al.* (2001) who used the Gompertz model, and the inflection ages of the KNP× Landrace breed, i.e. 5.05±0.11 and 5.24±0.13 month, reported by Cho *et al.* (2004), and the body weight at the inflection point was smaller than 68.00±1.61 and 77.97±2.63 kg (Cho *et al.*, 2001) and, 69.30±2.34 and 69.42±2.44 kg (Cho *et al.*, 2004) respectively.

Fig. 1 compared the estimated growth curve graph with the actual measurements for better understanding of the results shown in Table 3 and Table 4. The Landrace breed and the Yorkshire breed have a similar growth curve, but the Duroc breed showed a greater difference from measurements in the latter half according to sex, and particularly so in the case of boars according to models, and the estimation was greater than actual measurements in general. In addition, the use of the logistic model showed that all three

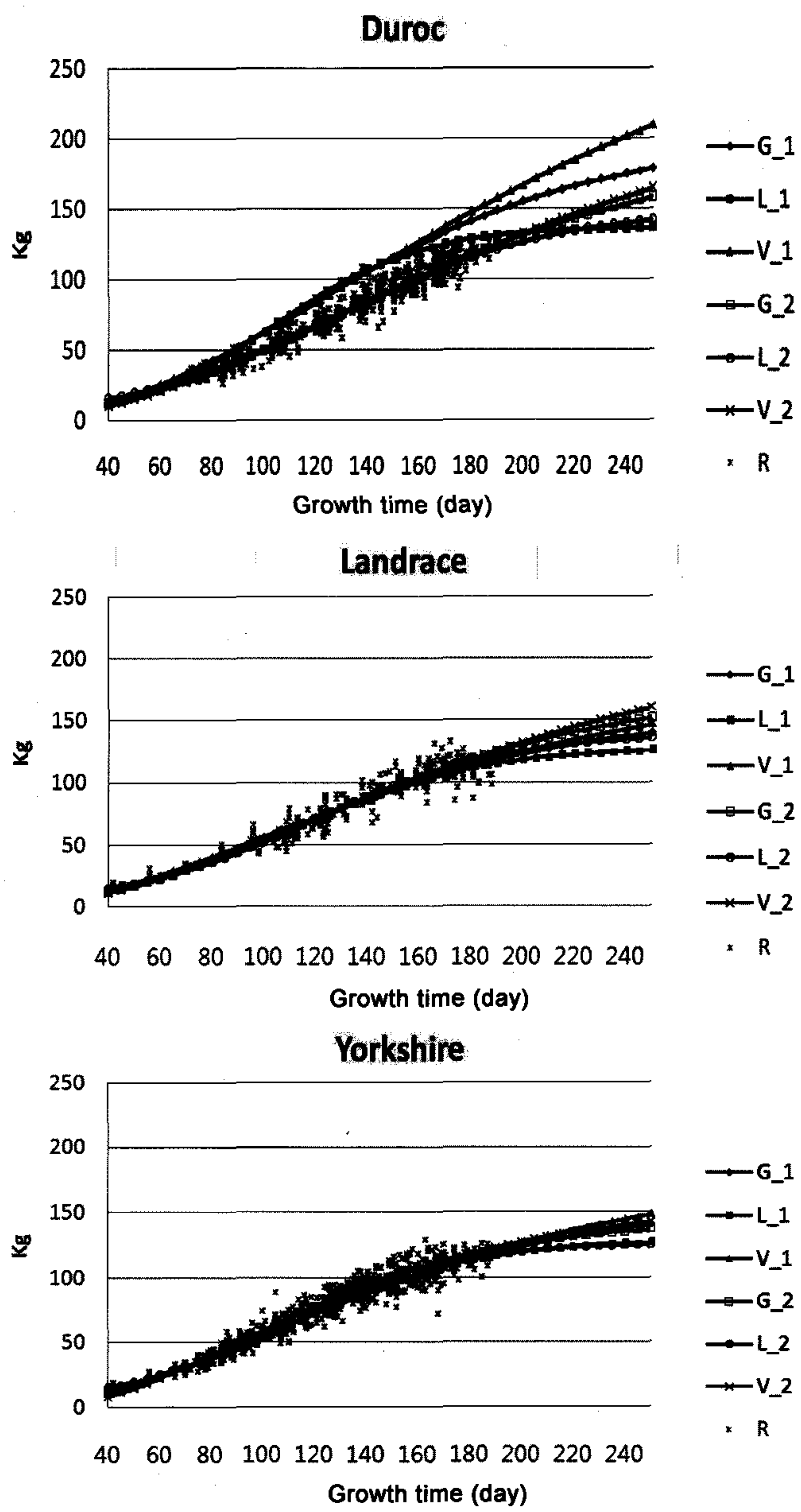

Fig. 1. Growth curves of body weight estimated with Gompertz, logistic, and Von Bertalanffy models by breed and sex. G : Gompertz, L : logistic, V : Von Bertalanffy, 1 : Boar, 2 : sow.

Table 4. Characteristics of body weight at the breed and sex inflection point, estimated by the growth curve model

Breed	Sex	Model	Inflection point	Weight at inflection	Growth rate at inflection
Duroc	Boar	Gompertz	111.4	75.05	1.096
		Logistic	104.6	68.60	0.055
		Von Bertalanffy	132.3	96.91	1.089
	Sow	Gompertz	127.3	73.61	0.869
		Logistic	129.1	74.70	0.069
		Von Bertalanffy	128.8	74.56	0.853
Landrace	Boar	Gompertz	103.1	58.16	0.826
		Logistic	111.7	64.15	0.067
		Von Bertalanffy	99.87	55.91	0.789
	Sow	Gompertz	114.0	65.63	0.886
		Logistic	119.4	69.80	0.065
		Von Bertalanffy	114.6	66.01	0.852
Yorkshire	Boar	Gompertz	103.5	57.79	0.861
		Logistic	111.7	64.70	0.068
		Von Bertalanffy	98.75	54.55	0.843
	Sow	Gompertz	94.11	53.45	0.962
		Logistic	104.9	63.20	0.065
		Von Bertalanffy	87.39	47.24	0.957

breeds showed smaller estimates in the latter half than other models, and the inflection ages was earlier than other model. The maturation body weight of the Duroc breed was greater than that of other breeds, and the growth pattern of the sows and boars was clearly different from each other. In all three breeds, even past the inflection ages, the degree to which the slope decreases is so small that the body weight growth continues even after 240 days of age, and additional studies based on measurement data seems necessary.

Backfat thickness

Like body weight, backfat thickness data was applied to the three models to estimate growth curve parameters as shown in Table 5.

As for the overall parameter estimates by breed, the maturation backfat thickness (A) of the Landrace boars was the greatest, and that of the Duroc boars was the smallest. Contrary to maturation backfat thickness, the maturation rate (k) of the backfat thickness of boars was the greatest in the Duroc breed, and the smallest in the Landrace breed. The estimates for the sows by breedwere somewhat different from those for the boars. The maturation backfat thickness of the Duroc breed was greater than that of other breeds, and except for the Duroc breed, that of the Landrace breed was next, followed by that of the Yorkshire breed.

As for difference by sex, unlike the Landrace breed or the Yorkshire breed, the maturation backfat thickness (A) and the growth rate (b) of the sows of the Duroc breed, was greater than that of the boars, whereas the maturation rate (k) of the boars was slightly greater than that of the sows. When compared to the estimates of the body weight, the Landrace breed showed a completely different pattern. The maturation backfat thickness of the boars was greater than that of the sows ($p<0.01$), and the growth rate and the maturation rate of the sows were greater than those of the boars, but the difference in the growth rate was not significant. The Yorkshire breed showed the same results as the parameter estimates, and the same growth pattern as the Landrace breed. The maturation backfat thickness of the boars was greater than that of the sows, but it was not statistically significant, and the growth rate and maturation rate of the sows were greater than those of the boars ($p<0.01$).

Like body weight, for backfat thickness, the growth curve parameter was used to estimate the inflection ages, and the characteristics at the inflection ages were calculated and listed in Table 6.

First of all, as for the difference by breed, the backfat thickness of the boars was the greatest in the Landrace breed, followed by the Yorkshire breed and the Duroc breed in that order, whereas the backfat thickness of the sows was the greatest in the Landrace breed, followed by the Duroc breed and the Yorkshire breed in that order. The sows displayed somewhat different results than the boars.

As for the difference in characteristics at the inflection point by breed and sex, the inflection ages and the backfat thickness at the inflection ages of the sows of the Duroc

Table 5. Breed and sex parameters for backfat thickness estimated by the growth curve model

Breed	Model	Parameter[1)]	Estimate±SE (boar)	Estimate±SE (sow)
Duroc	Gompertz	A^{NS}	2.163±1.320	2.409±0.265
		b^{NS}	3.348±1.959	3.477±0.519
		k^{NS}	0.015±0.014	0.014±0.003
	Logistic	A^{*}	1.892±0.748	2.114±0.135
		b^{NS}	10.16±7.302	11.32±2.200
		k^{NS}	0.024±0.015	0.023±0.003
	Von Bertalanffy	A^{NS}	2.346±1.814	2.604±0.374
		b^{NS}	0.774±0.426	0.793±0.108
		k^{NS}	0.011±0.014	0.011±0.003
Landrace	Gompertz	A^{**}	4.917±5.152	2.141±0.296
		b^{*}	3.945±0.544	5.386±2.390
		k^{**}	0.008±0.007	0.018±0.006
	Logistic	A^{**}	2.900±1.094	1.915±0.153
		b^{NS}	18.54±6.890	22.90±13.14
		k^{**}	0.020±0.008	0.029±0.006
	Von Bertalanffy	A^{*}	8.628±18.98	2.299±0.418
		b^{NS}	0.805±0.046	1.110±0.440
		k^{**}	0.004±0.006	0.014±0.005
Yorksire	Gompertz	A^{NS}	2.402±0.415	1.781±0.085
		b^{**}	2.809±0.413	7.383±3.091
		k^{**}	0.012±0.003	0.029±0.005
	Logistic	A^{NS}	2.126±0.237	1.729±0.064
		b^{**}	7.450±1.371	23.26±11.69
		k^{**}	0.019±0.004	0.039±0.006
	Von Bertalanffy	A^{*}	2.582±0.558	1.807±0.097
		b^{**}	0.679±0.093	1.689±0.665
		k^{**}	0.009±0.003	0.026±0.005

^{NS} Non-significant, $^{*}p<0.05$, $^{**}p<0.01$.

1) A, b and k are fitted parameters for mature backfat thickness, growth ratio, and maturing rate, respectively,

Table 6. Characteristics of backfat thickness at the breed and sex inflection point estimated by the growth curve model

Breed	Sex	Model	Inflection point	Measurement at inflection	Growth rate at inflection
Duroc	Boar	Gompertz	82.77	0.796	0.012
		Logistic	96.21	0.946	0.001
		Von Bertalanffy	73.93	0.695	0.012
	Sow	Gompertz	89.01	0.886	0.012
		Logistic	103.7	1.057	0.001
		Von Bertalanffy	79.49	0.771	0.013
Landrace	Boar	Gompertz	170.9	1.809	0.015
		Logistic	145.3	1.450	0.001
		Von Bertalanffy	220.3	2.554	0.015
	Sow	Gompertz	94.07	0.788	0.014
		Logistic	106.9	0.958	0.001
		Von Bertalanffy	86.52	0.681	0.014
Yorkshire	Boar	Gompertz	86.06	0.883	0.011
		Logistic	104.0	1.063	0.001
		Von Bertalanffy	75.38	0.764	0.011
	Sow	Gompertz	69.42	0.665	0.019
		Logistic	80.90	0.865	0.001
		Von Bertalanffy	63.64	0.535	0.020

breed, estimated by all three models, were greater than those of the boars, while contrary to the case of body weight, the inflection ages and the backfat thickness at the inflection ages of the boars of the Landrace breed were greater than those of the sows. In addition, the inflection ages and the backfat thickness at the inflection ages of the boars of the Yorkshire breed were greater than those of the sows according to all three models. The difference in the inflection ages and the backfat thickness at the inflection ages between boars and sows was the greatest for the Landrace breed.

Fig. 2 illustrates the growth model estimated by applying the three models to backfat thickness so that it is possible to easily understand the changes of backfat thickness according to age in days. In the case of the growth of backfat thickness of the boars of the Landrace breed, the slope hardly decreased past the inflection ages, and there was little change in growth, which was greatly different from the case of the sows. In addition, in the case of the sows of the Yorkshire breed, the slope sharply decreased past the inflection ages, and after 180 days the sows maintained backfat thickness of about 1.7-1.8 cm.

Fig. 3 illustrates a graph based on the estimated growth curve for the body weight and backfat thickness as shown above. It shows the changes in backfat thickness according to the changes in body weight, not changes in age in days, by breed and sex. The changes in backfat were examined with the body weight fixed between 10 kg and 145 kg for all three breeds regardless of age in days. Among the Gompertz, logistic and Von Bertalanffy model, only the Gompertz model was used for estimation. Only one out the three growth models was used because a report to the effect that the Von Bertalanffy model and the logistic model underestimate and overestimate the initial and maturation body weight respectively (Brown *et al.*, 1976) was taken into consideration. Body weight and backfat thickness are related to each other differently according to age in days by breed and sex. More than anything else, the boars of the Landrace breed showed an exponential relationship. Unlike the backfat thickness of the boars of the Landrace breed grew at an accelerated pace as their body weight exceeded 100 kg, and when the body weight reached 145 kg, there was more than 1 cm difference in backfat thickness. The boars of the Duroc breed showed the smallest backfat thickness until they grew to be 80-145 kg, but the trends of the curves predict that the backfat thickness of the sows of the Yorkshire breed would be the smallest as their body weight exceeds 145 kg. The slope of the backfat thickness growth of the Yorkshire breed according to body weight decreased more than that of the other breeds. If changes in body weight and backfat thickness according to age in days are known, and changes in backfat thickness according to changes in body weight is correctly understood, it will be possible to control shipping age by appropriately controlling body weight and backfat thickness. In addition, body weight and backfat thickness showed varied patterns according to breed and sex, and backfat thickness showed greater differences by sex. This data pertains to the phenotype, and additional studies about the characteristics of the growth curve and estimation of the genetic parameters relating to the inflection ages, are conducted, more correct shipping date control will be possible.

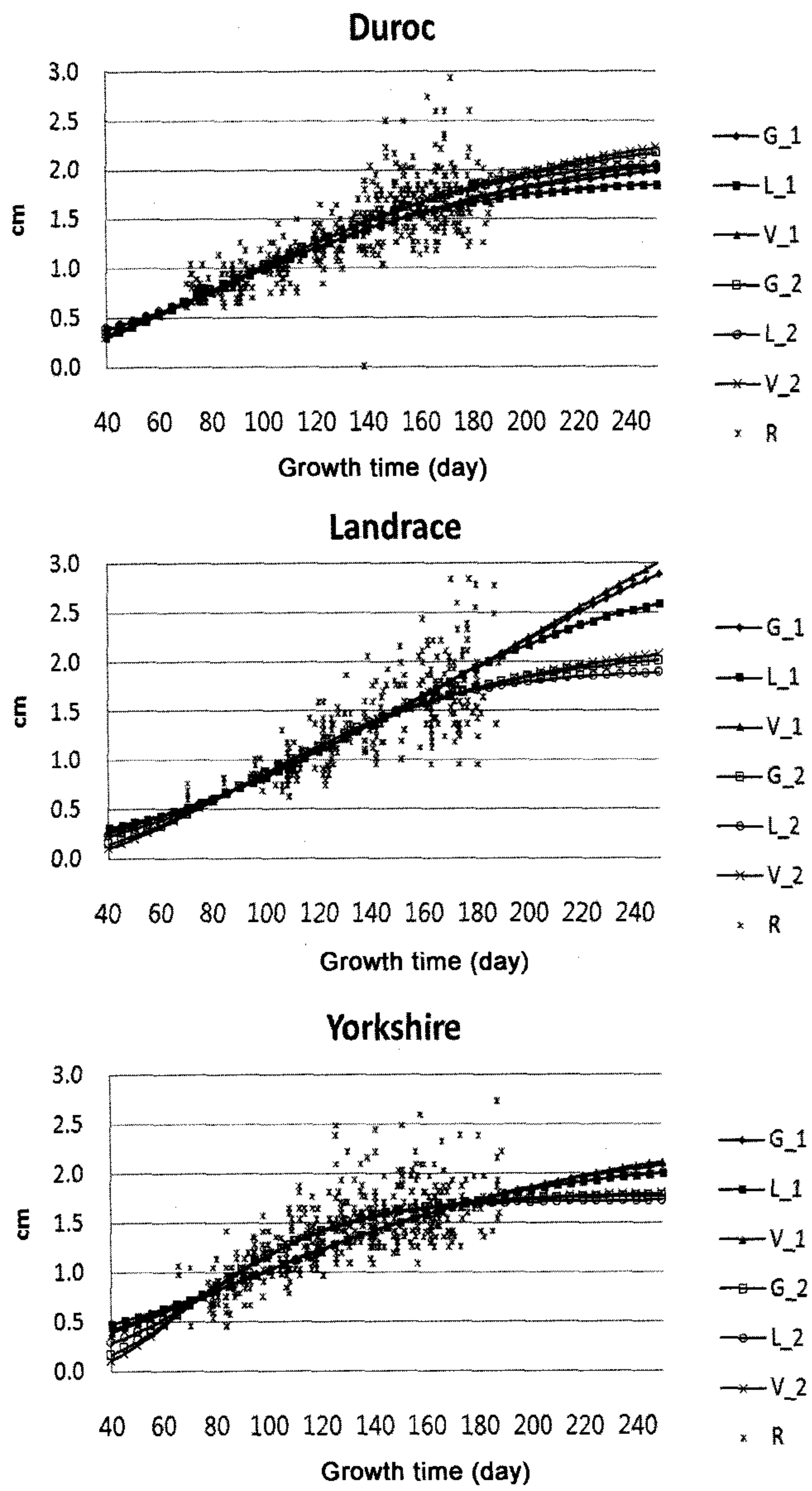

Fig. 2. Growth curves of backfat thickness estimated with Gompertz, logistic and Von Bertalanffy models by breed and sex. G : Gompertz, L : logistic, V : Von Bertalanffy, 1 : Boar, 2 : sow.

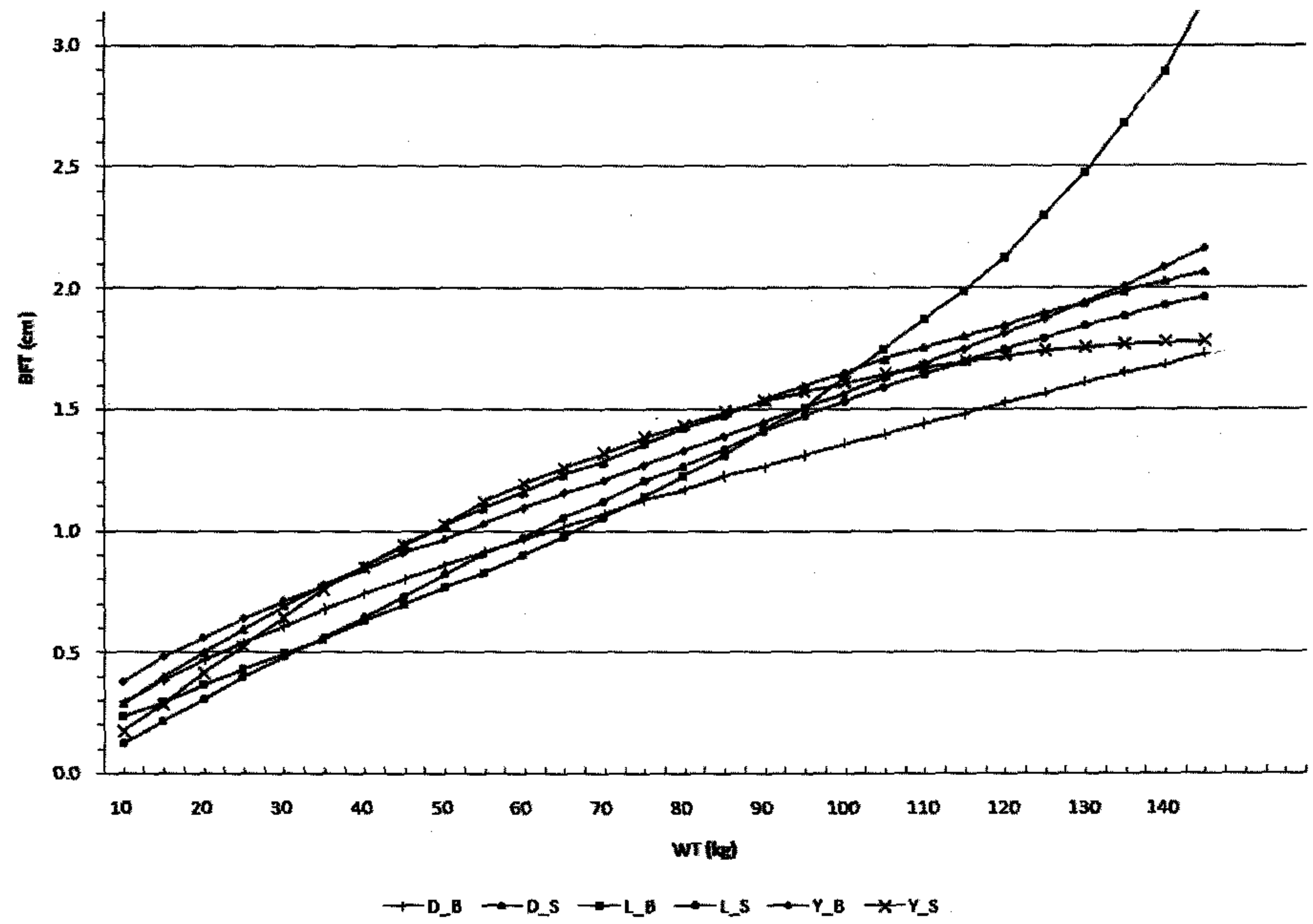

Fig. 3. Changes in backfat thickness of swine according to changes in body weight by breed and sex. WT : body weight, BFT : backfat thickness, D : Duroc, L : Landrace, Y : Yorkshire, B : boar, S : sow.

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References

1. Bertalanffy, L. von. (1957) Quantitative laws for metabolism and growth. *Quart. Rev. Biol.* **32**, 217-232.
2. Black, J. L., Campbell, R. G., Williams, I. H., James, K. J., and Davies, G. T. (1986) Simulation of energy and amino acid utilization in the pig. *Res. Dev. Agri.* **3**, 121-145.
3. Bridges, T. C., Turner, L. W., Smith, E. M., Stahly, T. S., and Loewer, O. J. (1986) A mathematical procedure for estimation animal growth and body composition. *Trans. Am. Assoc. Agri. Eng.* **35**, 1019-1028.
4. Brody, S. (1945) Bioenergetics and growth. Rheinhold Pbubliching, New York.
5. Brown, J. E., Fitzhugh, H. A. Jr., and Cartwright, T. C. (1976) Acomparison of nonlinear models for describing weight-age relationship in cattle. *J. Anim. Sci.* **34**, 525.
6. Campbell, R. G. and Taverner, M. R. (1988) Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. *J. Anim. Sci.* **66**, 676-686.
7. Cho, Y. M., Choi, B. H., Kim, J. T. H., Lee, W., Lee, J. E., Oh, S. J., and Cheong, I. C. (2004) A study on estimation of individual growth curve parameters and their relationships with meat quality traits of crossbred between Korean native boars and landrace sows. *J. Anim. Sci. Tech. (Kor.)* **46**, 503-508.
8. Cho, Y. M., Yoon, H. B., Lee, Y. C., Seo, K. S., Kim, S. D., and Park, Y. I. (2001) A study on growth characteristics of Korean native pig (KNP) and Landrace using individual growth curve parameters. *J. Anim. Sci. Tech. (Kor.)* **43**, 817-822.
9. Choi, T. J. 2006. A study on estimation of growth curve and correlation between body weight, measurements and carcass traits in Hanwoo (Bos Taurus Coreanae). Master thesis, Chonbuk National University, pp. 73-74.
10. France, J., Dijksta, J., Thornley, J. H. M., and Dhanoa, M. S. (1996) A simple but flexible growth function. *Growth Dev. Aging* **60**, 71-83.
11. Gompertz, B. (1825) On nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Phil. Trans. R. Soc.* **115**, 513-585.
12. Hill, A. V. (1913) The combinations of haemoglobin with oxygen and with carbon monoxide. *Biochemistry* **7**, 472-480.
13. Janoschek, A. (1957) Das reaktionskinetische grundgesetz und seine beziehungen zum wachs-tums- und ertragsgesetz. *Stat. Vjschr* **10**, 25-37.
14. Lee, I. J. (2001) Estimation of genetic parameters of economic traits for two different final weights of the test and measuring modes and growth curve parameters in swine. A doctor's thesis, Seoul National University, pp. 51-63.
15. Lopez, S., France, J., Gerrits, W. J., Dhanoa, M. S., Humphries, D. J., and Dijkstra, J. (2000) A generalized Michaelis-Menton equation for the analysis of growth. *J. Anim. Sci.* **78**, 1816-1828.
16. Moore, A. J. (1985) A mathematical equation for animal growth from embryo to adult. *Anim. Prod.* **40**, 441-453.
17. Parks, J. R. (1965) Prediction and entropy of half-tone pictures. *Behav. Sci.* **10**, 436-445.

18. Robertson, T. B. (1908) On the normal rate of growth of an individual and its biochemical significance. *Arch. Entwicklungsmechanik Org.* **25**, 581-614.
19. Richards, F. J. (1959) A flexible growth function for empirical use. *J. Exp. Bot.* **10**, 290-300.
20. Schinckel, A. P. (1994) Nutrient requirement of modern pig genotypes. In: Recent Advances in Animal Nutrition. Garnsworthy, P. C. and Cole, D. J. A. (eds), University of Nottingham Press, Nottingham., pp. 133.
21. Wan, X., Zhong, W., and Wang, M. (1998) New flexible growth function and its application to the growth of small mammals. *Growth Dev. Aging* **62**, 27-31.
22. Wellock, I. J., Emmans, G. C., and Kyriazakis, I. (2004) Describing and predicting potential growth in the pig. *Anim. Sci.* **78**, 379-388.

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