東北大学機関リポジトリ
TOUR
Tohoku University Repository
東北大学

Nutrition-Physiology-Gene Interactions in the Chicken

著者	AKIBA Yukio, TOYOMIZU Masaaki, TAKAHASHI Kazuaki, SATO Kan
journal or publication title	Tohoku journal of agricultural research
volume	55
number	1/2
page range	25-30
year	2004-11-25
URL	http://hdl.handle.net/10097/30045

Tohoku Journal of Agricultural Research
Vol. 55 No. 1-2, November 2004
Printed in Japan

Nutrition-Physiology-Gene Interactions in the Chicken

Yukio AKIBA, Masaaki TOYOMIZU, Kazuaki TAKAHASHI and Kan SATO

Laboratory of Animal Nutrition, Graduate School of Agricultural Science, Tohoku University, Sendai, 981-8555 Japan

(Received, September 22, 2004)

Summary

Nutrition entails the sum of processes involved in the ingestion of foods, digestion, absorption, transport of nutrients, intermediary metabolism, underlying anabolism and catabolism, and excretion of unabsorbed nutrients and metabolites. Research at the Animal Nutrition Laboratory is concerned with the identification of nutritional characteristics in several animal species with the aid of comparative biochemistry and molecular biology. This mini-review provides an overview of the nutritional regulation of metabolism, physiological functions and gene expression in avian species.

Animal nutrition is the science of investigating interrelationships between food intake and body function, and is carried out primarily by integrating biochemistry and physiology as well as other related sciences so as to understand and meet the nutritive requirements of animals under different environmental conditions. With the accumulation of knowledge and technology relating to the nutrition, biochemistry and molecular biology of tissues, cells and genes of animal species, nutrition today has evolved toward an integrated science unifying many fields of biology.

Relationship of Nutrition with Factors Involved in Glucose Metabolism in Chickens

Glucose is a fundamental energy source that, in mammals and other classes of vertebrates for example, can be transported between different tissues via the blood stream. Chickens have a blood glucose level that is twice as high as that of most mammals, and are regarded as being insulin resistant. Changes to plasma glucose concentrations in response to exogenously administered insulin are dependent on age in chickens (Tokushima *et al.*, 2003). The regulation of blood glucose in chickens is thus unorthodox and not well understood.

In order to elucidate the metabolic role of high blood glucose concentration and insulin resistance in chickens, we developed two experimental models of hypoglycemia using insulin infusion (Akiba *et al.*, 1999 ; Chida *et al.*, 2000) and administration of a sulfonylurea compound, tolbutamide, (Seki *et al.*, 2001). Using these models, persistent hypoglycemia could be induced in chickens fed a low carbohydrate diet, enabling low blood glucose concentrations to be maintained for at least 4 d.

Glucose is transported across the plasma membrane by facilitated diffusion which is mediated by glucose transporter proteins (GLUT). Among the twelve isoforms of GLUT expressed in a tissue-specific manner, GLUT4 is predominantly expressed in skeletal muscle and adipose tissue and plays a major role in insulin-responsive glucose transport in mammals (Rogers *et al.*, 2002). Northern blot analysis using a rat GLUT4 cDNA probe and RT-PCR using primers designed against conserved regions in mammalian GLUT4 cDNA were not successful in identifying GLUT4 homologue(s) in several types of chicken tissue (Seki *et al.*, 2003). Furthermore, genomic Southern blot analyses using a rat GLUT4 cDNA probe could not detect GLUT4 homologues in chicken tissue. These data infer that the GLUT4 homologous gene is deficient in chicken tissues. However, RACE reactions did identify the presence of GLUT8, another insulin-responsive glucose transporter, in chicken testis. We thus reported for the first time that broiler chickens lack the GLUT4 homologous gene but express the GLUT8 gene. It may therefore be postulated that a GLUT4 deficiency and low expression of GLUT8 in insulin responsive tissues causes, at least in part, the hyperglycemia and relative insulin resistance specifically characterized in chickens.

Nutrition and Mitochondrial Function

Uncoupling of oxidative phosphorylation in mitochondria can be an effective way to alter heat production in animals, and therefore may allow manipulation of body composition via fat reduction. The uncoupling of oxidative phosphorylation can be induced by both chemical compounds and cell-synthesized uncoupling protein (UCP), resulting in an increase of membrane proton permeability and collapse of the transmembrane proton gradient by shuttling protons across the membrane (Skulachev, 1998).

Of the natural uncouplers, anacardic acid (AA) is the product of hydrogenation of the naturally occurring unsaturated AAs, which are the chief constituents of cashew nut shell liquid. AA in the micromolar range produces uncoupling effects on state 4 respiration and the respiratory control ratio in succinate-oxidizing rat liver mitochondria. This uncoupling could be induced by the intramolecular hydrogen bonding between the phenolic and carboxylate oxygens formed in the AA anion, delocalizing the negative charge on the anions (Toyomizu

et al., 2002a). Further results of feeding experiments on rats revealed a unique function of AA, showing it to have the potential to decrease body fat deposition for dietary conditions that would normally enhance this deposition (Toyomizu *et al.*, 2003).

It is well established that bird species have no distinct stores of brown adipose tissue or any related type of thermogenic tissue (Saarela *et al.*, 1991). Little is known about diet-induced thermogenesis in birds except for studies which showed a lowered efficiency of oxidative phosphorylation in the liver mitochondria of chickens fed a high protein diet (Toyomizu *et al.*, 1995). We examined the effects of cold acclimation on the fatty acid-induced uncoupling of oxidative phosphorylation in skeletal muscle mitochondria of chickens and showed that suppression of palmitate-induced uncoupling by carboxyatractylate was greater in the subsarcolemmal skeletal muscle mitochondria from cold-acclimated chickens than that for control birds (Toyomizu *et al.*, 2002b). Northern blot analysis also showed that avUCP and avANT mRNA levels were increased 1.5- and 2.0-fold, respectively, by cold acclimation (Toyomizu *et al.*, 2002b). These increases are presumably accompanied by a decrease in respiration rate in muscle mitochondria. More recently, the possible role for PGC-1α in the transcriptional control of these genes encoding the mitochondrial uncoupling proteins was clarified, along with its role in the control of muscle fiber type expression (Ueda *et al.*, 2004).

Further screening for nutrients able to manipulate the uncoupling of oxidative phosphorylation, and clarification of the mechanisms of mitochondrial anion carrier regulation may provide new insights into applications to control meat quality and body composition of animals.

Molecular Regulation of Fat Metabolism in Chickens

Lipogenic activity in chickens is much greater in the liver than in adipose tissue. Most fats accumulated in adipose tissues can be accounted for by incorporation of triacylglycerols from plasma lipoproteins, which are either taken up as triacylglycerols from VLDL secreted and transported from the liver, or obtained from dietary fats (Griffin and Hermier, 1988). In mammals, on the other hand, fat synthesis and accumulation is mainly regulated by the adipose tissue. In chickens, the lipoprotein lipase (LPL)-catalyzed hydrolysis of triacylglycerols in adipose tissue is the rate-limiting step. The crucial role of LPL has been evidenced by inhibition of LPL activity by anti-LPL monoclonal antibodies, which cause lipemia and decrease adipose fat deposition to half that of control chickens (Sato *et al.*, 1999a). Thus, LPL has been targeted for nutritional modification in order to reduce fat deposition in chickens. However, LPL mRNA expression in growing chickens is less responsive to aging and nutritional manipulation than

that seen in mammals (Sato and Akiba, 2002), indicating the species-specificity of mechanisms regulating fat deposition as well as functionality of nutrients and/or feed ingredients. Based on the above experiments, we have further explored three possibilities to modulate chicken fat deposition; these involve the regulation of LPL-catalyzed hydrolysis (Sato *et al.*, 1999b), impairment of VLDL secretion from liver (Tachibana *et al.*, 2002; Chiba *et al.*, 2003) and alterations to adipose cell number (Sato *et al.*, 2004). From these experiments, novel methods to reduce fat deposition in chickens might be developed using new techniques involving molecular nutrition.

For decades there has been considerable interest in the modulation of cholesterol content in poultry products in order to prevent atherosclerosis and hyperlipidemia in humans. In recent studies on chicken cholesterol metabolism, we identified the molecular properties of two key enzymes, 3-hydroxy-3-methylglutaryl coenzyme A reductase and cholesterol 7-alpha hydroxylase (Sato *et al.*, 2003). Further studies on the expression of regulatory enzymes involved in cholesterol metabolism may reveal promising novel nutrients to modulate cholesterol metabolism and thereby enable the production of low-cholesterol poultry products.

Nutrition-Immune Function Interaction in Chickens

Chickens are susceptible to many kinds of stress, such as transportation to the growing site, overcrowding, vaccination, chilling and/or overheating. To maintain self-defense functions, immunocompetent cells must proliferate, express receptors for the recognition of foreign molecules, produce cytokines to regulate responses and produce antibodies and other effector molecules. To undertake these functions normally requires different nutrients to act as substrates. In general, immunological stress(es) or stimulation results in decreased nutrient intake, increased metabolic excretion and changes in nutrient partitioning. A deficiency or excess of nutrients may result in increased susceptibility to disease due to different stresses and enhance the virulence or pathogenicity of certain organisms.

An increase in dietary energy produced by corn starch, but not by corn oil, prevented suppression of body weight, feed intake and deposition of protein and energy caused by the stimulation of macrophage functions (Benson *et al.*, 1993). Supplementation of xylitol in the diet relieved the retardation of growth performance and nitrogen balance when chickens were subjected to immunological stimulation by LPS and Sephadex injections (Takahashi *et al.*, 1999, 2000b). Of the essential amino acids, branched chain amino acids (valine, leucine and isoleucine) and basic amino acids (arginine and lysine) are effective in influencing the immune function of chickens (Konashi *et al.*, 2000). We also showed that an increase of cysteine content and/or cysteine to methionine ratio in diets enhanced

immune fnction in broiler chickens (Takahashi *et al.*, 1997).

There has also been a significant upturn in interest in recent years in the functionality of conjugated linoleic acid (CLA). We suggested that CLA protected catabolic responses against endotoxin, and increased plasma IgG concentration in chickens (Takahashi *et al.*, 2002, 2003). The immune system of birds is partly developed at hatch and thereafter develops rapidly (Lowenthal *et al.*, 1994). We showed that residual egg yolk and/or supplementation of certain nutrients are important to maintain and enhance immune responses in chicks (Takahashi *et al.*, 2000a). Further investigation on the early nutritional modification of immune development in broiler chicks may improve production efficiency under stressful raising conditions.

References

Akiba, Y., Chida, Y., Takahashi, T., Ohtomo, Y., Sato, K. and Takahashi, K., *Br. Poult. Sci.*, **40**, 701-705 (1999)

Benson, B.N., Calvert, C.C., Roura, E. and Klasing, K.C., *J. Nutr.*, **123**, 1714-1723 (1993)

Chiba, T., Sato, K., Tachibana, S., Takahashi, K., Nishida, A. and Akiba, Y., *J. Poult. Sci.*, **40**, 212-220 (2003)

Chida, Y., Ohtsu, H., Takahashi, K., Sato, K., Toyomizu, M. and Akiba, Y., *Comp. Biochem. Physiol.*, **126C**, 187-193 (2000)

Griffin, H.D. and Hemier, D., "Leanness in Domestic birds" ed. by Leclercq, B. and Whitehead, C.C., Butterworths, London, U.K. pp 175-201 (1988)

Konashi, S., Takahashi, K. and Akiba, Y., *Br. J. Nutr.*, **83**, 449-4456 (2000)

Lowenthal, J.W., Connick, T.E., McWaters, P.G. and York, J.J., *Immunol. Cell. Biol.*, **72**, 115-122 (1994)

Rogers, S., Macheda, M.L., Docherty, S.E., Carty, M.D., Henderson, M.A., Soeller, W.C., Gibbs, E.M., James, D.E. and Best, J.D., *Am. J. Physiol. Endocrinol. Metab.*, **283**, E733-738 (2002)

Saarela, S., Keith, J.S., Hohtola, E. and Trayhurn, P., *Comp. Biochem. Physiol.*, **B100**, 45-49 (1991)

Sato, K., Akiba, Y., Chida, Y. and Takahashi, K., *Poult. Sci.*, **78**, 1286-1291 (1999a)

Sato, K., Takahashi, T., Takahashi, Y., Shiono, H., Katoh, N. and Akiba, Y., *J. Nutr.*, **129**, 126-131 (1999b)

Sato, K. and Akiba, Y., *Poult. Sci.*, **81**, 846-852 (2002)

Sato, K., Ohuchi, A., Seol, H.S., Toyomizu, M. and Akiba, Y., *Biochim. Biophys. Acta*, **1630**, 96-102 (2003)

Sato, K., Fukao, K. and Akiba, Y., *Poult. Sci.*, **83**, 1342-1347 (2004)

Seki, Y., Sato, K., Ohtsu, H. and Akiba, Y., *Domes. Anim. Endocr.*, **20**, 109-122 (2001)

Seki, Y., Sato, K., Kono, T., Abe, H. and Akiba, Y., *Gen. Comp. Endocrinol.*, **133**, 80-87 (2003)

Skulachev, V.P., *Biochim. Biophys. Acta*, **1363**, 100-124 (1998)

Tachibana, S., Sato, K., Takahashi, T. and Akiba, Y., *Comp. Biochem. Physiol.*, **A132**, 621-627 (2002)

Takahashi, K., Ohta, N. and Akiba, Y., *Br. J. Nutr.*, **78**, 815-821 (1997)
Takahashi, K., Onodera, K. and Akiba, Y., *Br. Poult. Sci.*, **40**, 546-548 (1999)
Takahashi, K., Akiba, Y., Ogura, N., Sulistiyanto, B. and Kaji, N., *Abstract and Proceedings CD-ROM (P.14.06) of 21st World's Poult. Cong. Montreal, Canada* (2000a)
Takahashi, K., Mashiko, K. and Akiba, Y., *Poult. Sci.*, **79**, 743-747 (2000b)
Takahashi, K., Kawamata, K., Akiba, Y., Iwata, T. and Kasai, M., *Anim. Sci. J.*, **73**, 41-46 (2002)
Takahashi, K., Kawamata, K., Akiba, Y., Iwata, T. and Kasai, M., *Br. J. Nutr.*, **89**, 691-694 (2003)
Tokushima, Y., Sulistiyanto, B., Takahashi, K., and Akiba, Y., *Brit. Poult. Sci.*, **44**, 746-751(2003)
Toyomizu, M., Tanaka, M., Kojima, M. and Ishibashi, T., *Br. J. Nutr.*, **74**, 797-806 (1995)
Toyomizu, M., Okamoto, K., Akiba, Y., Nakatsu, T. and Konishi, T., *Biochim. Biophys. Acta*, **1558**, 54-62 (2002a)
Toyomizu, M., Ueda, M., Sato, S., Seki, Y., Sato, K. and Akiba, Y., *FEBS Letters*, **529**, 313-318 (2002b)
Toyomizu, M., Okamoto, K., Ishibashi, T., Nakatsu, T. and Akiba, Y., *Animal Sci. J.*, **74**, 499-504 (2003)
Ueda, M., Watanabe, K., Sato, K., Akiba, Y. and Toyomizu, M., *FEBS Letters* (in press) (2004)