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Original article

Effects of ostrich meat intake on amino acid metabolism and growth hormone secretion: A clinical trial by repeated measurement

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Abstract

***Purpose*:** Chicken (especially breast meat) is a popular food for health-conscious people due to its low fat and high protein content. In this study, we focused on ostrich meat (OM), which is attracting attention from the perspective of Sustainable Development Goals (SDGs), and examined changes in blood amino acid composition after consumption, and compared it with blood composition after consuming chicken meat (CM).

***Methods*:** The subjects were 9 healthy men and women (2 men, 7 women, 23.0 ± 1.2 years old, BMI 20.1 ± 2.2). The test foods were OM food and CM (breast meat) food with adjusted protein content (20 g). CM food was consumed for the first 7 days and after a 1-month rest period, the subjects started taking OM for the latter 7 days. Blood tests were then performed at 1 day and 7 days after intake, respectively.

***Results*:** Seven days after ingesting the test food, the plasma amino acid composition showed a significant increase in taurine with OM intake, and a slight increase in citrulline and 3-methylhistidine with CM intake, while there was no difference in the total amino acid content. There was no difference in plasma aldehyde (3-deoxyglucosone, glyoxal, methylglyoxal) between the two groups, showing no difference in aldehyde trapping effect. Peripheral blood tests showed that the red blood cell count, hemoglobin content, and hematocrit value decreased by 3 to 5% when CM was ingested due to iron loss by blood sampling, whereas this was alleviated when OM, which has a high iron content, was ingested. No adverse events were observed during the study period.

***Conclusion*:** Among high-protein, low-fat avian meats, ostrich meat is richer in taurine and iron than chicken breast, making it a useful food for health-conscious people.

***KEY WORDS*:** ostrich meat, amino acids, taurine, iron, glycative stress

Introduction

In recent years, when considering the food situation, we have entered an era in which it is necessary to consider contributions to improving nutritional status and reducing the risk of starvation on a global scale. Plant-based foods made from legumes and cultured mycelium, which are more efficiently produced as protein foods than grain-fed meat, are also being researched as new food resources with low environmental impact. The ostrich used in this study has a low environmental impact and is a sustainable livestock. Flightless birds such as ostriches are called “ratites” and belong to the taxonomic group “paleognathians”. Ostriches, found in Africa, were the first of the modern paleognathians to diverge from other species. The flightlessness of ratites is not necessarily due to their primitive nature, but rather as a result of them adapting to life on the ground in order to survive [1,2].

The ostrich, which evolved to survive on the African savannah, has a long intestine and excellent digestive ability,

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and its abundance of intestinal bacteria produces a large amount of amino acids, allowing it to absorb nutrients with high efficiency. According to the Ministry of Agriculture, Forestry and Fisheries document "Did you know? Japan's food situation", the amount of grain (corn equivalent) required to produce 1 kg of livestock products is 11 kg for beef, 7 kg for pork, and 4 kg for chicken[3]. On the other hand, ostrich meat requires 4 kg of grain (calculated based on the assumption that 40 kg of meat can be obtained from 100 kg of ostrich). However, the main feed is not grains such as corn, so the advantage is that the feed is inedible for humans (*e.g.*, grass and vegetable scraps from food factories).

Regarding skeletal muscles, the wing and pectoral muscles have degenerated, but the skeletal muscles of the skeleton, thighs, and hips have evolved to enhance running ability in order to escape from natural enemies[4,5]. Therefore, ostrich thigh meat may contain nutritional components that help maintain muscle strength and endurance. In this study, we investigated changes in blood amino acid composition when ostrich meat was ingested and compared it with blood composition after ingesting chicken meat.

Method

Test implementation system

This study was evaluated by an ethics review committee consisting of a third party not involved in the study, in order to ensure the human rights and safety of test participants and the reliability of test data. The Ethics Review Committee for Research Involving Human Subjects of the Glycation Stress Research Association approved this study (approval number 2022-007, November 7, 2022). The study was conducted from December 2022 to January 2023 at the Anti-Aging Research Center, Faculty of Biomedical Sciences, Doshisha University (principal investigator: Yoshikazu Yonei) based on the study implementation plan (UMIN study ID: UMIN000049501). In conducting the study, we complied with ethical principles based on the Declaration of Helsinki (amended at the 2013 WMA Fortaleza General Meeting "Brazil") and the ethical guidelines for life science and medical research involving human subjects (Notification No. 1 of the Ministry of Education, Culture, Sports, Science and Technology, Ministry of Health, Labor and Welfare, and Ministry of Economy, Trade and Industry, 2021).

Subject

After conducting a study briefing session, nine healthy men and women between the ages of 20 and 40 who had given prior written consent to participate in this study and who did not meet the following exclusion criteria were included as subjects.

1) Those who are currently suffering from some kind of disease and are receiving drug treatment.
2) Persons with a past or current history of serious disorders of the liver, kidneys, heart, lungs, blood, etc.
3) Subjects with severe anemia.
4) Persons who may develop allergic symptoms to test foods, or those who may develop severe allergic symptoms to other foods or medicines.
5) Those who regularly consume high protein foods such as protein powder.
6) Those who are pregnant, breastfeeding, or may become pregnant.
7) Those who are currently participating in another human clinical trial, or 3 months have passed since participating in another human clinical trial.
8) Those who regularly take the following supplements/ health foods (*e.g.*, vitamins, folic acid, iron).
9) Other individuals who are judged by the study director to be inappropriate as subjects for this study

This study started with 9 people, and on the final test day (Visit-6), 2 people were unable to undergo the test due to reasons unrelated to this study. All test subjects were included in the analysis at the post-test case review meeting, and any data that could not be collected were treated as missing data.

Study design

As test foods, ham (protein amount 20 g) with ostrich meat (Yoshinoya Holdings Co., Ltd., Tokyo, Japan) was used as ostrich meat meal (OM) (***Fig. 1***), and Salad chicken (commercial product, protein content 20 g) with chicken breast meat (CM) was used as a control meal. The nutritional components of OM and CM are shown in ***Table 1***. ***Table 2*** shows the amino acid content per 100 g of OM.

The test schedule is shown in ***Fig. 2***. First, subjects were given a designated basic meal (BM, 200 g of steamed rice and a rice seasoning topping) and a cup of miso soup

Fig. 1. **Appearance of test food (ostrich meat).**

Table 1. Nutritional composition.

	Control food Steamed chicken (87 g)	Test food Smoked ham (91 g)
Water (g)	62.4	62.2
Energy (kcal)	96	112
Protein (g)	20.0	20.0
Carbohydrate (g)	1.6	4.4
Fat (g)	1.1	1.5
Sodium (mg)	282	783

for dinner on the day before the test (−1 day) and on the day of the test (day 0, Visit-1 and Visit-4). Subjects came to the facility without ingesting breakfast on the day they started taking the test food (Visit-2 and Visit-5), and after coming to the facility, they ingested OM (Visit-5) or CM (Visit-2) along with BM. For the following 5 days, subjects consumed OM or CM with BM at breakfast. For dinner on the 6th day, they ingested the same BM and a cup of miso soup as on day −1 and 0, and on the 7th day of intake, they came to the facility without having breakfast (Visit-3 and Visit-6), and after coming to the facility, they ingested OM (Visit-6) or CM (Visit-3) along with BM. For Visit-1 and Visit-4, physical measurements and blood samples were taken after the visit. For Visit-2, Visit-3, Visit-5, and Visit-6, after physical measurements were taken, the test food was ingested as described above, and after a 3-hour waiting period, blood samples were obtained.

Table 2. Amino acid composition.

Amino acid content per 100 g ostrich meat	
Arginine	1.32 g
Lysine	1.85 g
Histidine	0.56 g
Phenylalanine	0.94 g
Tyrosine	0.73 g
Leucine	0.75 g
Isoleucine	1.02 g
Methionine	0.55 g
Valine	1.08 g
Alanine	1.23 g
Glycine	0.93 g
Proline	0.91 g
Glutamic acid	3.78 g
Serine	0.94 g
Threonine	0.98 g
Aspartic acid	1.91 g
Tryptophan	0.29 g
Cystine	0.27 g
Taurine	0.12 g

Evaluation item

Body measurements

Physical measurements included height, weight, body fat percentage, and body mass index (BMI). A TANITA multi-frequency body composition meter MC-780A-N portable type (Tanita Co., Ltd., Tokyo) was used for body composition testing.

Blood test

Peripheral blood tests and biochemical tests were performed using blood samples. The evaluation items this time were amino acid analysis, vitamin B12, glucose, plasma aldehyde (3-deoxyglucosone; 3DG, glyoxal; GO, methylglyoxal; MGO), and peripheral hematology tests (white blood cell count [WBC], red blood cell count [RBC], hemoglobin [Hb], hematocrit [Ht], mean corpuscular volume [MCV], mean corpuscular hemoglobin [MCH], mean corpuscular hemoglobin concentration [MCHC], platelet count). Among the tests using blood samples, blood aldehyde was measured at the Glycation Stress Research Center, Faculty of Biomedical Sciences, Doshisha University (Kyotanabe, Kyoto, Japan), and other items were measured at LSI Medience Co., Ltd. (Tokyo, Japan).

Statistical analysis

Statistical analysis was performed using the statistical analysis software Excel Statistics (Social Information Service, Tokyo). Paired t test was used for comparative analysis with Day 0. Student's t test was used for between-group analysis. A significant difference was defined as a risk rate of less than 5%. No outliers were set. However, if data could not be obtained due to testing problems, or if there were major problems with the reliability of the data, they were treated as missing values and no alternative values were used.

		Visit-1		Visit-2						Visit-3
		day −1	day 0	day 1	day 2	day 3	day 4	day 5	day 6	day 7
Phase I	Breakfast	Meals as usual		No meal ※	**Steamed chicken + Steamed rice**					No meal ※
	Lunch	Meals as usual								
	Dinner	Designated meals		Meals as usual					Designated meals	Meals as usual

		Visit-4		Visit-5						Visit-6
		day −1	day 0	day 1	day 2	day 3	day 4	day 5	day 6	day 7
Phase II	Breakfast	Meals as usual		No meal ※	**OM + Steamed rice**					No meal ※
	Lunch	Meals as usual								
	Dinner	Designated meals		Meals as usual					Designated meals	Meals as usual

Fig. 2. **The test schedule.**

No meal ※ = Participants did not eat at home, but took the test meal (Steamed chicken+Steamed rice or OM+Steamed rice) after coming to the testing site. OM, ostrich meat.

Result

General background

The general background of the 9 subjects for analysis was 2 males and 7 females, age 23.0 ± 1.2 years, height 162.0 ± 7.7 cm, weight 52.7 ± 6.6 kg, body fat percentage 26.0 ± 6.6 %, and BMI 20.1 ± 2.2 (***Table 3***).

Table 3. Anthropometry.

		Mean		SD
Age	year	23.0	±	1.2
Height	cm	162.0	±	7.7
Weight	kg	52.7	±	6.6
Body fat	%	26.0	±	6.6
BMI		20.1	±	2.2

n = 9. BMI, body mass index; SD, standard deviation.

Amino acid analysis

Table 4 and ***Fig. 3*** show the results of plasma amino acid analysis. The blood amino acid analysis at each visit showed that, in the OM intake group, the amino acids (taurine, threonine, asparagine, proline, glycine, alanine, citrulline, valine, cystine, methionine, isoleucine, leucine, tyrosine, β-alanine, phenylalanine, ornithine, 1-methylhistidine, histidine, lysine, 3-methylhistidine, tryptophan, and arginine) significantly increased on the first day of intake (day 1, Visit-5) and on the 7th day of intake (day 7, Visit-6) compared to before intake (day 0, Visit-4). In addition, the glutamine and Fisher ratios significantly increased on day 7 (Visit-6) compared to day 0 (Visit-4).

On the 7th day of intake, significant differences were observed between the OM intake group and the CM intake group in taurine, citrulline, and 3-methylhistidine. Taurine was increased in the OM intake group on both days 1 (Visit-2, 5) and day 7 (Visit-3, 6, $p < 0.01$). 3-Methylhistidine was significantly increased ($p < 0.01$) on the day 1 (Visit-2, 5) and day 7 (Visit-3, 6), but the amount of change was slight. A significant increase in citrulline was observed in the CM intake group on day 7 (Visits-3 and 6, $p < 0.5$). There was no difference in total amino acid content (sum of measurement items) between the two groups.

Vitamin B12

Vitamin B12 significantly increased on day 7 of CM intake (Visit-3) compared to day 0 (Visit-1), but there was no significant difference between groups compared to the OM intake group (***Table 5***).

Blood glucose (PG)

Blood glucose (PG) significantly decreased on day 1 of OM intake (Visit-5) compared to day 0 (Visit-4), and there was a significant difference between groups compared to the CM intake group ($p < 0.01$, ***Table 5***). The CM intake group showed a significant decrease on day 7 (Visit-3) compared to day 0 (Visit-1), but there was no significant difference between the groups.

Plasma aldehydes (3DG, GO, MGO)

Among blood aldehydes, no significant changes were observed in 3DG and GO in both the OM and CM intake groups. MGO significantly increased on day 1 (Visit-2) and day 7 (Visit-3) of CM intake compared to day 0 (Visit-1). There were no differences between groups in the amount of change for any item (***Table 6***).

Hematological tests

Changes in peripheral blood are shown in ***Table 7*** and ***Fig. 4***. In the CM intake group, the RBC count, Hb content, and Ht on day 1 (Visit-2) and day 7 (Visit-3) significantly decreased compared to day 0 (Visit-1). The effect remained even on day 7; the rate change rate was −3.4 % in RBC, −5.0 % in Hb content, and −3.4 % in Ht.

On the other hand, the decrease in these three items was alleviated in the OM intake group. The RBC count was significantly decreased on the first day (Visit-5) compared to before intake (Visit-4) (***Fig. 4-a***). No significant decrease was observed on day 7 (Visit-6). No significant decrease in Hb or Ht was observed at any time point compared to day 0 (Visit-4) (***Fig. 4-b, c***).

In a group comparison with the CM intake group, there was no significant difference in RBC on day 7 (Visit-6) of intake. It was shown that the decrease in the OM intake group was significantly alleviated on day 1 of RBC (Visit-5), and on day 1 and day 7 of Hb and RBC (Visit-5, 7).

MCV significantly increased only on day 7 of OM intake (Visit-6) compared to day 0 (Visit-4) with a significant difference between the groups (***Fig. 4-d***).

Discussion

Summary of results

The main goal of this study is to observe the changes in blood amino acids due to the intake of ostrich meat (20 g of protein) and to compare it with that of chicken meat (20 g of protein). The subjects were 9 healthy men and women (2 men, 7 women, 23.1 ± 1.2 years old, BMI 20.1 ± 2.2). The first half was one week of CM intake, and after a rest period (one month), the second half was OM intake. Blood biochemical tests including plasma amino acid analysis were performed, and a comparative analysis was performed between the OM intake group and the CM intake group.

As a result of plasma amino acid analysis, there was no difference in the total amount between the OM intake group and the CM intake group, but an increase in taurine concentration was observed in the OM intake group regarding the composition.

Since there was no difference in plasma aldehyde (3DG, GO, MGO) between the two groups, there was no difference in aldehyde trapping effect. When there is postprandial hyperglycemia, multiple types of aldehyde-producing chain reactions (aldehyde sparks) occur, which induce alkylation and carbonylation modifications to proteins in the blood and cells. However, as the total amino acids increased after ingesting the test food, both OM and CM are excellent foods in that they can be expected to have an aldehyde trapping effect.

Table 4. Plasma amino acid concentration.

		Group	Before and after analysis								Between-group analysis		
			Before intake (day 0)			day 1		vs day 0	day 7		vs day 0	day 1	day 7
			n	Mean	SD	n	Mean SD	p value	n	Mean SD	p value	p value	p value
Taurine	nmol/mL	OM	9	45.38	± 4.54	9	59.22 ± 8.02	0.000	7	70.17 ± 6.68	0.000	0.009	0.000
		CM	9	45.54	± 3.00	9	51.49 ± 5.57	0.003	9	49.70 ± 6.22	0.089		
Hydroxyproline*	nmol/mL	OM	9	11.73	± 9.35	9	9.41 ± 2.66	0.453	7	12.66 ± 6.96	0.195	0.102	0.719
		CM	9	8.31	± 2.28	9	10.92 ± 1.99	0.008	9	10.91 ± 2.99	0.044		
Threonine	nmol/mL	OM	9	128.37	± 27.04	9	162.84 ± 29.53	0.001	7	170.89 ± 47.13	0.008	0.018	0.297
		CM	9	111.39	± 26.19	9	176.14 ± 34.11	0.000	9	177.20 ± 34.48	0.002		
Serine	nmol/mL	OM	9	130.58	± 22.80	9	138.27 ± 25.40	0.130	7	138.57 ± 29.11	0.161	0.022	0.522
		CM	9	121.87	± 13.67	9	152.79 ± 26.93	0.005	9	139.51 ± 25.17	0.070		
Asparagine	nmol/mL	OM	9	47.60	± 6.66	9	64.47 ± 8.82	0.000	7	69.39 ± 14.14	0.001	0.268	0.474
		CM	9	45.04	± 5.04	9	68.04 ± 13.42	0.001	9	63.70 ± 12.96	0.003		
Glutamine	nmol/mL	OM	9	22.69	± 6.80	9	18.41 ± 3.54	0.092	7	21.06 ± 5.80	0.168	0.003	0.064
		CM	9	19.34	± 4.71	9	23.32 ± 4.28	0.001	9	20.84 ± 4.91	0.264		
Glutamic acid	nmol/mL	OM	9	534.03	± 68.40	9	556.99 ± 51.19	0.105	7	607.99 ± 78.28	0.022	0.011	0.520
		CM	9	500.97	± 64.50	9	603.58 ± 72.86	0.003	9	615.40 ± 78.43	0.002		
Proline	nmol/mL	OM	9	140.16	± 37.75	9	169.91 ± 30.81	0.007	7	184.71 ± 40.88	0.001	0.157	0.437
		CM	9	136.19	± 46.98	9	183.94 ± 47.05	0.001	9	183.43 ± 43.51	0.002		
Glycine	nmol/mL	OM	9	233.74	± 46.51	9	257.37 ± 48.08	0.042	7	255.30 ± 37.70	0.036	0.027	0.533
		CM	9	214.47	± 27.72	9	282.19 ± 44.70	0.002	9	253.10 ± 52.39	0.025		
Alanine	nmol/mL	OM	9	355.99	± 82.39	9	426.56 ± 58.66	0.007	7	452.86 ± 91.19	0.013	0.159	0.673
		CM	9	342.46	± 94.89	9	468.60 ± 57.97	0.004	9	461.09 ± 66.96	0.010		
Citrulline	nmol/mL	OM	9	25.52	± 3.14	9	29.91 ± 6.42	0.044	7	32.03 ± 5.55	0.004	0.077	0.045
		CM	9	24.00	± 4.16	9	33.76 ± 6.95	0.002	9	37.27 ± 6.52	0.000		
α-Amino-n-butyric acid	nmol/mL	OM	9	21.38	± 4.78	9	20.57 ± 4.16	0.367	7	21.69 ± 5.38	0.857	0.024	0.872
		CM	9	19.43	± 7.71	9	22.07 ± 7.34	0.042	9	19.41 ± 3.92	0.989		
Valine	nmol/mL	OM	9	204.36	± 25.92	9	263.79 ± 27.75	0.002	7	317.89 ± 46.54	0.001	0.012	0.329
		CM	9	190.30	± 24.60	9	306.29 ± 29.35	0.000	9	334.10 ± 47.93	0.000		
Cystine	nmol/mL	OM	9	37.97	± 6.44	9	34.08 ± 6.38	0.000	7	45.09 ± 6.87	0.004	0.000	0.177
		CM	9	33.80	± 5.74	9	40.07 ± 6.08	0.015	9	38.72 ± 5.80	0.022		
Methionine	nmol/mL	OM	9	27.87	± 3.61	9	42.76 ± 6.32	0.000	7	46.60 ± 7.42	0.000	0.311	0.862
		CM	9	26.37	± 3.59	9	45.23 ± 8.84	0.000	9	45.08 ± 10.81	0.001		
Isoleucine	nmol/mL	OM	9	62.74	± 8.53	9	101.76 ± 17.80	0.000	7	126.77 ± 23.50	0.001	0.041	0.654
		CM	9	53.14	± 9.23	9	116.47 ± 20.99	0.000	9	123.57 ± 26.12	0.000		
Leucine	nmol/mL	OM	9	109.44	± 14.52	9	158.41 ± 24.81	0.001	7	194.99 ± 29.30	0.000	0.186	0.575
		CM	9	107.59	± 16.54	9	179.30 ± 30.00	0.001	9	185.06 ± 34.10	0.001		
Tyrosine	nmol/mL	OM	9	63.77	± 8.20	9	81.42 ± 15.56	0.008	7	90.44 ± 11.44	0.000	0.126	0.217
		CM	9	57.74	± 7.51	9	86.80 ± 11.73	0.000	9	96.83 ± 20.26	0.000		
Alanine *	nmol/mL	OM	9	5.30	± 0.00	9	17.96 ± 4.41	0.000	7	22.01 ± 3.40	0.000	0.042	0.998
		CM	9	7.56	± 0.77	9	26.14 ± 5.58	0.000	9	24.62 ± 7.46	0.000		
Phenylalanine	nmol/mL	OM	9	61.21	± 7.34	9	77.79 ± 7.29	0.000	7	89.30 ± 12.07	0.000	0.673	0.262
		CM	9	60.30	± 7.56	9	78.57 ± 8.64	0.001	9	84.06 ± 11.85	0.000		
Mono-ethanolamine	nmol/mL	OM	9	9.02	± 1.38	9	9.02 ± 0.98	1.000	7	9.01 ± 0.69	0.736	0.467	0.617
		CM	9	9.29	± 0.81	9	9.68 ± 1.21	0.313	9	9.22 ± 0.88	0.713		
Ornithine	nmol/mL	OM	9	57.19	± 12.83	9	88.41 ± 20.06	0.000	7	95.47 ± 25.78	0.004	0.639	0.239
		CM	9	65.32	± 11.94	9	93.14 ± 17.48	0.001	9	91.90 ± 19.29	0.006		
1-Methylhistidine*	nmol/mL	OM	9	14.38	± 6.17	9	33.04 ± 6.64	0.000	7	45.63 ± 6.67	0.000	0.032	0.108
		CM	9	9.87	± 5.41	9	39.43 ± 6.47	0.000	9	50.06 ± 8.54	0.000		
Histidine	nmol/mL	OM	9	85.62	± 13.87	9	95.20 ± 10.75	0.008	7	108.53 ± 13.96	0.000	0.033	0.433
		CM	9	86.01	± 8.06	9	111.20 ± 18.31	0.003	9	108.54 ± 14.87	0.000		
Lysine	nmol/mL	OM	9	158.62	± 18.47	9	256.93 ± 17.76	0.000	7	298.71 ± 34.02	0.000	0.166	0.544
		CM	9	153.36	± 24.04	9	285.84 ± 53.35	0.000	9	282.17 ± 52.08	0.000		
3-Methylhistidine*	nmol/mL	OM	9	6.00	± 0.00	9	5.92 ± 0.75	0.027	7	6.64 ± 0.80	0.019	0.000	0.000
		CM	9	5.30	± 0.00	9	7.01 ± 0.96	0.000	9	8.58 ± 0.96	0.000		
Tryptophan	nmol/mL	OM	9	70.37	± 15.50	9	80.21 ± 10.55	0.014	7	91.07 ± 8.74	0.010	0.151	0.760
		CM	9	70.06	± 14.24	9	87.99 ± 7.17	0.003	9	97.59 ± 10.36	0.003		
Arginine	nmol/mL	OM	9	82.92	± 17.36	9	120.31 ± 15.79	0.000	7	126.29 ± 26.34	0.002	0.050	0.242
		CM	9	64.07	± 17.85	9	128.27 ± 34.58	0.000	9	133.19 ± 37.61	0.001		
Fischer ratio	nmol/mL	OM	9	3.04	± 0.44	9	3.31 ± 0.34	0.082	7	3.55 ± 0.26	0.049	0.034	0.541
		CM	9	2.99	± 0.31	9	3.65 ± 0.33	0.000	7	3.59 ± 0.43	0.001		

* Statistical analysis was performed using input values due to the data below the detection sensitivity. Paired t test was used for comparative analysis with Day 0. Student's t test was used for between-group analysis. OM, ostrich meat; CM, chicken meat; SD, standard deviation.

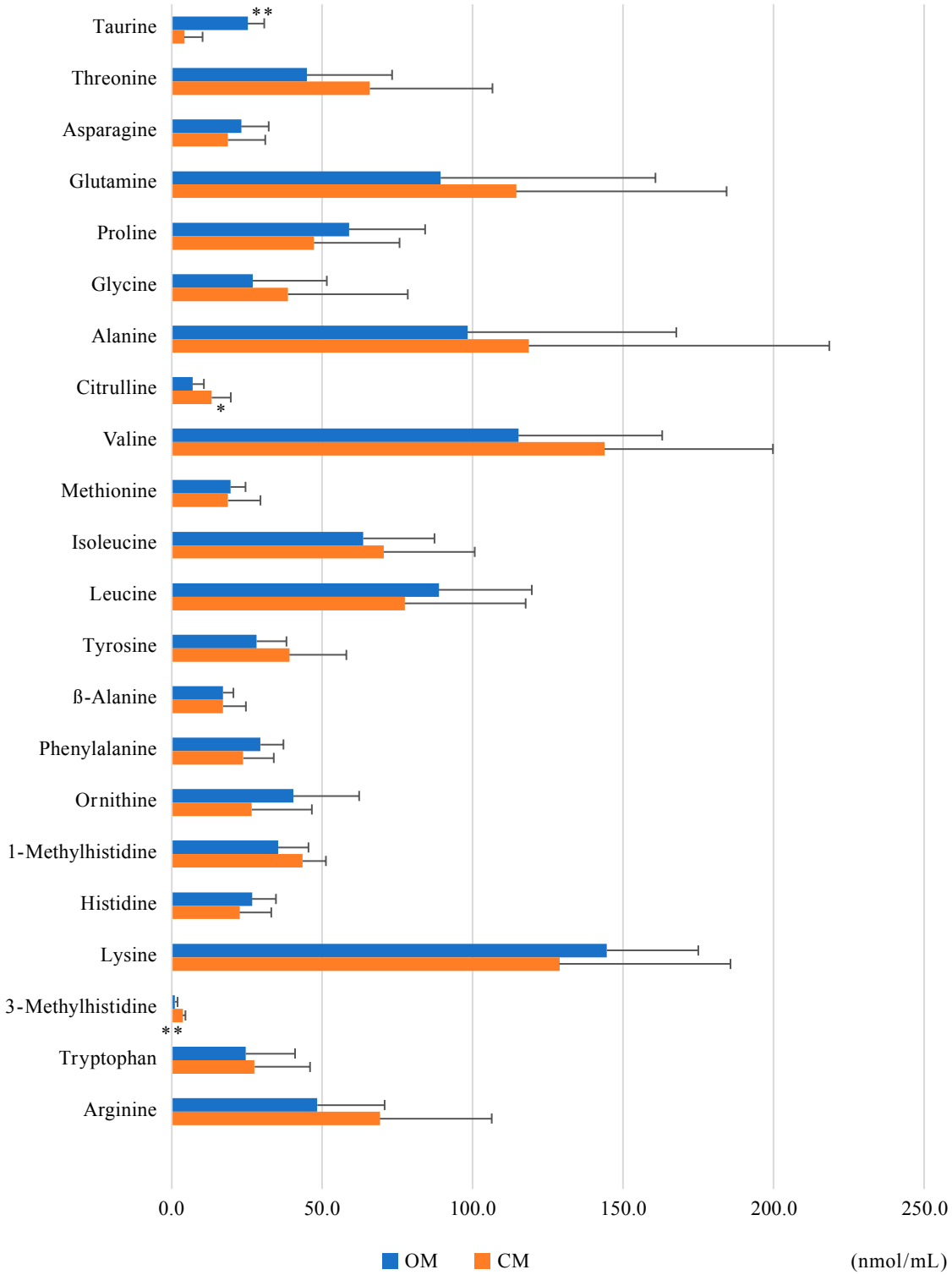

Fig. 3. **Changes in plasma amino acids on day 7 of intake.**
Results are expressed as mean ± SD. * $p < 0.05$, ** $p < 0.01$ by Student's t test, n = 9. OM, ostrich meat; CM, chicken meat; SD, standard deviation.

Table 5. Plasma vitamin B12 and glucose concentration.

		Group	Before and after analysis									Between-group analysis		
			Before intake (day 0)			day 1		vs day 0	day 7			vs day 0	day 1	day 7
			n	Mean	SD	n	Mean	SD	p value	n	Mean	SD	p value	p value	p value
Vitamine B12	pg/mL	OM	9	488.78 ± 122.35		9	523.44 ± 139.04		0.343	7	574.29 ± 190.35		0.382	0.848	0.151
		CM	9	503.67 ± 237.27		9	547.11 ± 232.63		0.173	9	620.67 ± 304.24		0.005		
Glucose	mg/dL	OM	9	80.89 ± 5.15		9	65.56 ± 9.92		0.000	7	80.29 ± 12.54		0.762	0.000	0.223
		CM	9	79.44 ± 5.23		9	81.89 ± 7.72		0.337	9	72.11 ± 6.92		0.009		

Paired t test was used for comparative analysis with Day 0. Student's t test was used for between-group analysis. OM, ostrich meat; CM, chicken meat; SD, standard deviation.

Table 6. Plasma aldehyde concentration.

		Group	Before and after analysis									Between-group analysis		
			Before intake (day 0)			day 1		vs day 0	day 7			vs day 0	day 1	day 7
			n	Mean	SD	n	Mean	SD	p value	n	Mean	SD	p value	p value	p value
3DG	μg/mL	OM	9	0.098 ± 0.028		9	0.096 ± 0.025		0.759	7	0.103 ± 0.015		0.906	0.636	0.505
		CM	9	0.087 ± 0.020		9	0.081 ± 0.019		0.175	9	0.078 ± 0.018		0.379		
GO	μg/mL	OM	9	0.021 ± 0.007		9	0.020 ± 0.005		0.464	7	0.036 ± 0.031		0.324	0.727	0.341
		CM	9	0.079 ± 0.143		9	0.054 ± 0.101		0.717	9	0.036 ± 0.023		0.418		
MGO	μg/mL	OM	9	0.770 ± 0.862		9	0.798 ± 0.886		0.467	7	1.085 ± 1.037		0.305	0.083	0.273
		CM	9	0.405 ± 0.593		9	0.601 ± 0.770		0.046	9	0.698 ± 0.820		0.054		

Paired t test was used for comparative analysis with Day 0. Student's t test was used for between-group analysis. 3DG, 3-deoxyglucosone; GO, glyoxal; MGO, methylglyoxal; OM, ostrich meat; CM, chicken meat; SD, standard deviation.

Table 7. Peripheral blood test.

		Group	Before and after analysis									Between-group analysis		
			Before intake (day 0)			day 1		vs day 0	day 7			vs day 0	day 1	day 7
			n	Mean	SD	n	Mean	SD	p value	n	Mean	SD	p value	p value	p value
WBC	/μL	OM	9	6155.56 ± 1071.98		9	5455.56 ± 1393.72		0.025	7	5642.86 ± 2224.45		0.745	0.697	0.930
		CM	9	6422.22 ± 1299.38		9	5900.00 ± 1139.20		0.197	9	6044.44 ± 1220.30		0.321		
RBC	×10^4/μL	OM	9	465.44 ± 29.74		9	458.00 ± 36.35		0.335	7	450.43 ± 25.04		0.568	0.037	0.156
		CM	9	481.89 ± 35.83		9	454.22 ± 35.42		0.001	9	465.67 ± 39.91		0.001		
Hb	g/dL	OM	9	14.27 ± 0.96		9	14.11 ± 1.12		0.415	7	13.77 ± 0.84		0.118	0.004	0.017
		CM	9	14.98 ± 1.14		9	13.99 ± 1.12		0.000	9	14.23 ± 1.26		0.000		
Ht	%	OM	9	43.27 ± 3.07		9	42.47 ± 2.86		0.218	7	42.93 ± 2.19		0.529	0.027	0.014
		CM	9	44.91 ± 3.36		9	42.21 ± 2.89		0.001	9	43.39 ± 3.09		0.002		
MCV	fL	OM	9	92.78 ± 3.15		9	92.67 ± 2.58		0.849	7	95.43 ± 4.03		0.038	0.619	0.035
		CM	9	93.33 ± 3.13		9	92.89 ± 2.96		0.225	9	93.22 ± 3.12		0.860		
MCH	pg	OM	9	30.66 ± 0.80		9	30.80 ± 0.64		0.429	7	30.57 ± 0.79		0.372	0.060	0.357
		CM	9	31.08 ± 0.74		9	30.81 ± 0.83		0.037	9	30.57 ± 0.71		0.011		
MCHC	%	OM	9	32.99 ± 0.74		9	33.21 ± 0.64		0.139	7	32.07 ± 0.83		0.003	0.073	0.247
		CM	9	33.37 ± 0.54		9	33.11 ± 0.71		0.257	9	32.77 ± 1.00		0.033		
Plt	×10^5/μL	OM	9	29.59 ± 6.03		9	29.21 ± 5.58		0.521	7	32.03 ± 4.91		0.563	0.074	0.496
		CM	9	28.91 ± 4.25		9	27.16 ± 4.72		0.005	9	28.87 ± 4.32		0.933		

Paired t test was used for comparative analysis with Day 0. Student's t test was used for between-group analysis. WBC, white blood cell; RBC, red blood cell, Hb hemoglobin, Ht Hematocrit value; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration: Plt, platelet count; OM, ostrich meat; CM, chicken meat; SD, standard deviation.

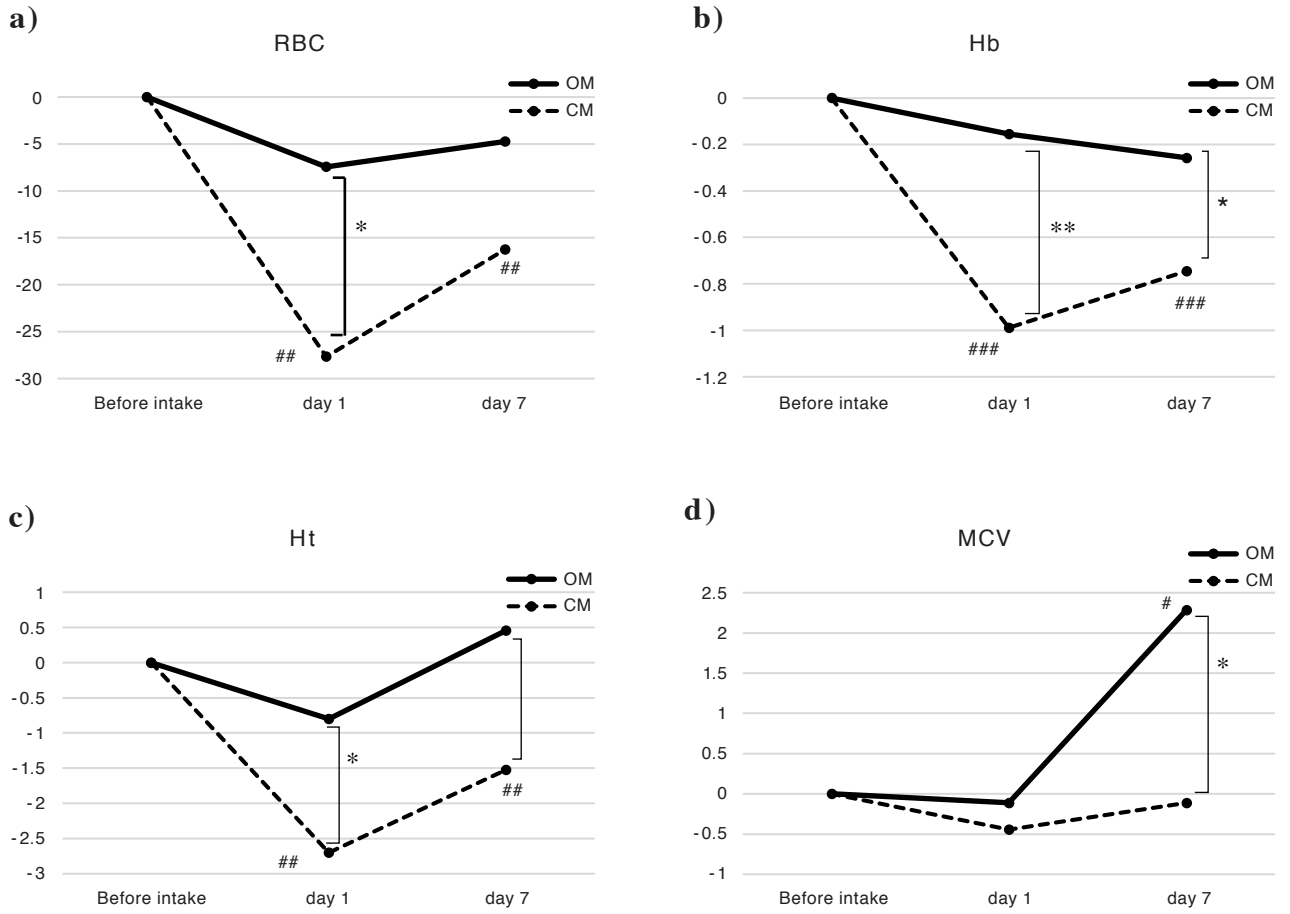

Fig. 4. **Changes of RBC profiles.**

a) Red blood cell (RBC) count, **b)** Hemoglobin (Hb), **c)** Hematocrit (Ht), **d)** mean corpuscular volume. (MCV). Results expressed as mean values. * $p < 0.05$, ** $p < 0.01$ vs CM, Student's t test, n = 9, # $p < 0.5$, ## $p < 0.01$, ### $p < 0.001$ vs day 0 by Paired t test. OM, ostrich meat; CM, chicken meat,

Peripheral blood tests showed decreases in RBC, Hb and Ht in the CM intake group, which are considered to be iron-deficiency changes, but these were alleviated in OM (***Fig. 4***).

MCV significantly increased only in the OM intake group on day 7 (Visit-6) compared to before intake (day 0, Visit-4) with a significant difference between the groups. MCHC significantly decreased on day 7 in both the OM and CM intake groups, and this change is considered to be due to iron deficiency. In the group that ingested OM potentially with high iron content, RBC, Hb, and Ht were maintained, and it is assumed that the fluctuations in MCV also reflect the homeostatic effect of OM intake. Additionally, the iron-deficiency changes observed in the subjects' red blood cells were due to blood sampling. Such fluctuations have been observed in clinical trials in the past[6].

The discussion is necessary regarding the fact that vitamin B12 was higher in CM than in OM. The subjects in this study had a reduced blood volume due to blood sampling (although the condition cannot be called anemic), so they consumed iron and vitamin B12 to maintain homeostasis, activating blood-forming function.

It is speculated that B12 consumption increased in the OM intake group because iron and vitamin B12 were utilized for recovery. Whereas, in the CM intake group, iron supplementation was insufficient, hematopoiesis and hemoglobin synthesis were not as active, and vitamin B12 consumption was likely to be correspondingly low. As a result, it is possible that the blood vitamin B12 concentration in the CM intake group was higher than that in the OM group. In order to maintain homeostasis of hematopoietic function, it is desirable to ingest necessary components such as iron, B12, and folic acid as food coexisting with protein from the diet, before taking them as supplement ingredients.

Taurine is a sulfur-containing amino acid-like compound that exists in a free state in living organisms. In food, it is abundant in squid, octopus, shellfish, crustaceans, and fish (heart, spleen, and blood meat). The taurine content (mg/100 g) of the main foods is oysters (1130), clams (1080), octopus (830), and squid (770). The taurine content of livestock meat is low, such as pork (22) and beef (30). The taurine content of chicken meat varies depending on the part, including thigh meat (412), wing meat (97), and breast meat (29)[7].

Ostrich meat nutritional information

This survey revealed that ostrich meat (120) is richer in taurine than chicken breast meat, which can be said to be a noteworthy feature along with being rich in iron.

Comparing the nutritional content (per 100 g) of chicken and ostrich meat, ostrich thigh meat (21.9 g protein, 1.8 g fat, 104 kcal) and chicken breast (23.3 g protein, 1.9 g fat, 105 kcal) are similar. However, it should be noted that some parts of chicken are high in fat; thighs with skin-on (16.6 g protein, 14.2 g fat, 190 kcal), and thighs without skin (23.3 g protein, 5.0 g fat, 105 kcal)[8].

Chicken thighs are rich in taurine, but even without the skin, they have a rather high amount of fat. Chicken breast is a popular food among health-conscious people, and its composition is high in protein and low in fat, similar to ostrich meat, but ostrich meat is superior in terms of taurine and iron supplementation. As a result of examining the lipid composition of five different edible parts of the ostrich (leg, thigh, heart, gizzard, and liver), the thigh had the highest PUFA/saturated fatty acids (SFA) and the highest n-6/n-3 ratio, showing the most favorable lipid quality index[9]. Ostrich thigh meat may have an advantage in this regard, so we would like to compare it with other meats.

Taurine

Taurine exists in almost all tissues in the living body. The human body contains 0.1% of body weight of taurine, and a person weighing 60 kg has approximately 60 g of taurine[10]. of this, 60-70% is located in muscles, where it plays an important role in muscle contraction and maintenance of muscle function through Ca^{2+} mobilization, osmotic pressure regulation, and antioxidant effects[11].

Taurine is a molecule (H_2N-CH_2-CH_2-SO_3H) that plays an important role in living organisms, and is synthesized from sulfur-containing amino acids (methionine and cysteine). Since taurine does not have a carboxyl group, it is not classified as an amino acid, and in principle does not constitute a protein, and exists in a free state in the blood, tissue fluid, and cells of living organisms. Taurine is the second most concentrated amino acid in the brain after glutamate. When taurine passes through biological membranes, a transporter (taurine transporter: TauT) is involved in the processes of gastrointestinal absorption[12], renal tubular reabsorption[13, 14], and blood-retinal barrier passage[15]. In the liver, γ-amino butyric acid transporter 2 (GAT2)[16] is involved.

Taurine can be derived from diet or synthesized within the body (particularly in the liver). Dietary taurine is absorbed from the gastrointestinal tract via TauT, transported to the liver via the portal vein, and taken up by hepatocytes via GAT2[16]. It is then supplied to tissues and cells throughout the body via the hepatic vein. Some taurine is conjugated with bile in the liver, secreted into the intestinal tract, and excreted in feces. Blood taurine is excreted into the renal tubule via the renal glomerulus, and is reabsorbed depending on taurine sufficiency.

Taurine also plays an important role in maintaining homeostasis, which keeps the body and cells in a normal state.

Since taurine suppresses lipid peroxidation, it is generally said to have antioxidant ability, but in reality it is an aldehyde trapping effect by the $-NH_2$ group. In the process of lipid peroxidation, fatty acids are oxidized due to oxidative stress (excess of ROS and free radicals) and fatty acid-derived aldehydes are formed[17], causing glycation stress (excess of aldehydes). Many aldehydes are strong electrophilic compounds and alkylate and modify biological macromolecules such as nucleic acids and proteins[18]. Oxidative stress and glycative stress (including alkylation stress and carbonylation stress) should be appropriately distinguished.

Various experimental results have shown that taurine increases or preserves glutathione (GSH)[19], but this also requires the perspective of glycative stress. By reducing MGO, a typical biological aldehyde, by trapping, the load on glyoxalase (an enzyme that metabolizes MGO, which consumes GSH as a coenzyme) is reduced, and GSH is conserved. Reduction of intracellular aldehydes is thought to prevent the accumulation of abnormal proteins such as carbonylated proteins and advanced glycation end products (AGEs), thereby preventing an increase in ER stress.

Furthermore, cytoplasmic taurine is important as a molecule responsible for regulating osmotic pressure[20]. During high osmotic loads such as dehydration, taurine moves into cells and protects the cells, and during low osmotic loads such as water intoxication, taurine moves out of cells.

Taurine modification of tRNA encoded by mitochondrial DNA is essential for mitochondria to function physiologically[21, 22]. When taurine becomes insufficiently modified due to lack of taurine or genetic mutations (*i.e.*, mitochondrial disease), normal protein synthesis is inhibited, disrupting the electron transport chain and reducing energy production.

Taurine has the effect of conjugating with bile acids, reducing toxicity and regulating the affinity of bile acids with the specific nuclear receptor FXR and G protein-coupled receptor TGR-5. It is involved in the regulation of energy metabolism in the body[23].

At the site of inflammation, it neutralizes the bactericidal substance (hypochlorous acid) secreted by neutrophils and acts to control excessive inflammatory reactions[24].

Compared to reports on cultured cells and experimental animals, there are fewer studies on taurine in humans. An international epidemiological research study (WHO CARDIAC Study) conducted by Yamori and colleagues for over 30 years, targeting approximately 20,000 people in 25 countries around the world, has shown that dietary taurine intake may be effective in preventing lifestyle-related diseases. Dietary taurine intake, as measured by urinary taurine excretion, was found to be negatively correlated with ischemic heart disease mortality rate[25]. Furthermore, it has been shown that people who consume large amounts of taurine are more likely to have proper blood pressure and blood cholesterol levels, and less likely to be obese[26].

Ostrich evolution and skeletal muscle

The characteristics of ostrich meat are thought to have been acquired through the process of evolution. Flightless birds such as ostriches are called ratites (*Ratitae*). South American snipe ostriches (*Tinamidae*) can fly, and

together with ratites they form a taxonomic group called "*Palaeognathae*". Ostriches, which are found in Africa, were the first living *Palaeognathae* to separate from other species. The most likely theory is that this divergence took place more than 100 million years ago, when *Palaeognathae* speciated in conjunction with the breakup of Gondwana, or that it occurred 79 million years ago, based on research that emphasizes DNA analysis [27].

Ratites is a general term for birds belonging to the order Ostriformes, which includes the ostrich (*Struthio camelus*), rhea (*Rhea americana*), cassowary (*Casuarius casuarius*), emu (*Dromaius novaehollandiae*), moa (*Dinornithidae*), epiornis (*Aepyornis*), and kiwis (*Apteryx mantelli*). All of these species are terrestrial, unable to fly, and, with the exception of the kiwis, are all large birds. It is thought that the reason ratites cannot fly is not necessarily because they are primitive, but because their wings and pectoral muscles have degenerated as they adapted to life on the ground [1, 2].

Ostriches have evolved the ability to run, reaching speeds of 70 km/h. It is possible to travel several kilometers at speeds of 50 to 60 km/h. The ostrich's running performance depends on its well-developed buttocks and upper thighs, a well-balanced anatomical structure, and the characteristics of powerful and durable muscles [4, 5]. In particular, taurine is an essential amino acid for the energy production in mitochondria, so it seems to play an important role in exerting both muscle strength and endurance.

Safety

No adverse events or side effects caused by the test product were observed during the study period or after the study was completed. Taurine is taken into cells via transporters as necessary. Excess taurine is quickly excreted from the kidneys into the urine, and no more taurine than is needed accumulates in the body. On the other hand, when the body is deficient in taurine, the kidney tubules increase taurine reabsorption to suppress urinary excretion and maintain the amount of taurine in the body. It was determined that there is no problem with the safety of ostrich meat.

Conclusion

The ostrich's feed consists mainly of grass, which is not eaten by humans, and the production of ostrich meat is said to have a low environmental impact. Among high-protein, low-fat avian meats, ostrich meat is richer in taurine and iron than chicken breast, and has been shown to be useful as a safe food ingredient. Among high-protein, low-fat avian meats, ostrich meat is richer in taurine and iron than chicken breast, and has been shown to be useful as a safe food ingredient for health-conscious consumers. Ingestion of the test foods (OM, CM) increased the plasma total amino acid concentration, which is expected to have an aldehyde trapping effect, and the foods are also excellent in alleviating aldehyde sparks that occur secondary to postprandial hyperglycemia.

Conflict of interest declaration

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