Diet-Induced Thermogenesis and Expression Levels of Thyroid Hormone Target Genes and Their Products in Rats Differ between Meat Proteins

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Summary We compared the effects of purified meat proteins on postprandial thermogenesis and on the secretion of and responsiveness to thyroid hormones (THs) in rats. Body temperatures at 2 h after feeding were significantly higher in the chicken and mutton protein groups than in the other groups, and these proteins seem to have a strong thermogenic effect. There were no significant differences in plasma TH concentrations among the groups, but levels of TH-responsive Spot 14 protein in the liver and brown adipose tissue were significantly higher in the chicken and mutton protein groups than in the other groups. Levels of malic enzyme 1 protein in the liver and brown adipose tissue were significantly higher in the chicken protein group than in the other groups except for the mutton protein group. Furthermore, levels of uncoupling protein 1 were higher in the chicken and mutton protein groups than in the other groups. The results suggest that the difference in postprandial thermogenesis of meat is strongly dependent on meat proteins; chicken and mutton proteins are strong promoters of postprandial thermogenesis, and THs may contribute to this effect. Since strong postprandial thermogenesis and high expression levels of TH target genes and their products were not observed in the amino acid group, chicken and mutton proteins or their digested peptides might contribute to these effects.

Key Words meat protein, diet-induced thermogenesis, brown adipose tissue, thyroid hormone target gene, UCP1

Daily energy expenditure consists of basal metabolic rate, energy cost of physical activity, and diet-induced thermogenesis (DIT). DIT can be defined as heat production due to consumption of a meal, and its magnitude depends on the components of the food, not the energy content of the food (1, 2). Proteins have a larger DIT effect than do carbohydrates or lipids (1–5). Since enhancement of DIT can suppress obesity (6), various foods and their ingredients that enhance DIT have been widely studied. For example, red peppers have a large DIT effect due in part to capsaicin (6–8). Green tea also has a large DIT effect due in part to catechins and caffeine (6, 7, 9). Capsaicin, catechins, and caffeine promote DIT by stimulating lipolysis and enhancing the function of brown adipose tissue (BAT), which has an important role in heat production (6–9).

Our previous studies showed that the DIT effects of meat vary depending on the source species: chicken and mutton have stronger DIT effects than those of pork and beef. Even when chicken and mutton were fractionated, the protein fractions showed strong DIT effects comparable to those of chicken and mutton (10, 11). The differences in the DIT effects of meats may be caused

by differences in meat proteins. However, to our knowledge, there has been no study on the DIT effects of meat proteins of other animal species.

Body temperature in homeothermic animals is mainly regulated by hormones such as adrenaline, noradrenaline, corticosteroids, and thyroid hormones (THs). Capsaicin acts on the brain stem and promotes the secretion of adrenaline from the adrenal medulla, resulting in a strong DIT effect (6–8). In contrast, the strong DIT effect of chicken and mutton might be due to stimulation of the secretion of THs rather than stimulation of the secretion of adrenaline (10, 11). The THs triiodothyronine (T₃) and thyroxine (T₄) play important roles in metabolic control and regulate whole-body thermogenesis, particularly basal metabolism (12, 13). Both T₃ and T₄ bind to intracellular receptors (TH receptors) to regulate the transcription of genes involved in metabolism and thermogenesis (14, 15). Genes that are markedly induced by THs include genes encoding TH-responsive Spot 14 protein (THRSP), malic enzyme 1 (ME1), and uncoupling protein 1 (UCP1) (14–17). Moreover, it has been shown that T₃ and T₄ enhanced thermogenesis in BAT by promoting *Ucp1* gene expression (14, 17). A number of studies have been carried out on the effects of THs on DIT (18–20). The results of the above-described studies indicate that the differences in the

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Table 1. Amino acid compositions of purified meat proteins and amino acid mixture.

	Purified meat protein					AA* [†]
	CP*	MP*	PP*	BP*	HP*	
Amino acid, %						
Asp	10.0	9.6	10.1	9.9	9.9	9.5
Thr	4.9	4.9	4.9	4.8	4.9	4.8
Ser	4.3	4.3	4.3	4.2	4.3	4.1
Glu	15.8	16.2	15.8	16.0	16.0	15.8
Gly	4.2	4.4	4.2	4.9	4.1	4.7
Ala	5.9	6.0	5.9	6.2	5.9	5.9
Cys	0.0	0.1	0.1	0.1	0.1	1.2
Val	5.1	5.1	5.3	5.1	5.1	5.1
Met	3.1	2.9	3.0	2.9	2.8	2.8
Ile	5.2	4.9	5.1	5.0	5.0	4.8
Leu	8.7	8.9	8.8	8.9	9.1	8.3
Tyr	3.8	3.8	3.8	3.7	3.9	3.6
Phe	4.4	4.4	4.4	4.4	4.6	4.1
Lys	9.6	9.7	9.6	9.1	9.6	9.3
His	2.8	2.8	2.8	2.8	2.9	4.4
Trp	0.8	0.8	0.8	0.7	0.8	1.1
Arg	7.3	7.1	7.0	7.0	7.0	6.6
Pro	4.0	4.2	4.0	4.3	4.2	4.0

* CP: chicken protein, MP: mutton protein, PP: pork protein, BP: beef protein, HP: horse meat protein, AA: amino acids.

[†] Amino acid ratio is based on the average value of amino acid compositions of five kinds of lean meat (chicken, mutton, pork, beef and horse meat) described in Standard Tables of Food Composition in Japan 2010.

effects of meat on DIT might be caused by differences in the effects of meat proteins on the secretion and responsiveness of THs.

To determine whether the differences in effects of meat on DIT are caused by differences in meat proteins, we compared the body temperatures of rats that were fed diets containing different meat proteins. With a focus on THs and their responsiveness, we also compared the expression levels of TH target genes and their translation products in the liver and BAT, both of which are major heat-producing tissues in the body at rest.

MATERIALS AND METHODS

Animals and diets. This study was approved by the Laboratory Animal Care Committee of Hokkaido University. The experiment was carried out as in our previous study (10). Five-week-old male Wistar rats were purchased from Japan Laboratory Animals Inc. (Tokyo, Japan). The rats were housed individually in stainless steel cages with a 12-h light–dark cycle (lights on from 10:00 to 22:00) in an isolated room at a temperature of 22–24°C and humidity of 40–60%. For 1 wk before the experiment, all of the rats were acclimatized to an AIN-93G diet (using corn oil in place of soybean oil). The rats had free access to feed and water.

Chicken legs, mutton hind legs, pork outside round, beef bottom round, and horse round meat were pur-

Table 2. Compositions of the experimental diets.

	Diet					AA*
	CP*	MP*	PP*	BP*	HP*	
Ingredient, %						
CP*	17.4	—	—	—	—	—
MP*	—	18.1	—	—	—	—
PP*	—	—	18.0	—	—	—
BP*	—	—	—	17.9	—	—
HP*	—	—	—	—	18.1	—
AA*	—	—	—	—	—	19.5
Corn oil	7.0	7.0	7.0	7.0	7.0	7.0
Corn starch	55.5	54.9	55.0	55.1	54.9	53.4
Nutrient, %						
Total protein	17.3	17.3	17.3	17.3	17.3	17.3
Total fat	7.0	7.0	7.0	7.0	7.0	7.0

Other constituents common to both diets include cellulose (5%), sucrose (10%), L-cystine (0.3%), mineral mix (3.5%), vitamin mix (0.1%), and choline bitartrate (0.25%). Vitamin and mineral mixes were formulated according to AIN-93G. Diet components were purchased from CLEA Japan, Inc., Tokyo, Japan.

* CP, chicken protein; MP, mutton protein; PP, pork protein; BP, beef protein; HP, horse meat protein; AA, amino acids.

chased from a domestic market. Proteins in the meat were purified as described previously (10). First, as much fat and connective tissue as possible were removed, and then the meat was ground and freeze-dried. The freeze-dried meat was defatted with *n*-hexane and then washed with hot ethanol and boiling water. The protein contents of each preparation, calculated from the N content determined by the Kjeldahl method, were 99.2% for chicken protein (CP), 95.8% for mutton protein (MP), 96.3% for pork protein (PP), 96.9% for beef protein (BP), and 95.6% for horse meat protein (HP). Amino acid composition analysis of the purified protein was outsourced to Instrumental Analysis Division, Equipment Management Center, Creative Research Institution, Hokkaido University (ninhydrin method after hydrolysis with 3 M mercaptoethanesulfonic acid at 110°C for 22 h; Table 1). We mixed amino acids (AA) on the basis of the composition of these lean meats (Standard Tables of Food Composition in Japan 2010 (21), Table 1), creating a preparation with a protein content of 88.5%. Using each preparation, we prepared AIN-93G diets (using corn oil) with the same contents of protein and fat (Table 2). After fasting for 18 h, the rats were fed the experimental diets (7 g/animal) in the last 1 h of the dark cycle (from 22:00 to 10:00).

Measurements of body weight and body temperature. Eighteen rats were prepared as described previously (10). Immediately after feeding for 1 h, the rats were anesthetized with an intraperitoneal injection of urethane (700 mg/kg) and α -chloralose (60 mg/kg), and body weights were measured (“immediately after feeding” = 0 h). To exclude the effect of heat loss, temperature

Fig. 1. Changes in postprandial body temperatures (A, rectal; B, dorsal; C, concha; D, sole) of rats fed diets containing purified meat protein (CP, chicken protein; MP, mutton protein; PP, pork protein; BP, beef protein; HP, horse meat protein) or amino acids (AA) after feeding for 1 h. Values are means $\pm$ SEM (1, 2 and 3 h after feeding; $n=18$, 12, and 6 rats per group, respectively). Columns with different letters are significantly different ($p<0.05$; Tukey's multiple comparison test).

was measured on a thermostatic plate (33°C, KN-210-6, Natsume Seisakusho Co. Ltd., Tokyo, Japan) in a room at a controlled temperature of 33°C. To measure rectal temperature, we gently inserted a glycerol-dipped thermocouple 2 cm into the rectum (1600K-T21-ASP, Anritsu Meter Co. Ltd., Tokyo, Japan) and read the temperature on a CT-1307 thermometer (Custom, Tokyo, Japan). The back hair was clipped short and the dorsal temperature was measured at the interscapular area with an infrared thermometer (IT-550, Horiba Ltd., Kyoto, Japan). Concha and sole temperatures were also measured with an infrared thermometer.

Immediately after each hourly measurement of body temperature, six anesthetized rats were bled out through the inferior vena cava, and blood was collected into plastic tubes containing EDTA (2 mg/mL). The right lobe of the liver and interscapular BAT were then removed and immediately frozen in liquid nitrogen. Plasma was separated from the blood by centrifugation, and all plasma and tissue samples were stored at -80°C until analysis.

Analysis of thyroid hormones in plasma. Total levels of T_3 and T_4 in plasma were measured using the ECLIA (electrochemiluminescent immunoassay) method by a clinical laboratory testing service (SRL Inc., Tokyo, Japan).

RNA extraction and quantitative real-time PCR. Total RNA was extracted from the liver and BAT with ISOGEN II reagent (Nippon Gene Co. Ltd., Tokyo, Japan), and 1 μg of RNA was reverse-transcribed with a Transcriptor First-Strand cDNA Synthesis Kit (Roche Diagnostics GmbH, Mannheim, Germany) to generate cDNA (11). Real-time PCR was performed with 2 μL of cDNA in a LightCycler FastStart DNA MasterPLUS SYBR Green I Kit (Roche Diagnostics) using the following primers: for *Thrsp*, F 5'-GAGCCCCCGATCTCTATACC-3' and R 5'-GGCTTC-TAGGTCCAGCTCCT-3'; for *Me1*, F 5'-AGGCCTCTT-TATCAGTATCCAC-3' and R 5'-CCATCCCGTTACAAC-CAA-3'; for *Ucp1*, F 5'-CCACATAGGCGACTTGGA-3' and R 5'-TTCGTGGTCTCCAGCATAG-3'; and for β -actin (*Actb*), F 5'-AGCCATGTACGTAGCCATCC-3' and

Table 3. Food intake during 1 h of feeding and body weights of each group of rats fed the experimental diets.

	CP*	MP*	PP*	BP*	HP*	AA*	Significant difference
Food intake, g							
1 h [†]	3.98±0.25	4.68±0.52	4.42±0.40	4.95±0.13	4.37±0.40	3.48±0.48	N.S.
2 h [†]	4.68±0.46	3.98±0.50	4.55±0.62	4.30±0.33	4.15±0.40	3.93±0.32	N.S.
3 h [†]	5.00±0.48	4.78±0.36	4.55±0.24	4.50±0.47	4.52±0.52	3.47±0.20	N.S.
Body weight, g							
1 h [†]	184.5±3.4	182.1±1.4	184.9±1.3	180.4±2.2	179.3±3.0	185.9±3.1	N.S.
2 h [†]	182.4±2.2	180.5±1.8	183.4±1.7	179.3±5.4	181.4±1.9	186.1±3.0	N.S.
3 h [†]	187.4±2.2	182.2±1.5	186.8±3.6	181.8±3.1	178.2±3.1	182.0±2.8	N.S.

Values are means±SEM (*n*=6 rats per group).

* CP, chicken protein; MP, mutton protein; PP, pork protein; BP, beef protein; HP, horse meat protein; AA, amino acids.

[†] Elapsed time after feeding.

Table 4. Plasma T₃ and T₄ levels in rats fed the experimental diets.

	CP*	MP*	PP*	BP*	HP*	AA*
T ₃ , ng/mL						
1 h [†]	1.11±0.04	1.12±0.05	1.11±0.04	1.11±0.04	1.16±0.03 ^a	1.24±0.06
2 h [†]	1.08±0.04	1.14±0.05	1.14±0.03	1.09±0.03	1.06±0.04 ^b	1.07±0.06
T ₄ , µg/dL						
1 h [†]	4.21±0.22 ^a	4.26±0.30	3.90±0.23	3.65±0.22	3.76±0.14	4.35±0.25 ^a
2 h [†]	3.45±0.13 ^b	3.71±0.23	3.94±0.19	3.47±0.22	3.55±0.16	3.34±0.14 ^b

Values are means±SEM (*n*=6 rats per group). Columns with different letters are significantly different between 1 and 2 h within the same group (*p*<0.05).

* CP, chicken protein; MP, mutton protein; PP, pork protein; BP, beef protein; HP, horse meat protein; AA, amino acids.

[†] Elapsed time after feeding.

R 5'-CTCTCAGCTGTGGTGGTGA-3'. The PCR conditions for amplification were 45 cycles of denaturation at 95°C for 10 s; annealing at 56°C (*Thrsp*), 52°C (*Me1*), 55°C (*Ucp1*), or 54°C (*Actb*) for 5 s; and extension at 72°C for 10 s.

SDS-PAGE and Western blotting. For extraction of proteins, each liver and BAT sample was homogenized in an extraction buffer containing 50 mM Tris-HCl (pH 6.8), 20% glycerol, 1% 2-mercaptoethanol, and 1% SDS (liver) or 2% SDS (BAT) and then heated at 105°C for 5 min to denature the proteins. Each extract was centrifuged at 2,070 × *g* for 10 min (4°C), and the supernatants were collected. Each sample was separated in 12.5% SDS-polyacrylamide gel, and the separated proteins were transferred onto Hybond™-P PVDF membranes (30 V, 30 min; General Electric Company, Fairfield, CT). After brief washing in T-PBS (137 mM NaCl, 2.68 mM KCl, 8.10 mM Na₂HPO₄, 1.47 mM KH₂PO₄, 0.1% Tween 20, unadjusted pH), the membranes were blocked with 0.5% skim milk in T-PBS for 1.5 h at room temperature. The membranes were then incubated for 1 h at room temperature with primary antibodies in blocking buffer: rabbit polyclonal antibodies against THRSP (1/200 for liver, 1/150 for BAT; Santa Cruz Biotechnology Inc., Dallas, TX), ME1 (1/300 for liver, 1/500 for BAT; Santa Cruz Biotechnology), UCP1

(1/1,000 for BAT; AnaSpec Inc., Fremont, CA), and β-actin (1/1,000 for liver, 1/500 for BAT; AnaSpec). After washes in T-PBS, the membranes were incubated for 2 h at room temperature with horseradish peroxidase-conjugated anti-rabbit IgG (H+L) secondary antibody (1/10,000; Chemicon International Inc., Billerica, MA) in blocking buffer. After further washes in T-PBS, the membranes were treated with chemiluminescence detection reagents (Chemi-Lumi One L, Nacalai Tesque Inc., Kyoto, Japan), and immunoreactive protein bands were visualized in a ChemiDoc™ XRS Plus System and analyzed by Image Lab™ software (both from Bio-Rad Laboratories Inc., Hercules, CA).

Statistical analysis. Values are given as means±SEM. All data were analyzed by parametric one-way analysis of variance (ANOVA) and then by Tukey's multiple comparison test when appropriate (Excel Toukei 2006, Social Survey Research Information Co., Ltd., Japan). A *p* value of <0.05 was considered statistically significant.

RESULTS

Postprandial changes in body temperatures of rats fed the experimental diets

All body temperatures in each of the feeding groups approached their peaks at 2 h after feeding, and dorsal, concha, and sole temperatures were significantly higher

Fig. 2. Effects of meat protein diets (CP, chicken protein; MP, mutton protein; PP, pork protein; BP, beef protein; HP, horse meat protein) on the expression of thyroid hormone target genes and their translation products in the rat liver. A, relative expression of thyroid hormone-responsive Spot 14 protein (THRSP) mRNA; B, representative bands of THRSP; C, relative production of THRSP; D, relative expression of malic enzyme 1 (ME1) mRNA; E, representative bands of ME1 protein; F, relative production of ME1 protein. Samples were collected at 1, 2, and 3 h after feeding for 1 h. Values are normalized to β -actin. Values are means $\pm$ SEM ($n=6$ rats per group). Columns with different letters are significantly different ($p<0.05$; Tukey's multiple comparison test).

in the CP and MP groups than in the other groups (Fig. 1A–D). The high concha temperatures in the CP and MP groups were maintained at 3 h after feeding. All body temperatures in the AA group were as low as those in the PP, BP, and HP groups. There were no significant differences in food intake or body weight among the groups (Table 3).

Plasma T_3 and T_4 levels in rats

Levels of T_3 and T_4 did not differ significantly among the groups at 1 or 2 h after feeding (Table 4). However, the level of T_3 at 1 h after feeding was significantly higher than that at 2 h after feeding in the HP group, and the level of T_4 at 1 h after feeding was significantly higher than that at 2 h after feeding in the CP and AA groups.

Levels of thyroid hormone target genes and translation products in the liver

The levels of *Thrsp* mRNA at 1, 2, and 3 h after feeding were not significantly different among the groups (Fig. 2A). However, the level of THRSP protein at 3 h after feeding was significantly higher in the CP and MP groups than in the other groups (Fig. 2B, C). The levels of *Me1* mRNA at 1 and 2 h after feeding were not

significantly different among the groups, but the level at 3 h after feeding was significantly higher in the CP group than in the AA group (Fig. 2D). The level of ME1 protein at 3 h after feeding in the CP group was significantly higher than that in the other groups except for the MP group (Fig. 2E, F).

Levels of thyroid hormone target genes and translation products in BAT

The level of *Thrsp* mRNA at 1 h after feeding was significantly higher and the levels at 2 and 3 h after feeding tended to be higher, in the MP group than in the other groups (Fig. 3A). The level of THRSP protein at 3 h after feeding was significantly higher in the CP and MP groups than in the other groups (Fig. 3B, C). The levels of *Me1* mRNA at 1, 2, and 3 h after feeding were not significantly different among the groups (Fig. 3D). However, the level of ME1 protein at 3 h after feeding was significantly higher in the CP group than in the other groups except for the MP group (Fig. 3E, F). The levels of *Ucp1* mRNA at 1, 2, and 3 h after feeding were not significantly different among the groups (Fig. 3G). However, the level of UCP1 protein at 3 h after feeding was significantly higher in the CP and MP groups than in the

Fig. 3. Effects of meat protein diets (CP, chicken protein; MP, mutton protein; PP, pork protein; BP, beef protein; HP, horse meat protein) on the expression of thyroid hormone target genes and their translation products in rat BAT. A, relative expression of thyroid hormone-responsive Spot 14 protein (THRSP) mRNA; B, representative bands of THRSP; C, relative production of THRSP; D, relative expression of malic enzyme 1 (ME1) mRNA; E, representative bands of ME1 protein; F, relative production of ME1 protein; G, relative expression of uncoupling protein 1 (UCP1) mRNA; H, representative bands of UCP1 protein; I, relative production of UCP1 protein. Samples were collected at 1, 2, and 3 h after feeding for 1 h. Values are normalized to β -actin. Values are means $\pm$ SEM ($n=6$ rats per group). Columns with different letters are significantly different ($p<0.05$; Tukey's multiple comparison test).

HP and AA groups (Fig. 3H, I).

DISCUSSION

In this study, we compared the effects of purified meat proteins on postprandial thermogenesis and on the secretion of and responsiveness to thyroid hormones in rats. In order to reproduce the response in humans, we gave the rats experimental diets including not only

the proteins but also other nutrients. Body temperatures measured at 2 h after feeding, when they had almost peaked, were higher in the CP and MP groups than in the other groups. The temperatures of the concha and rectum remained high even at 3 h after feeding in the MP group. In agreement with our previous results, CP and MP had stronger DIT-enhancing effects than those of the other proteins (10, 11). Therefore, the purified

proteins contributed to differences in the effects of meat consumption on DIT. Although traditional Chinese medicine claims that horse meat “cools” the body (22, 23), its protein fraction had no DIT-suppressing effect. Since we could not clarify whether the consumption of horse meat cools the body, further studies are needed.

THs are likely to be involved in the enhancing effects of chicken and mutton on DIT (10, 11). Thus, different meat proteins may have different effects on the secretion of, or responsiveness to, THs. The level of *Thrsp* mRNA in BAT at 1 h after feeding was high in the MP group, in which there was a large DIT effect. The levels of THRSP in both the liver and BAT at 3 h after feeding were high in the CP and MP groups, in both of which there was a large DIT effect. The response of *Thrsp* to THs is so fast that its expression is regulated before that of other TH target genes; *Thrsp* regulates the expression of enzymes involved in subsequent lipid metabolism (14, 24, 25). Thus, there may have been rapid transcriptional regulation of *Thrsp* by THs in the CP and MP groups, resulting in increased production of the proteins. The levels of *Me1* mRNA in the liver and of ME1 protein in the liver and BAT at 3 h after feeding were high in the CP group. The expression of *Me1* is regulated not only directly by THs but also indirectly by THRSP (14). Therefore, this biphasic transcriptional regulation of *Me1* may have increased the production of the protein in the CP group. These results show that different meat proteins had different effects on THs and that in the CP and MP groups, in which there were large DIT effects, expression levels of TH target genes and their products were high. However, the levels of *Me1* and ME1 were not high in the MP group. These results show that the effect of MP on THs is likely to be different from that of CP.

Plasma T_3 and T_4 levels were not high in the CP and MP groups. T_3 has high affinity for TH receptors in tissues, and T_4 is converted to T_3 through the action of deiodinase (Dio) (26). Thus, differences in the activity of Dio influence tissue responsiveness to THs. However, neither *Dio1* mRNA (highly expressed in the liver (27)) nor *Dio2* mRNA (highly expressed in BAT (28)) levels were high in the CP or MP groups (data not shown). Therefore, the enhancing effects of CP and MP on expression levels of TH target genes and their products likely resulted from the direct action of THs. Because the plasma T_4 level in the CP group was significantly reduced between 1 and 2 h after feeding, the T_4 level in the first hour after feeding was likely to have been higher. Feedback inhibition may already have acted, and differences among meat proteins in effects on THs or their target genes likely occurred in the first hour after feeding. Therefore, the expression levels of their translation products may have been high in the CP and MP groups.

Dorsal temperature was higher in the CP and MP groups than in the other groups. The level of UCP1 protein in BAT was high in the CP and MP groups. BAT is the only tissue in the body that functions only to produce heat, and UCP1 plays a key role in this mechanism. Because UCP1 is an uncoupling protein that converts the energy emitted during the oxidation process of the

electron transport chain directly to heat (29–31), any difference in UCP1 action alters the amount of heat production. Previous studies have shown that an increase in T_3 concentration enhances the promotive effect of noradrenaline on *Ucp1* mRNA expression in BAT in rats (17, 32–34). Thus, THs were very likely to have been involved in the regulation of levels of *Ucp1* mRNA and UCP1 protein in the CP and MP groups. The results suggest that thermogenesis by UCP1 in BAT played a major role in the DIT-enhancing effects of CP and MP and that THs were involved in this mechanism.

Our results did not show high body temperatures in the AA group. In recent years, many bioactive peptides have been identified in food protein digests, and it has been shown that peptides obtained through proteolysis play a role in biological regulation (35–37). For example, angiotensin 1-converting enzyme inhibitory peptides (38) and peptides with a plasma cholesterol-reducing effect (39) have been derived from soy protein. The amino acid compositions of meat proteins are similar, but the amino acid sequences might be different. Thus, digestion-derived peptides from meat proteins may vary, and this variation may affect how they influence DIT. Therefore, proteins or their digested peptides derived from CP and MP are assumed to contribute to DIT. However, from the fact that the effects of CP and MP on THs may be different, the CP-derived peptides contributing to DIT may be different from those of MP. Further studies are needed to elucidate the mechanisms by which consumption of CP and MP raises body temperature.

CONCLUSIONS

The DIT-enhancing effects of meat proteins differ between animal species, and CP and MP have strong DIT effects. In addition, thermogenesis by UCP1 in BAT plays a major role in the strong DIT effects of CP and MP, and THs are involved in this mechanism. Because there is little difference in the amino acid composition of meat proteins from different animal species, proteins or their digested peptides may be involved in the strong DIT effects of CP and MP.

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