INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
10–365/ZIP/2011/13–1–51–56
http://www.fspublishers.org

*Full Length Article*

# Relationship of Porcine Plasma Free Insulin-like Growth Factor 1 (IGF-1) with the Growth Performance and Scrotal Length of Landrace Boars

PERCIVAL P. SANGEL[1] AND NINFA P. ROXAS†
*Department of Biology, School of Science and Engineering, Ateneo de Manila University, Philippines*
*†Animal and Dairy Sciences Cluster, College of Agriculture, University of the Philippines Los Banos, Philippines*
[1]Corresponding author's e-mail: ppsangel@yahoo.com

## ABSTRACT

Insulin-like Growth Factor I (IGF-I) is a 7.6 kDa, 70 amino acid residue peptide hormone that has been shown to be involved in the metabolic regulation of growth and reproduction in livestock. The present study was undertaken to quantify the concentrations of plasma free IGF-I in growing Landrace boars and determine whether the plasma free IGF-I concentration can be used as a selection criterion for growth. A total of fourteen (n = 14) Landrace boars were bled, weighed and monitored for ADG, backfat thickness and scrotal length at 15 and 24 weeks of age. Plasma samples were extracted from the blood and plasma free IGF-I concentrations were measured using the DSL 10-9400 Active free IGF-I Enzyme-Linked Immunosorbent (ELISA) kit. Experimental Landrace boars data on live weight, ADG, backfat thickness and scrotal length were correlated with their levels of plasma free IGF-I. This study has demonstrated a significant decrease (P = 0.0001) in the circulating plasma free IGF-I concentration of Landrace boars from 15 to 24 weeks of age. Furthermore, correlation of plasma free IGF-I concentration with growth traits showed a positive association with ADG (r = 0.726), while negative associations were established with backfat thickness (r = -0.412), scrotal length (r= -0.700) and live weight (r= -0.579). Results of this study suggest that circulating plasma free IGF-I is related to leaner body composition in swine. © 2011 Friends Science Publishers

**Key Words:** IGF-I; Landrace boars; Growth performance; Growth factor

## INTRODUCTION

Insulin- like Growth Factor I (IGF-I) is a peptide hormone that has been shown to be involved in metabolic regulation of growth in livestock species. Several tissues in pigs have been found to produce insulin-like growth factors including the IGF- I (Lee *et al*., 1993). These peptides have both an endocrine as well as paracrine functions (Sara & Hall, 1990).

The positive correlation of circulating concentrations of IGF-I with growth rate in pigs and other animals have been demonstrated (Buonomo *et al*., 1987; Daughaday & Rotwein, 1989; Dammacco *et al*., 1993). Endogenous production of IGF- I in pigs was shown to increase in the latter half of fetal life and further increase postnatally. This suggests that IGF- I is primarily a postnatal growth mediator in pigs (Lee *et al.*, 1991). Between 15 and 24 weeks of age, IGF- I was positively associated with growth rate, voluntary feed intake and gain: feed ratio (Owens *et al.,* 1999). Moreover, it has been found that higher serum IGF-I concentration will result in increased scrotal circumference of breeder animals (Yilmaz *et al.*, 2004). In mice, the study of Baker *et al.* (1996) has stressed the potential of IGF- I as a selection criterion for producing favorable correlated responses in growth.

The development of criterion that is measurable at early life and is influential to the future growth and reproductive performance would be an important tool in selection. In male pigs, the practice of maintaining small number of intact (non-castrated) animals precludes the full expression of performance traits of the other boars. This limits the selection process.

In view of the above-mentioned findings, the concentration of free IGF- I in the serum is a probable candidate for selection due to its association with economically important productive traits and its possible involvement in the reproductive aspects of the animal. In addition, IGF- I release is not pulsatile and is moderately to highly heritable trait (Yilmaz *et al.*, 2004).

This study was aimed at demonstrating the relationship between endogenous concentration of plasma free Insulin-like Growth Factor- I (IGF- I) with the growth performance of Landrace boars through the use of commercially available DSL 10-9400 Active free IGF-I Enzyme-Linked Immunosorbent (ELISA) kit.

**To cite this paper:** Sangel, P.P. and N.P. Roxas, 2011. Relationship of porcine plasma free insulin-like growth factor 1 (IGF-1) with the growth performance and scrotal length of landrace boars. *Int. J. Agric. Biol.*, 13: 51–56

## MATERIALS AND METHODS

**Experimental design:** From a certified swine breeder farm, a total of fourteen (n= 14) fifteen-week old Landrace boars were randomly selected. All experimental animals were properly marked and subjected to the same management and herd health program implemented in the farm. The experiment was laid following a Completely Randomized Design (CRD).

**Data recorded**

**Average daily gain (ADG):** With a use of a standard scale, the weights of the animals at 15 and 24 weeks of age were collected. The average daily gain was computed by dividing the difference between initial and final weights by the number of days the animal had been fed within the comparison period.

**Body weight and backfat thickness:** The body weights of the experimental animals were also measured and recorded using a standard scale at 15$^{th}$ and 24$^{th}$ week of age. The backfat thickness was measured approximately over the first rib, the last rib and the last lumbar vertebra using an electronic probe. The measurement was made about 4 and 5 centimeters away from the midline. Then the average of the 3 measurements represented the backfat thickness of the animal (Argañosa, 1989). Backfat thickness measurements were also done at 15$^{th}$ and 24$^{th}$ week of age.

**Scrotal length:** The right and left scrotal lengths were measured independently with the scrotal groove as their boundary. Measurement was done at 15$^{th}$ and 24$^{th}$ week of age in all of the experimental animals using a tape measure.

**Blood sample collection:** Using a spinal 19 gauge needle syringe, 5 mL of blood was collected from the carotid artery of each boar at 15 and 24 weeks of age. The blood was transferred to a clean conical tube, mixed with Ethylene Di-amine Tetra-acetic Acid (EDTA) and placed in an ice box for transport. After arriving in the laboratory the blood samples were immediately centrifuged at 2500 rpm for 15 minutes after which the plasma was separated by transferring to another clean conical tube and used for further analysis.

**Plasma free IGF-I measurement:** For the quantitative analysis of the free plasma IGF-I, the DSL 10-9400 Active free IGF-I Enzyme-Linked Immunosorbent (ELISA) kit was used following the manufacturer's protocol. All the specimens and reagents were set at room temperature (25 degrees Celsius) and mixed thoroughly by gentle inversion before use. All standards and unknown samples were assayed in duplicate.

**Farm's performance testing data:** All the experimental boars underwent performance testing. Results of the farm's performance testing on Average Daily Gain (ADG), Backfat Thickness/Index, Feed Conversion Rate (FCR) and Feed Intake were requested from the Farm Record Office and were used for correlation analyses with the levels of free plasma Insulin-like Growth Factor I concentrations at 15$^{th}$ and 24$^{th}$ weeks.

## RESULTS AND DISCUSSION

**Production performance of the experimental landrace boars:** The means of the production traits, scrotal lengths and plasma free IGF-I levels are summarized in Tables I and II. The live body weight of the animals (n= 14) at 15 and 24 weeks of age averaged at 61.70 kg and 117.02 kg, respectively. The average backfat thickness at 15$^{th}$ week measures 0.89 cm, which increased to an average of 1.39 cm at 24$^{th}$ week of age. The average length measurements of the left and right scrotal areas of the Landrace boars were 12.91 cm and 19.11 cm at 15 and 24 weeks of age, respectively.

**Porcine plasma free IGF-I concentrations at 15$^{th}$ and 24$^{th}$ week of age:** Concentrations of plasma free IGF-I from blood samples taken at 15$^{th}$ and 24$^{th}$ weeks of age showed a very significant decline (P = 0.0001) from Least Square (LS) mean plasma free IGF-I concentration of 0.3088 ± 0.0273 ng/mL at 15$^{th}$ week to 0.1350 ± 0.0273 ng/mL at 24$^{th}$ week (Table II). Although there are limited available studies on plasma free IGF-I, similar declining trend was also reported by Lamberson *et al.* (1995) in serum total IGF-I concentration of male and female pigs at 6 to 21 weeks of age. Their study showed an increased in the concentrations of serum total IGF-I for both sexes from 6$^{th}$ week, peaking at 18$^{th}$ week and declining at 21$^{st}$ week. Greater rate of increase was seen in males than in their female counterparts. The study of Clapper *et al*. (2000) reported similar results of increasing trend in the serum total IGF-I concentrations in boars over barrows and gilts starting from 84 days (12 weeks) up to 140 days (20 weeks) of age. Owens et al. (1999) had a similar observation except for an increasing trend of plasma total IGF-I from the 21$^{st}$ towards the 24$^{th}$ week of age in boars. Furthermore, this study also reported higher plasma total IGF-I concentration in boars than gilts. In contrast, Buonomo and Klindt (1993) observed different result in their study and no significant difference was noted between sexes.

Growth hormone (GH) or somatotrophin, a polypeptide produced and secreted by the somatotroph cells (acidophils) of the adenohypophysis or anterior pituitary gland, has long been implicated to influence the IGF-I blood levels. The GH, acting primarily in the liver, which is considered as the major source of blood IGF-I, stimulates the IGF-I synthesis and release. This was clearly demonstrated in the study of Brameld *et al.* (1996), where animals that received exogenous pST (porcine GH) manifested a greater proportion of exon 2-containing IGF-I mRNAs in liver RNA indicating an active synthesis of the IGF-I. Then, IGF-I upon release by the liver, circulates via the blood plasma to the main target organs, where it exerts its biological activities. The circulating IGF-I also provides a feedback effect within the somatotrophic axis (hypothalamo-pituitary-liver axis), suppressing the further release of GH from the anterior pituitary gland (Le Roith *et al.,* 2001).

**Table I: Average measurements and standard errors of some production traits and scrotal lengths of the Landrace boars taken at 15th and 24th weeks of age (n=14)**

| TRAITS | Age (weeks) | |
|---|---|---|
| | 15 | 24 |
| body weight (kg) | 61.70 ± 1.93 | 117.02 ± 4.13 |
| average daily gain (ADG) [kg/day] | 0.93 ± 0.05 | 0.33 ± 0.02 |
| backfat thickness (cm) | 0.89 ± 0.05 | 1.39 ± 0.07 |
| scrotal length (cm) | 12. 91 ± 0.51 | 19.11 ± 0.62 |

**Table II: Least square (LS) means and standard errors of plasma free Insulin-like Growth Factor I (IGF-I) in Landrace boars taken at 15 and 24 weeks of age (n=14)**

| AGE | IGF-I (ng/mL) |
|---|---|
| at 15th week | 0.3088** ± 0.0273 |
| at 24th week | 0.1350 ± 0.0273 |

** (P= 0.0001)

**Table III: Relationship between growth performance characteristics, scrotal length and free plasma IGF-I concentrations of landrace pigs taken at 15 and 24 weeks of age (n=14)**

| TRAITS | Correlation coefficient (r) (significance) | |
|---|---|---|
| Weight | -0.57916 | (P= 0.0012)** |
| ADG | 0.72575 | (P< 0.0001)** |
| backfat thickness | -0.41236 | (P=0.0292)* |
| scrotal length | -0.70016 | (P< 0.0001)** |

**Table IV: Correlation analysis of the performance testing results with the plasma free IGF-I concentrations (n=14)**

| TRAITS | Correlation coefficient (r) (significance) | | |
|---|---|---|---|
| | At 15th week | At 24th week | Delta IGF-I |
| ADG | 0.4152 | -0.4036 | -0.5712 |
| | (P= 0.1399) | (P= 0.1529) | (0.0329)* |
| Backfat thickness | 0.2696 | 0.5680 | -0.0572 |
| | (P= 0.3513) | (P= 0.0341)* | (P= 0.8461) |
| FCR | 0.4083 | 0.2244 | -0.3271 |
| | (P= 0.1472) | (P= 0.4406) | (P= 0.2536) |
| Feed intake | -0.5408 | -0.1374 | 0.4936 |
| | (P= 0.0459)* | (P= 0.6395) | (P=0.0728)' |

*significant at 5%
'significant at 10%

Studies in humans and other species showed that serum IGF-I levels and growth are positively correlated with the peak amplitudes of GH, rather than the concentration of GH between pulses (Le Roith *et al.*, 2001). Age-related changes in total 24-h secretion of GH have also been noted. In humans, GH levels remain rather constant during the period of accelerated growth in the early childhood, while a marked increase was observed during the period of maximal growth in adolescence (Hadley, 2000). In addition, a similar age-dependent pattern for IGF (IGF-I & IGF-II) and IGFBPs is also established in humans. The IGF-I levels are low prenatally and at birth but rise during childhood to high levels during puberty, after which they decline with increasing age. The same IGF-I pattern has also been found in rats, where serum IGF-I levels begin to rise at the time growth becomes GH dependent (Sara & Hall, 1990).

In view of the reports on GH and its influence on IGF-I blood levels, the observed declining trend of the plasma free IGF-I concentrations from 15 to 24 weeks of age of the experimental Landrace boars may be in part due to the decreasing peak amplitudes of GH. Recall that at 24th week (6 months) of age, the experimental boars had gained their mature live weights and reached puberty.

**Correlation of plasma free IGF-I concentration with the growth performance traits and scrotal length of boars:** Correlation analysis of plasma free IGF-I concentrations at 15th and 24th week of age of the experimental animals as shown in Table III revealed a strong positive linear correlation between plasma free IGF-I concentration taken at 15th and 24th week of age with the Average Daily Gain (r= 0.7258 at P< 0.0001) of Landrace boars. While among negative linear correlations, this study shows that it is strong for the scrotal length (r= -0.7002 at P = 0.0001) and live body weight (r = -0.5792 at P = 0.0012). A moderate negative linear correlation was observed for the backfat thickness measurements of the experimental Landrace boars (r= -0.4124 at P = 0.0292).

Since protocols on measuring free IGF-I are just being developed, available literature on free IGF-I and growth performance are very limited. However, related studies on total IGF-I in swine have been reported.

**A. IGF-I and ADG:** Similarly, the study of Owens *et al*. (1999) showed a positive linear association of IGF-I or IGFBP3 with the Average Daily Gain, voluntary feed intake and gain: feed ratio of pigs. They further reported that boars have higher average plasma total IGF-I concentration, Average Daily Gain and feed: gain ratio between 15 and 23 weeks of age over barrows and gilts. But there was no significant difference found on voluntary feed intake among the three experimental groups. In addition, they established a negative linear correlation between plasma total IGF-I concentration and backfat thickess, which was found to be not significant. On the contrary, Lamberson *et al*. (1995) reported that concentration of total IGF-I is not related to compositional traits of swine. Although, a weak positive relationship between total IGF-I concentration and growth, particularly during the growing phase, was observed in their study.

Consistent with the other reports on serum or plasma total IGF-I (Owens *et al.*, 1999; Clapper *et al*., 2000), particularly its strong positive association with the Average Daily Gain (ADG) and moderate negative association with the backfat thickness of the experimental Landrace boars, this study also suggest that IGF-I promotes lean tissue growth in swine. The circulating IGF-I, secreted mainly by the liver and other organs (Brameld *et al.,* 1995) could have exerted its biological activity either via endocrine mechanisms leading to lean tissue growth or as IGF-I

somatic tissue secretion acting as an autocrine or paracrine growth factor (Le Roith *et al*., 2001).

The IGF's original growth-promoting activity was characterized in terms of protein synthesis. Exogenous IGF-I administration has been shown to increase whole body protein metabolism by increasing protein synthesis as well as inhibiting proteolysis. These actions are distinct from the metabolic effects of insulin, which acts primarily by inhibiting proteolysis (Fryburg, 1994). The IGF-I also enhances glucose uptake into the peripheral tissues, which is insulin-like effect (Jacob *et al*., 1989). In an experiment with *igf-I* null mice, expression of insulin-sensitive glucose transporter, GLUT4, is decreased. The glycogen synthase kinase 3b is hypophosphorylated and glycogen stores are depleted. Chondrocytic ribosomal RNA levels were also drastically reduced among experimental mice (Wang *et al.,* 1999).

The IGF-I growth-promoting activity can also be viewed as a result of its mitogenic, hypertrophic or both mitogenic and hypertrophic effects on tissues. Like in the long bones, the IGF-I insulin-like effect has been demonstrated augmenting chondrocytic hypertrophy rather than promoting a mitogenic activity (Shinar *et al*., 1993).

In muscles, the IGF (IGF-I & IGF-II) have been reported to stimulate both proliferation and rate of differentiation. Studies on muscle cell cultures showed that initial addition of the IGF stimulates proliferation in a dose dependent way. Later on IGF stimulates the rate of differentiation in dose-dependent biphasic way, where at low levels, the addition of IGF stimulates differentiation in a dose-dependent way, while at higher levels, addition of IGF decrease differentiation in a dose-dependent way (Oksbjerg, *et al*., 2004).

From birth to puberty, the level of IGF-I increases inversely with a decrease in protein turnover observed in muscles (Garlick *et al*., 1989). However, the number of myofiber membrane type I IGF-receptors or mRNA expression of these receptors decreases by age (Louveau *et al*., 1996). Seemingly, the levels of plasma free IGF-I declines after reaching its peak level at the onset of puberty in pigs based from the results of this study. Therefore, high level of blood IGF-I, high concentration of IGF receptors and decrease in muscle protein turnover during the growing period reflect an increase in the lean mass composition of the animal. This is also translated to increasing Average Daily Gain (ADG) of the animal with increasing IGF-I blood levels thus, a positive association between plasma free IGF-I and Average Daily Gain (ADG) has been established.

**B. IGF-I and backfat thickness:** On the other hand, negative association was observed between the levels of plasma free IGF-I and backfat thickness of the experimental Landrace boars. As discussed earlier, fat or adipose tissue is late maturing and its rate of development increases after the growth rates of bone and muscle begin to decline and level off.

GH, rather than the IGF-I, may be considered as one of the possible factors that affects the characteristic growth pattern of the adipose tissues among animals, since adiposity is excessive in state of GH deficiency and GH treatment significantly reduces the abundance of the adipose tissues. However, GH is clearly not essential for the differentiation of adipocytes, since abundance of differentiated adipose cells was observed in GH-deficient and GH receptor deficient mice and humans (Russel-Jones *et al*., 1993). In a different study involving both muscle and adipose tissues, there was an increase in the blood levels of free fatty acids (FFA) and glycerol after acute administration of GH, suggesting a lipolytic action. This effect is apparently mediated by the inhibition of lipoprotein lipase, an enzyme involved in lipid accumulation in adipocytes (Ottosson *et al*., 1995).

The above findings highlight the lipolytic effects of GH than any effect it might have on the differentiation of the adipocytes. Since GH influences blood IGF-I levels and has been shown to cause body fat mobilization while the IGF-I was demonstrated to stimulate proliferation and differentiation particularly of the muscle tissue, then blood levels of both IGF-I and GH may be partly accounted for the leaner body composition of animals especially during the rapid growing phase where both GH and IGF-I blood levels are relatively high.

Another factor that may affect the level of body fat in animals is leptin, adipostat hormone, which stimulates GH release by regulating the Growth Hormone Releasing Hormone (GHRH) and somatostatin (SS), released by the hypothalamus. The effect of leptin on GH secretion may involve neuropeptide Y (NPY), since leptin suppresses NPY expression and infusion of NPY is known to suppress GH secretion (Chan *et al*., 1996). Similar to GH and IGF-I, the blood leptin levels may also be increasing during the rapid growing phase and decreases after maturity.

**C. IGF-I and scrotal length:** Little information is available on the putative role of the IGF-I in testicular growth, development and function. Presence of mRNA has also been demonstrated in boar testes (Clark *et al*., 1994). In addition, receptors were identified to be present in the Leydig, Sertoli cells, spermatogonia, spermatocytes and spermatids suggesting a possible role of IGFs in the regulation of testicular growth, development and function (Zhou *et al*., 1993; Lejeune *et al*., 1996). In this study, porcine plasma free IGF-I concentration has been found to have a strong negative correlation with scrotal length (r=-0.700). Although no attempt was made to quantify the somatic or seminal levels of free IGF- I in boars, data on this would be helpful in estimating the actual concentration of free IGF-I within the testes that could further explain its growth dynamics. Study of Clapper *et al.* (2000) has also implicated the possible influence of testosterone on levels of IGF- I and IGFBPs. In their study, the porcine serum testosterone concentration was found to be negatively correlated with the IGFBPs particularly IGFBP-2, while

positively correlated with IGF-I. Thus, higher serum testosterone concentration is translated to higher free IGF-I and lower IGFBPs concentration. However, more studies along this area are needed to further elucidate IGF-I and testosterone interaction in bringing about not just testicular but more so, bodily growth and development.

**D. IGF-I and live body weight:** This study also observed a negative association of the plasma free IGF-I with the live body weights of experimental boars at 15th and 24th week of age. This result must be interpreted along with the animals' age. Indeed, levels of IGF-I during the rapid growth phase is remarkably higher as compared to its blood level after the animals met their mature live weight. This growth phase is still considered as GH-dependent. However, after reaching their mature weight the animals will continue on gaining more, though GH and IGF-I blood levels gradually decline. This is possibly due to the concerted effects of other hormonal factors like testosterone and other fat tissue growth regulators that may have gain higher control over bodily gains. Thus, negative correlation between plasma free IGF-I and live body weight has been established.

**Correlations of plasma free IGF-I concentration taken at 15th and 24th week of age with the performance testing data:** The Holiday Breeder Farm conducts its own performance testing. The farm's performance testing starts at day 30 of the animal's life and those pigs passing the preliminary screening with the animal's initial live weight (at day 30) as one of the pre-qualifying standards would be tested until they reach a live weight of 90 kg or higher. Within the said testing period various production traits like Average Daily Gain, Feed Conversion Rate, Feed Intake and Backfat thickness are being noted. Since the blood and data collection were done independently with the on-going farm performance testing in the same animals (n=14), some of the experimental boars have already reached 90 kg even before week 24 (168 days), which was the 2nd and last scheduled blood and data collection for this study. Thus, results obtained by this study differ with the results of the farm's own performance testing. Nonetheless, the two levels of IGF-I (at 15th & 24th) and the change in levels of IGF-I (delta IGF-I) between two collection periods were correlated with the data on farm's performance testing to see notable relationships.

As shown in Table IV, results showed that the plasma free IGF-I concentration at 15th week of age of boars has a strong positive linear association with Feed Intake (r= 0.5408), while there are no significant correlations seen with that of Average Daily Gain, Backfat thickness and Feed Conversion Rate. A strong positive linear association was also found between plasma free IGF-I concentration at 24th week of age and Backfat thickness (r= 0.0341). No other significant correlation findings were observed between plasma free IGF-I concentration and other production traits. Correlation analysis of the change in the plasma free IGF-I concentration (delta IGF-I) between the two consecutive blood sampling (i.e., 15 & 24 weeks) showed a moderate positive linear association at P= 0.10 between delta IGF-I and Feed Intake (r= 0.494). And a significant strong negative linear association was seen with delta IGF-I and the Average Daily Gain (r= -0.571).

Correlation analysis results of free plasma IGF-I (i.e., levels at 15 weeks, levels at 24 weeks & delta IGF-I levels: difference between levels at 24 week & levels at 15 week) with data on farms performance testing of the same experimental Landrace boars showed conflicting relationships with the previously discussed associations in this study and correlation analyses reported by early researches on plasma/serum total IGF-I and growth traits. This observation highlights the importance of time in establishing valid relationships between porcine plasma free IGF-I levels and growth traits. Valid correlations are better obtained if the IGF-I blood levels taken at a particular period is synchronized with the growth traits data collection. This is mainly, because both the blood IGF-I levels and growth performance vary over time especially during the rapid growing phase as evidently seen in fast growing breeds of swine like the Landrace where mature body weight is early reached compared to slow growing pigs. Therefore, "retrospective correlation" of IGF-I and growth traits is deemed irrelevant.

## CONCLUSION

Based on the results, the IGF-I is related to the growth performance of boars. Therefore, IGF-I is a potential selection criterion for leaner body composition in pigs.

## REFERENCES

Argañosa, V.G., 1989. *A Primer on Pork Production*, p: 173. Milrose Printing Corp, Parañaque City

Baker, J., M.P. Hardy, J. Zhou, C. Bondy, F. Lupu, A.R. Bellve and A. Efstratiadis, 1996. Effects of IGF-I gene null mutation on mouse reproduction. *Mol. Endocrinol.,* 10: 903–916

Brameld, J.M., P.A.Weller, J.C. Saunders, P.J. Buttery and R.S. Gilmour, 1995. Hormonal control of insulin-like growth factor-I and growth hormone receptor mRNA expression by porcine hepatocytes in culture. *J. Endocrinol*., 146: 239–245

Buonomo, F.C. and J. Klindt, 1993. Ontogeny of growth hormone (GH), Insulin-like growth factors (IGF-I and IGF-II), and IGF binding protein-2 (IGFBP-2) in genetically lean and obese swine. *Domest. Anim. Endocrinol.,* 10: 257–265

Buonomo, F.C., T.J. Lauteria, C.A. Baile and D.R. Campion, 1987. Determination of insulin-like growth factor I (IGF- I) and IGF binding protein levels in swine. *Domest. Anim. Endocrinol.,* 4: 23–31

Chan, Y.Y., R.A. Steiner and D.K. Clifton, 1996. Regulation of hypothalamic neuropeptide-Y neurons by growtONDYh hormone in the rat. *Endocrinology*, 137: 2109–2112

Clapper, J.A., T.M. Clark and L.A. Rempel, 2000. Serum concentrations of IGF-I, estradiol-17 β, testosterone and relative amounts of IGF binding proteins (IGFBP) in growing boars, barrows and gilts. *J. Anim. Sci.,* 78: 2581–2588

Clark, A.M., S.E. Samaras, J.M. Hammond and D.R. Hagen, 1994. Changes in the messenger ribonucleic acid for insulin-like growth factor-I and II in the porcine testis during and between two waves of testicular development. *Biol. Reprod.*, 50: 993–999

Dammacco, F., M.F. Boghen, F. Cammani, M. Cappa, C. Ferrari, E. Ghigo, G. Giordano, S. Loche, F. Minuto, M. Mucci, E.E. Muller and the Italian Collaborative Group of Neuroendocrinology, 1993. Somatotrophic function on short stature: evaluation by integrated auxological and hormonal indices in 214 children. *J. Clin. Endocrinol. Metab.,* 77: 68–72

Daughaday, E. and P. Rotwein, 1989. Insulin like growth factors I and II. Peptide, messenger ribonucleic acid and gene structures, serum and tissue concentrations. *Endocrin. Rev.,* 10: 68–91

Fryburg, D.A., 1994. Insulin-like growth factor I exerts growth hormone- and insulin-like actions on human muscle protein metabolism. *American J. Physiol.,* 267: E331–336

Garlick, P.J., C.A. Maltin, A.G. Baillie, M.I. Delday and D.A. Grubb, 1989. Fiber-type composition of nine rat muscles II. Relationship to protein turnover. *American J. Physiol.,* 257: E828–832

Hadley, M., 2000. *Endocrinology*, 5th edition, p: 585. Prentice Hall, New Jersey

Jacob, R.E. Barret, G. Plewe, K.D. Fagin and R.S. Sherwin, 1989. Acute effects of insulin-like growth factor I on glucose and amino acid metabolism in awake fasted rat. Comparison with insulin. *J. Clin. Invest.,* 83: 1717–1723

Lamberson, W.R., T.J. Safranski, R.O. Bates, D.H. Keisler and R.L. Matteri, 1995. Relationship of serum insulin-like growth factor-I concentrations to growth, composition and reproductive traits of swine. *J. Anim. Sci.,* 73: 3241–3245

Lee, C.Y., C.S. Chung and F.A. Sunmen, 1993. Oncogeny of the porcine insulin- like growth factor systems. *Mol. Cell Endocrinol.,* 93: 71–80

Lee, C.Y., F.W. Bazer, T.D. Etherton and F.A. Simmen, 1991. Ontogeny of insulin- like growth factors (IGF- I & IGF- II) and IGF- binding proteins in porcine serum during fetal and postnatal development. *Endocrinology*, 128: 2336–2344

Lejeune, H., F. Chuzel, T. Thomas, O. Avallet, R. Habert, P. Durand and J. Saez, 1996. Paracrine regulation of Leydig cells. *Acta Endocrinol*., 57: 55–63

Le Roith, D., C.B.S. Yakar, J.L. Lin and A. Butler, 2001. The somatomedin hypothesis: 2001. *Endocrinol. Rev.,* 22: 53–74

Louveau, I., S. Combes, A. Cochard and M. Bonneau, 1996. Developmental changes in insulin-like growth factor-I (IGF-I) receptor levels and plasma IGF-I concentration in large white and Meishan pigs. *Gen. Comp. Endocrinol.,* 104: 29–36

Oksbjerg, N., F. Gondret and M. Vestergaard, 2004. Basic principles of muscle development and growth in meat-producing mammals as affected by the insulin-like growth factor (IGF) system. *Domes. Anim. Endocrinol.,* 27: 219–240

Ottosson, M., K. Vikman-Adolfsson, S. Enerback, A. Elander, P. Bjorntorp and S. Eden, 1995. Growth hormone inhibits lipoprotein lipase activity in human adipose tissue. *J. Clin. Endocrinol. Metab.,* 80: 936–941

Owens, D.C., K.L. Gatford, D.E. Walton, W. Morley and R.G. Campbell, 1999. The relationship between endogeneous insulin-like growth factors and growth in pigs. *J. Anim. Sci.,* 77: 2098–2103

Russel-Jones, D.L., A.J. Weissberger, S.B. Bowes, J.M. Kelly, M. Thomason, A.M. Jones and P.H. Sonksen, 1993. The effects of growth hormone on protein metabolism in adult growth hormone deficient patients. *Clin. Endocrinol.* 38: 427–431

Sara, V.R. and K. Hall, 1990. Insulin- like growth factors and their binding proteins. *Physiol. Rev.,* 70: 591–614

Shinar, D.M., N. Endo, D. Halperin, G.A. Rodan and M. Weinreb, 1993. Differential expression of insulin-like growth factor-I (IGF-I) and IGF-II messenger ribonucleic acid in growing rat bone. *Endocrinology,* 132: 1158–1167

Wang, E., J. Zhou and C.A. Bondy, 1999. Igf1 promotes longitudinal bone growth by insulin-like actions augmenting chondrocyte hypertrophy. *FASEB J*., 13: 1985–1990

Yilmaz, A., M.E. Davis and R.C.M. Simmen, 2004. Estimation of (co) variance components for reproduction traits in Angus beef cattle divergently selected for blood serum IGF- I concentrations. *J. Anim. Sci.,* 2285–2292

Zhou, J. and C. Bendy, 1993. Anatomy of the insulin- like growth factor system in the human testis. *Rertil. Steril.,* 60: 897–904

**(Received 12 July 2010; Accepted 08 September 2010)**