Effects of three types of bone marrow extracts treated with different treatment methods on the taste of chicken soup

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Abstract Bone marrow extracts (BME) are good flavor enhancing substance. Three types of BME (from porcine, chicken and bovine) were treated by enzymatic hydrolysis or Maillard reaction. To explore their effects on soup taste, they were added into chicken and non-chicken soups. The contents of free amino acids, nucleotides, peptides and soluble solids in the soup were measured and the taste activity value and equivalent umami concentration value were calculated, in addition to sensory evaluation. These parameters were weighted according to a certain ratio. Most taste-active substances increased upon enzymatic hydrolysis, while reached their maximum values after Maillard reaction. In addition, the presence of chicken alleviated bitter and fatty tastes in soups added with bone extracts, thus causing the soup to be more flavorful. Sensory evaluation results revealed that umami and kokumi tastes of soups supplemented with Maillard reaction-treated bone marrow extracts were more intense.

Keywords Bone marrow extracts · Soup · Taste active substance · Equivalent umami concentration (EUC) · Sensory evaluation

Introduction

The concept of bone marrow extracts (BME) was first defined in 1974, due to the oil panic in Japan, chemical seasoning prices had risen sharply and production had fallen sharply. Since then, natural seasonings extracted from animal and plant raw materials by the manufacturers were replaced by bone marrow extracts. Processes for the preparation of natural seasonings from fresh animal bones, as raw materials, include crushing, extraction, separation, vacuum concentration and high temperature sterilization. Since China is a country that mainly consumes pigs, cattle and chicken, there are a large number of bone by-products from these animals. Because bone contains a variety of complex umami ingredients, it has natural aroma components of livestock and poultry meat, and has a strong taste. Therefore, it is used in the processing of meat products and flavored instant noodles.

Study found that protein content in fresh bone is about 11%, while that in fresh meat is 17%. After completed physical process, the protein content in BME could reach > 30%. During the extraction process, certain proteins are decomposed or degraded into low molecular weight peptides, and 17 different free amino acids. The extracts also contain calcium, phosphorus, phospholipids, phosphoproteins, etc., which are important for brain functions. The content of lysine and methionine in BME is particularly rich, but glutamate in natural fresh ingredients is as high as 5.9%, soluble solids 50%, crude protein 40%, salt 10% (Xia and Wang 2007).

Enzymatic hydrolysis of bone extracts can increase the content of amino acids and peptides, e.g. Protamex complex protease has been used for hydrolysis of porcine bone (Bai et al. 2011). Additionally, enzymatic hydrolysis of chicken bone marrow extracts has been conducted using

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complex protease and flavor protease (Dong and Tang 2013), while that of bovine bone has been carried out using papain and alkaline protease (Jing-Kai and Zhang 2013). It is known that Maillard reaction not only changes food color change, but also produces aroma during thermal processing of foods (Cerny 2008); it may be also change taste due to the formation of flavor peptides and the increase in free amino acids. The Maillard reaction system is established from porcine bone protein hydrolysates and glucose-xylose model systems (Sun et al. 2013). The optimal process parameters for Maillard reaction of chicken bone have been determined by using the fuzzy mathematics evaluation method (Sun et al. 2015). Maillard reaction products (MRPs) of bovine bone extracts have been prepared using a xylose/cysteine/hydrolysate model (Song et al. 2016). Thus, the enzymatic hydrolysis and Maillard reaction are widely used worldwide.

Chicken soup is an auxiliary material commonly used in cooking. It is usually made of old hen, bones of chicken and pork, and ginger, etc. The purpose of chicken soup is to enhance umami flavor, leading to more intense taste. Equivalent umami concentration (EUC) in chicken broth cubes is between 0.30 and 0.53 g monosodium glutamate (MSG) (Chiang et al. 2006). While some studies largely focus on enzymatic hydrolysis or Maillard reaction's effect on flavor of BME, others focus on flavor of chicken soup. Taste compounds from chicken soup and chicken enzymatic hydrolysate have been isolated, purified and identified (Kong et al. 2017). Thus far, comprehensive analysis of using bone extracts instead of fresh bone in soup making and study of effect of different treatments of bone extracts on taste have not been carried out.

The objective of this research is to study the effects of BME from porcine, bovine and chicken bones obtained by different treatment methods, including enzymatic hydrolysis and Maillard reaction, on the taste of soup. Replacing fresh bone with bone marrow extracts could not only provide a rich meaty taste and umami taste-like fresh bone to the soup, but also reduce its cost.

Materials and methods

Samples and chemicals

BME from porcine, bovine and chicken bones were obtained from Fushun Dufengxuan Bone God Biotechnology Co., Ltd (Fushun, Liaoning, China). Chicken, shallots and gingers were purchased from a local market.

Standard compounds including cytidine 5'-monophosphate (5'-CMP), guanosine 5'-monophosphate (5'-GMP), inosine 5'-monophosphate (5'-IMP) and adenosine 5'-monophosphate (5'-AMP) were purchased from Sigma-

Aldrich (St Louis, MO, USA). Amino acid standards, o-phthalaldehyde and 3-mercaptopropionic acid in borate buffer (OPA), 9-fluorenylmethylchloroformate in acetonitrile (FMOC) and borate buffer were obtained from Agilent Technologies (Palo Alto, CA, USA). Other HPLC-grade solvents were purchased from Thermo Fisher Scientific (Waltham, MA, USA). Ultrapure water was purified from deionized water using a Millipore simplicity system (Millipore Corp., Saint-Quentin, France).

Sample preparation

Preparation of chicken soup: 50 g of chicken, 0.5 g of shiitake mushroom, 0.25 g of ginger, 0.5 g of shallot, BME and 500 mL of water were mixed and boiled in a pot. When the mixture (chicken soup) started to boil, it was simmered at a lower temperature for 6 h. The specific treatment methods of the three kinds of BME are shown in the Table 1.

Sensory evaluation of samples

The sensory evaluation was carried out according to the <Sensory Evaluation Practices> method by ten evaluators (four men and six women, ages between 20 and 50 years old), who have more than 3 years of previous experience in sensory evaluation of food products. The evaluators obtained additional training that focuses on chicken soup for 1 month; and prior to the evaluation, they also received training on taste of standard solutions. For example, sweet taste was trained by using 50 mmol/L sucrose, whereas umami and bitter tastes were trained by using 10 mmol/L MSG and 1 mmol/L caffeine, respectively; the complex taste of kokumi was trained by using blank chicken soup. During the evaluation, the evaluators gave a ten-point universal intensity scale (evaluation index) as follows: 1–2, weaker; 3–4, weak; 5–6, middle; 7–8, strong; and 9–10, stronger (Han et al. 2017). The sensory evaluation criteria are shown in Table 2.

Determination of non-volatile compounds

After centrifugation, the samples were filtered through a 0.22 µm microporous membrane and stored at 4 °C until further analysis. Each test was repeated three times under the same conditions.

Nucleotides

The determination of nucleotides (5'-CMP, 5'-GMP, 5'-IMP, 5'-AMP) were measured by high-performance liquid chromatography (HPLC) (Xi et al. 2016) with some modifications. The quantification of nucleotides based on

Table 1 Treatment methods for different bone marrow extracts

No.	BME	Content (g)	Chicken	Treatment
1	Porcine	5	✓	–
2	Bovine	5	✓	–
3	Chicken	5	✓	–
4	Porcine	50	✗	–
5	Bovine	50	✗	–
6	Chicken	50	✗	–
7	Porcine	5	✓	Enzymatically hydrolyzed (Dong et al. 2014)
8	Bovine	5	✓	Enzymatically hydrolyzed (Tan et al. 2010)
9	Chicken	5	✓	Enzymatically hydrolyzed (Bai et al. 2011)
10	Porcine	50	✗	Enzymatically hydrolyzed
11	Bovine	50	✗	Enzymatically hydrolyzed
12	Chicken	50	✗	Enzymatically hydrolyzed
13	Porcine	5	✓	Maillard reaction (Sun et al. 2013)
14	Bovine	5	✓	Maillard reaction (Sun et al. 2015)
15	Chicken	5	✓	Maillard reaction (Jie et al. 2010)
16	Porcine	50	✗	Maillard reaction
17	Bovine	50	✗	Maillard reaction
18	Chicken	50	✗	Maillard reaction

Table 2 Sensory evaluation criteria

<i>Umami taste evaluation criteria</i>											
MSG (mmol/L)	0	1	2	3	4	5	6	7	8	9	10
Scores	0	1	2	3	4	5	6	7	8	9	10
<i>Kokumi taste evaluation criteria</i>											
blank chicken soup (mmo/L)	0	2	4	6	8	10	12	14	16	18	20
Scores	0	1	2	3	4	5	6	7	8	9	10
<i>Fatty taste evaluation criteria</i>											
chicken fat (mmo/L)	0	1	2	3	4	5	6	7	8	9	10
Scores	0	1	2	3	4	5	6	7	8	9	10
<i>Sweet taste evaluation criteria</i>											
Sucrose (mmo/L)	0	5	10	15	20	25	30	35	40	45	50
Scores	0	1	2	3	4	5	6	7	8	9	10
<i>Bitter taste evaluation criteria</i>											
Caffeine (mmo/L)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Scores	0	1	2	3	4	5	6	7	8	9	10

external standard method, was performed on an Agilent 1200 HPLC system equipped with an Agilent Eclipse XDB-C₁₈ column (Agilent Technologies, Palo Alto, CA, USA). Other conditions were as follows: mobile phase, 0.02 mol/L KH₂PO₄, pH 3.8; flow rate, 1 mL/min; DAD detection wavelength, 254 nm; and column temperature, 35 °C.

Free amino acid

Mixed amino acid standards, consisting of Asp, Glu, Ser, His, Gly, Thr, Arg, Ala, Tyr, Cys, Val, Met, Phe, Ile, Leu and Lys, were used as external standards according to the method (Dai et al. 2014). The content of each free amino

acid in 18 samples were calculated based on the standard curves. The determination was carried out using an Agilent 1200 HPLC system equipped with a Zorbax Eclipse-AAA column (Agilent Technologies, Palo Alto, CA, USA). Prior to injection, the samples were treated with OPA, FMOC and borate buffer. Other conditions include: mobile phase, 0.04 mol/L NaH₂PO₄, pH 7.80 and methanol:acetonitrile:water (45:45:10, v:v:v); column temperature, 40 °C; and DAD detection wavelength, 338 nm (Yang et al. 2016).

Distribution of peptide

The distribution of peptide was determined using an Agilent 1200 HPLC system equipped with a TSK G2000

SWXL column (Tosoh Co., Tokyo, Japan). Acetonitrile (20 mL/dL, pH 3.00) was used as the mobile phase at a flow rate of 0.5 mL/min. Peptides including glycine (75 Da), glutathione (GSH, 307 Da), pentapeptide (GASST, 421 Da), heptapeptide (TEDVDVK, 804 Da), bacitracin (1422 Da) and aprotinin (6512 Da) were used as standards.

Soluble solids

Sample (1–2 mL) was dropped on the test window of handheld Abe refractometer, previously calibrated with ultrapure water. Each sample was washed 5 times with ultrapure water.

Statistical analysis

Each experiment was repeated more than three times; the data were averaged and presented as mean value $\pm$ SD. The data were subjected to one-way analysis of variance (ANOVA) and Duncan's multi-range test by using SPSS 17.0 and Origin 8.0 software.

Principal component analysis, typical correlation analysis and multiple linear regression analysis were carried out by partial least square regression (PLSR), a layer-to-layer linear regression model (Qiao et al. 2017). Correlation between non-volatile compounds and sensory evaluation was analyzed by PLSR using SIMCA-P + 11.

Results and discussion

Analysis of free amino acids

Standard curves for 16 amino acids, showing amino acid concentration (g/L) in the abscissa and peak area in the ordinate, were constructed. The total free amino acids and taste-active amino acids for umami, sweet and bitter taste were quantified (Rotzoll et al. 2006); the results are shown in Table 3. Based on Duncan's multiple range test, the free amino acid contents in all samples were significantly differences with $P \leq 0.05$.

Porcine bone marrow extract has the highest content of umami taste-active amino acids, followed by chicken and bovine bone marrow extracts, respectively. Porcine bone marrow extract also contains the highest content of sweet taste-active amino acids, followed by bovine and chicken bone marrow extracts, respectively (Xia and Wang 2007). As shown in Table 3, the same results (as described above) were observed in samples No. 4–6, however, with larger contents in sample Nos. 1–3. Chicken contains a large content of amino acids, which can be dissolved during a cooking process; chicken and bone marrow extracts are

cooked together that will also increase the amino acid content. The contents of nearly all amino acids, except for Ser, Gly, Tyr and Leu, drastically increased after the enzymatic hydrolysis. The content of each taste-active amino acid in sample Nos. 7–9 is higher than that in sample Nos. 10–12; among which the highest content is in sample No. 8. During the Maillard reaction, amino acids, such as Gly, Ala, Cys, Glu, etc., react with sugars (during heating) to produce meaty substances. This can results in the decrease of amino acids content, and the generation of umami and kokumi tastes. The total content of amino acids in sample Nos. 13–18 (the samples after Millard reaction) were decreased; however, it remains higher than that in the samples before enzymatic hydrolysis. The total content of amino acids in sample No. 13 is highest among all samples after Millard reaction, whereas that in sample No. 8 is highest among all 18 samples. Sample No. 8 also has the highest the highest content of umami taste-active amino acids, while sample Nos. 10 and 12 contains the highest content of sweet taste-active amino acids.

Analysis of nucleotides

Umami has been unknowingly appreciated for years in, among others, broths, stocks, aged cheeses, tomato products, protein-rich foods, dried mushrooms and kelp (Ninomiya 1998). These naturally occurring compounds exist in a variety of foods, for example, IMP is more abundant in meats, GMP is more abundant in plant foods and AMP is abundant in fish and shellfish (Yamaguchi and Ninomiya 2000). Table 4 shows nucleotide content. According to Duncan's multiple range tests, the nucleotide contents in all samples were significantly differences ($P \leq 0.05$).

As raw materials, bone marrow extracts have low content of nucleotides, which is increased after being boiled with chicken. Whereas sample No. 3 has the highest umami taste-active nucleotides, sample Nos. 4–6, from which chicken was removed, have decreased content of nucleotides. This demonstrates that the presence of chicken can contribute to a great taste of soup. After enzymatic hydrolysis, the content of nucleotides drastically increased, indicating that the enzymatic hydrolysis can enhance umami taste. However, the content of nucleotides reached its maximum value after Maillard reaction; the highest value was observed in sample No. 13. The results in which 5'-IMP and 5'-GMP were added into Maillard reaction showed that nucleotides could participate in Maillard reaction, and the desired umami taste was produced. Among 18 samples, sample No. 13 has the highest content of 5'-IMP; IMP with amounts of as low as 0.012–0.025% in aqueous solution can generate strong taste (Zhen and Yang 2013). The content of nucleotides 5'-IMP and 5'-GMP, which have favor-enhancing activity (Mori et al. 1997), is

Table 3 The amount of each taste active compound in 18 samples

No.	1	2	3	4	5	6	7	8	9
Amino acids (g L ⁻¹)									
<i>Umami</i>									
Asp	4.09 ± 0.08	4.81 ± 0.19	4.23 ± 0.07	5.28 ± 0.16	0.84 ± 0.04	4.78 ± 0.06	5.40 ± 0.22	6.52 ± 0.14	5.73 ± 0.10
TAV	4.09 ± 0.08	4.81 ± 0.19	4.23 ± 0.07	5.28 ± 0.16	0.84 ± 0.04	4.78 ± 0.06	5.40 ± 0.22	6.52 ± 0.14	5.73 ± 0.10
Glu	6.25 ± 0.14	12.72 ± 1.38	6.67 ± 0.20	15.17 ± 1.28	7.44 ± 0.04	9.55 ± 0.08	15.73 ± 1.09	18.84 ± 1.39	15.09 ± 1.06
TAV	20.83 ± 0.47	42.4 ± 1.27	22.23 ± 0.67	50.57 ± 0.93	24.8 ± 0.13	31.83 ± 0.27	52.43 ± 0.30	62.80 ± 1.30	50.30 ± 0.20
Total	20.34 ± 0.22	27.54 ± 1.57	20.90 ± 0.27	30.45 ± 1.44	8.28 ± 0.08	24.33 ± 0.14	31.12 ± 1.31	35.36 ± 1.53	30.83 ± 1.16
<i>Sweet</i>									
Ser	2.08 ± 0.04	1.30 ± 0.16	2.24 ± 0.08	0.88 ± 0.08	0.84 ± 0.14	4.72 ± 0.09	1.49 ± 0.03	1.16 ± 0.05	2.11 ± 0.05
TAV	1.39 ± 0.03	0.87 ± 0.11	1.49 ± 0.05	0.59 ± 0.05	0.56 ± 0.10	3.15 ± 0.06	0.99 ± 0.02	0.77 ± 0.03	1.41 ± 0.03
Gly	7.37 ± 0.12	1.20 ± 0.10	0.24 ± 0.05	0.24 ± 0.07	0.24 ± 0.03	0.24 ± 0.07	0.64 ± 0.22	0.24 ± 0.06	10.29 ± 1.22
TAV	5.67 ± 0.10	0.92 ± 0.08	0.18 ± 0.04	0.18 ± 0.05	0.18 ± 0.02	0.18 ± 0.05	0.49 ± 0.17	0.18 ± 0.05	7.92 ± 0.94
Thr	1.73 ± 0.04	2.02 ± 0.05	44.51 ± 3.24	0.86 ± 0.04	0.86 ± 0.05	0.86 ± 0.07	4.23 ± 0.10	51.62 ± 4.14	1.41 ± 0.09
TAV	0.67 ± 0.02	0.78 ± 0.02	17.12 ± 1.25	0.33 ± 0.02	0.33 ± 0.02	0.33 ± 0.03	1.63 ± 0.04	19.85 ± 1.59	0.54 ± 0.03
Ala	32.31 ± 3.22	0.87 ± 0.03	4.30 ± 0.12	0.87 ± 0.06	0.87 ± 0.06	0.87 ± 0.04	47.96 ± 4.25	1.42 ± 0.11	0.87 ± 0.07
TAV	53.85 ± 5.37	1.45 ± 0.05	7.17 ± 0.20	1.45 ± 0.10	1.45 ± 0.10	1.45 ± 0.07	79.93 ± 7.08	2.37 ± 0.18	1.45 ± 0.12
Total	43.49 ± 3.42	5.39 ± 0.34	51.29 ± 3.49	2.85 ± 0.25	2.81 ± 0.28	6.69 ± 0.27	54.33 ± 4.6	54.44 ± 4.36	14.69 ± 1.43
<i>Bitter</i>									
His	0.89 ± 0.05	0.63 ± 0.06	0.63 ± 0.04	0.63 ± 0.07	25.63 ± 2.24	12.04 ± 1.19	1.65 ± 0.09	6.44 ± 0.13	1.11 ± 0.04
TAV	4.45 ± 0.25	3.15 ± 0.3	3.15 ± 0.2	3.15 ± 0.35	128.15 ± 11.2	60.2 ± 5.95	8.25 ± 0.45	32.2 ± 0.65	5.55 ± 0.2
Arg	1.44 ± 0.05	6.59 ± 0.13	0.68 ± 0.05	0.68 ± 0.03	0.68 ± 0.08	0.68 ± 0.04	4.78 ± 0.12	0.68 ± 0.06	60.66 ± 6.14
TAV	2.88 ± 0.1	13.18 ± 0.26	1.36 ± 0.1	1.36 ± 0.06	1.36 ± 0.16	1.36 ± 0.08	9.56 ± 0.24	1.36 ± 0.12	121.32 ± 12.28
Tyr	1.47 ± 0.04	0.79 ± 0.09	4.88 ± 0.13	1.21 ± 0.05	0.79 ± 0.08	1.98 ± 0.07	0.79 ± 0.14	1.54 ± 0.04	1.72 ± 0.04
TAV	—	—	—	—	—	—	—	—	—
Val	2.38 ± 0.05	0.81 ± 0.04	1.96 ± 0.04	1.99 ± 0.06	0.81 ± 0.06	3.32 ± 0.07	4.28 ± 0.12	2.27 ± 0.03	4.63 ± 0.13
TAV	5.95 ± 0.13	2.03 ± 0.1	4.90 ± 0.1	4.98 ± 0.15	2.03 ± 0.15	8.30 ± 0.18	10.70 ± 0.30	5.68 ± 0.08	11.58 ± 0.33
Phe	1.94 ± 0.10	0.79 ± 0.03	1.70 ± 0.07	3.46 ± 0.09	0.79 ± 0.04	3.01 ± 0.13	2.14 ± 0.12	1.65 ± 0.04	0.79 ± 0.05
TAV	2.16 ± 0.11	0.88 ± 0.03	1.89 ± 0.08	3.84 ± 0.10	0.88 ± 0.04	3.34 ± 0.14	2.38 ± 0.13	1.83 ± 0.04	0.88 ± 0.06
Ile	2.05 ± 0.14	0.81 ± 0.04	2.08 ± 0.12	5.73 ± 0.13	1.35 ± 0.03	1.76 ± 0.04	2.35 ± 0.05	5.04 ± 0.19	0.81 ± 0.07
TAV	2.28 ± 0.16	0.90 ± 0.04	2.31 ± 0.13	6.37 ± 0.14	1.50 ± 0.03	1.96 ± 0.04	2.61 ± 0.06	5.60 ± 0.21	0.90 ± 0.08
Leu	4.67 ± 0.05	0.67 ± 0.04	3.92 ± 0.09	0.67 ± 0.07	1.86 ± 0.04	7.2 ± 0.12	4.02 ± 0.13	4.07 ± 0.03	0.67 ± 0.07
TAV	2.46 ± 0.03	0.35 ± 0.02	2.06 ± 0.05	0.35 ± 0.04	0.98 ± 0.02	3.79 ± 0.06	2.12 ± 0.07	2.14 ± 0.02	0.35 ± 0.04
Lys	3.69 ± 0.16	0.79 ± 0.11	0.79 ± 0.06	0.80 ± 0.09	0.80 ± 0.05	2.58 ± 0.07	5.96 ± 0.10	3.75 ± 0.14	0.80 ± 0.07
TAV	7.38 ± 0.32	1.58 ± 0.22	1.58 ± 0.12	1.60 ± 0.18	1.60 ± 0.10	5.16 ± 0.14	11.92 ± 0.20	7.50 ± 0.28	1.60 ± 0.14
Total	18.54 ± 0.64	11.88 ± 0.54	16.66 ± 0.60	15.18 ± 0.59	32.72 ± 2.62	32.60 ± 1.73	25.95 ± 0.87	25.45 ± 0.66	71.18 ± 6.61

Table 3 continued

No.	1	2	3	4	5	6	7	8	9
<i>Tasteless</i>									
Cys	1.16 ± 0.06	0.90 ± 0.14	1.17 ± 0.04	0.90 ± 0.11	1.32 ± 0.06	1.72 ± 0.07	1.60 ± 0.09	1.27 ± 0.19	1.26 ± 0.07
TAV	–	–	–	–	–	–	–	–	–
Met	2.79 ± 0.09	0.72 ± 0.04	0.72 ± 0.05	1.21 ± 0.14	0.72 ± 0.03	0.72 ± 0.09	3.01 ± 0.10	3.55 ± 0.11	0.72 ± 0.09
TAV	9.30 ± 0.30	2.40 ± 0.13	2.40 ± 0.17	4.03 ± 0.47	2.40 ± 0.10	2.40 ± 0.30	10.03 ± 0.33	11.83 ± 0.37	2.40 ± 0.30
Total taste-active	86.31 ± 4.28	46.45 ± 2.45	90.74 ± 4.36	50.59 ± 2.28	45.85 ± 2.98	66.06 ± 2.14	116.01 ± 6.78	120.08 ± 6.55	118.67 ± 9.2
No.	10	11	12	13	14	15	16	17	18
<i>Amino acids (g L⁻¹)</i>									
<i>Umami</i>									
Asp	5.99 ± 0.12	3.78 ± 0.13	5.86 ± 0.11	5.27 ± 0.03	2.79 ± 0.05	0.84 ± 0.07	3.37 ± 0.05	4.80 ± 0.04	5.81 ± 0.09
TAV	5.99 ± 0.12	3.78 ± 0.13	5.86 ± 0.11	5.27 ± 0.03	2.79 ± 0.05	0.84 ± 0.07	3.37 ± 0.05	4.80 ± 0.04	5.81 ± 0.09
Glu	16.21 ± 1.05	3.16 ± 0.18	16.20 ± 1.24	15.37 ± 2.07	5.08 ± 0.11	6.56 ± 0.13	11.25 ± 1.04	9.06 ± 0.15	16.09 ± 1.14
TAV	54.03 ± 0.17	43.87 ± 0.6	54.00 ± 0.80	51.23 ± 0.23	16.93 ± 0.37	21.87 ± 0.43	37.5 ± 0.13	30.2 ± 0.50	53.63 ± 0.47
Total	32.20 ± 1.17	16.94 ± 0.31	32.20 ± 1.35	30.64 ± 2.10	12.87 ± 0.16	17.39 ± 0.20	14.62 ± 1.09	23.86 ± 0.19	31.90 ± 1.23
<i>Sweet</i>									
Ser	20.61 ± 2.14	0.93 ± 0.07	21.89 ± 1.60	1.34 ± 0.07	0.67 ± 0.01	0.67 ± 0.04	23.93 ± 1.16	0.67 ± 0.07	0.85 ± 0.05
TAV	13.74 ± 1.43	0.62 ± 0.05	14.59 ± 1.07	0.89 ± 0.05	0.45 ± 0.01	0.45 ± 0.03	15.95 ± 0.77	0.45 ± 0.05	0.57 ± 0.03
Gly	0.82 ± 0.07	0.24 ± 0.04	0.24 ± 0.04	0.72 ± 0.06	7.00 ± 0.13	13.49 ± 1.11	0.24 ± 0.05	0.24 ± 0.04	20.95 ± 2.15
TAV	0.63 ± 0.05	0.18 ± 0.03	0.18 ± 0.03	0.55 ± 0.05	5.38 ± 0.10	10.38 ± 0.85	0.18 ± 0.04	0.18 ± 0.04	16.12 ± 1.65
Thr	36.30 ± 3.16	3.25 ± 0.12	3.61 ± 0.07	7.58 ± 0.13	1.44 ± 0.06	0.86 ± 0.09	0.86 ± 0.04	0.86 ± 0.07	1.44 ± 0.06
TAV	13.96 ± 1.22	1.25 ± 0.05	1.39 ± 0.03	2.92 ± 0.05	0.55 ± 0.02	0.33 ± 0.03	0.33 ± 0.02	0.33 ± 0.03	0.55 ± 0.02
Ala	1.79 ± 0.05	4.74 ± 0.13	2.24 ± 0.10	48.72 ± 5.14	0.87 ± 0.07	0.87 ± 0.04	0.87 ± 0.22	0.87 ± 0.04	34.38 ± 3.16
TAV	2.98 ± 0.08	7.90 ± 0.22	3.73 ± 0.17	81.20 ± 8.57	1.45 ± 0.12	1.45 ± 0.07	1.45 ± 0.37	1.45 ± 0.07	57.30 ± 5.27
Total	59.52 ± 5.42	9.16 ± 0.36	59.52 ± 1.81	58.36 ± 5.4	9.99 ± 0.27	15.90 ± 1.28	25.89 ± 1.47	2.64 ± 0.22	57.61 ± 5.42
<i>Bitter</i>									
His	0.63 ± 0.06	17.16 ± 1.16	0.63 ± 0.05	1.97 ± 0.09	1.86 ± 0.12	2.08 ± 0.07	19.26 ± 2.13	0.63 ± 0.04	1.08 ± 0.07
TAV	3.15 ± 0.3	85.8 ± 5.8	3.15 ± 0.25	9.85 ± 0.45	9.3 ± 0.6	10.4 ± 0.35	96.3 ± 10.65	3.15 ± 0.2	5.4 ± 0.35
Arg	0.68 ± 0.04	39.34 ± 4.15	29.25 ± 3.09	1.76 ± 0.10	29.21 ± 3.19	45.66 ± 4.22	6.78 ± 0.06	0.68 ± 0.07	2.71 ± 0.07
TAV	1.36 ± 0.08	78.68 ± 8.3	58.5 ± 6.18	3.52 ± 0.2	58.42 ± 6.38	91.32 ± 8.44	13.56 ± 0.12	1.36 ± 0.14	5.42 ± 0.14
Tyr	2.30 ± 0.07	1.48 ± 0.03	1.67 ± 0.06	2.77 ± 0.10	0.79 ± 0.04	2.12 ± 0.12	3.26 ± 0.22	0.79 ± 0.09	1.45 ± 0.06
TAV	–	–	–	–	–	–	–	–	–
Val	13.77 ± 1.16	3.03 ± 0.08	1.95 ± 0.09	0.81 ± 0.04	2.02 ± 0.07	3.68 ± 0.22	2.63 ± 0.10	1.82 ± 0.05	1.86 ± 0.07
TAV	34.43 ± 2.90	7.58 ± 0.20	4.88 ± 0.23	2.03 ± 0.10	5.05 ± 0.18	9.20 ± 0.55	6.58 ± 0.25	4.55 ± 0.13	4.65 ± 0.18
Phe	0.78 ± 0.04	2.69 ± 0.04	2.39 ± 0.05	1.85 ± 0.09	1.38 ± 0.07	2.23 ± 0.07	2.84 ± 0.06	3.51 ± 0.22	3.79 ± 0.05
TAV	0.87 ± 0.04	2.99 ± 0.04	2.66 ± 0.06	2.06 ± 0.10	1.53 ± 0.08	2.48 ± 0.08	3.16 ± 0.07	3.90 ± 0.24	4.21 ± 0.06

Table 3 continued

No.	10	11	12	13	14	15	16	17	18
Ile	0.81 ± 0.03	2.92 ± 0.11	1.38 ± 0.08	2.13 ± 0.04	2.49 ± 0.06	3.26 ± 0.10	2.43 ± 0.22	2.33 ± 0.07	0.81 ± 0.07
TAV	0.90 ± 0.03	3.24 ± 0.12	1.53 ± 0.09	2.37 ± 0.04	2.77 ± 0.07	3.62 ± 0.11	2.70 ± 0.24	2.59 ± 0.08	0.90 ± 0.08
Leu	0.67 ± 0.06	8.07 ± 0.09	4.07 ± 0.35	3.75 ± 0.04	9.06 ± 0.15	7.17 ± 0.14	9.42 ± 0.16	8.53 ± 0.10	0.67 ± 0.04
TAV	0.35 ± 0.03	4.25 ± 0.05	2.14 ± 0.18	1.97 ± 0.02	4.77 ± 0.08	3.77 ± 0.07	4.96 ± 0.08	4.49 ± 0.05	0.35 ± 0.02
Lys	0.79 ± 0.08	0.79 ± 0.04	2.34 ± 0.19	4.69 ± 0.13	0.79 ± 0.05	4.72 ± 0.22	5.37 ± 0.03	3.69 ± 0.12	0.80 ± 0.07
TAV	1.58 ± 0.16	1.58 ± 0.08	4.68 ± 0.38	9.38 ± 0.26	1.58 ± 0.10	9.44 ± 0.44	10.74 ± 0.06	7.38 ± 0.24	1.60 ± 0.14
Total	20.46 ± 1.54	75.49 ± 5.7	20.46 ± 3.96	19.74 ± 0.63	47.62 ± 3.75	70.92 ± 5.16	51.98 ± 2.98	21.99 ± 0.76	13.17 ± 0.5
<i>Tasteless</i>									
Cys	1.96 ± 0.13	1.11 ± 0.05	1.43 ± 0.07	1.52 ± 0.06	0.90 ± 0.03	1.26 ± 0.05	1.81 ± 0.12	1.98 ± 0.10	1.19 ± 0.04
TAV	–	–	–	–	–	–	–	–	–
Met	0.72 ± 0.06	3.87 ± 0.13	3.81 ± 0.07	3.82 ± 0.19	2.18 ± 0.22	3.02 ± 0.12	0.72 ± 0.04	1.76 ± 0.07	1.88 ± 0.05
TAV	2.40 ± 0.20	12.90 ± 0.43	12.70 ± 0.23	12.73 ± 0.63	7.27 ± 0.73	10.07 ± 0.40	2.40 ± 0.13	5.87 ± 0.23	6.27 ± 0.17
Total taste-active	114.87 ± 8.13	106.58 ± 6.37	114.87 ± 7.12	114.08 ± 8.13	73.55 ± 4.18	108.49 ± 6.64	95.03 ± 5.54	52.23 ± 1.17	105.75 ± 7.15

Results of each sample were significantly differences in content with Duncan's multiple range test based on the relative concentration at $P \leq 0.05$

highest in sample No. 13. In meat from animals (such as poultry, etc.), umami nucleotides are mainly produced by the degradation of ATP in muscle, and the degradation pathway is as follows: $\text{ATP} \rightarrow \text{ADP} \rightarrow \text{AMP} \rightarrow \text{IMP} \rightarrow \text{I} \rightarrow \text{Hypoxanthine}$ (Lv et al. 2009). The pathway shows that AMP is an important precursor that can be converted to IMP; thus the higher the AMP content in meat, the higher the content of IMPs can be generated. Sample No. 12 contains the highest AMP content.

Analysis of peptide distribution

Peptides particularly derived from proteolysis can impart taste, for example, glutamyl peptides impart umami taste, and hydrophobic peptides containing proline impart bitter taste (Zhao et al. 2016). Most taste-active peptide derivatives are composed of short-chain amino acids, and in traditional chicken soup, peptides with molecular weight of < 3000 Da has the strongest umami taste (Lin et al. 2016). Other studies have also reported that umami taste-active peptides in ham is from the fraction with molecular weight of < 5000 Da (Dang et al. 2015).

The changes in peptide distribution are exhibited in Fig. 1. In this study, the contents of peptides with molecular weights of < 5000 Da in sample Nos. 1–6 were similar; the highest content was observed in sample No. 3. Protein content in bone extracts is 30–40%, while that in chicken is 20–30%. After enzymatic hydrolysis, the content of peptides with molecular weights of < 5000 Da were nearly 100%, suggesting that the enzymatic hydrolysis can effectively reduce the molecular weight of peptides. However, the Maillard reaction also produced other macromolecular components; however, but the content were still higher than sample Nos. 1–6. The analysis of peptide distribution showed that at the initial stage of reaction, a large number of 1000–3000 Da peptides were cleaved into 500–1000 Da peptides, whereas the 300–500 Da peptides not only were cleaved into < 300 Da peptides, but may also participate in the Maillard reaction.

Analysis of taste activity value (TAV) and equivalent umami concentrations (EUC)

Taste active value (TAV) is the ratio between concentration of taste substance and its threshold value (generally measured in water or in a simple matrix). Compounds with TAV of greater than 1 are considered taste active in food, and low threshold value indicates that a small amount of amino acids presented in small amount of samples can have strong taste. To evaluate the effects of compounds on taste, TAV index was used (Kato et al. 1989). As tabulated in Table 3, in all 18 samples, concentration and TVA value

Table 4 The amount of each nucleotide in 18 samples

No.	1	2	3	4	5	6	7	8	9
<i>Nucleotide (mg L⁻¹)</i>									
CMP	122.12 ± 1.11	98.26 ± 0.61	41.91 ± 0.15	58.05 ± 0.69	33.08 ± 0.68	249.73 ± 2.68	105.67 ± 0.96	67.39 ± 0.95	111.25 ± 1.74
TAV	–	–	–	–	–	–	–	–	–
GMP	42.18 ± 0.31	27.61 ± 0.55	62.20 ± 0.17	92.78 ± 0.34	39.32 ± 0.25	197.67 ± 2.31	29.99 ± 0.88	29.72 ± 0.35	5.61 ± 0.03
TAV	0.34 ± 0.00	0.22 ± 0.00	0.50 ± 0.00	0.74 ± 0.00	0.31 ± 0.00	1.58 ± 0.02	0.24 ± 0.01	0.24 ± 0.00	0.04 ± 0.00
IMP	190.51 ± 1.76	87.40 ± 0.98	76.81 ± 0.12	26.54 ± 0.51	27.94 ± 0.19	46.93 ± 0.09	208.18 ± 1.81	75.02 ± 0.87	289.19 ± 2.32
TAV	0.76 ± 0.01	0.35 ± 0.00	0.31 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.19 ± 0.00	0.83 ± 0.01	0.30 ± 0.00	1.16 ± 0.01
AMP	53.92 ± 0.63	54.59 ± 0.91	57.05 ± 0.82	52.59 ± 0.09	77.73 ± 0.02	443.39 ± 3.68	144.17 ± 0.86	110.66 ± 1.06	74.48 ± 0.38
TAV	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.16 ± 0.00	0.89 ± 0.01	0.29 ± 0.00	0.22 ± 0.00	0.15 ± 0.00
EUC	3.49 ± 0.03	3.36 ± 0.20	2.76 ± 0.03	6.04 ± 0.16	1.38 ± 0.01	9.50 ± 0.02	7.54 ± 0.16	4.98 ± 0.18	7.69 ± 0.15
No.	10	11	12	13	14	15	16	17	18
<i>Nucleotide (mg L⁻¹)</i>									
CMP	75.31 ± 0.79	107.09 ± 1.51	262.62 ± 2.09	69.42 ± 0.14	61.30 ± 0.39	70.74 ± 0.61	116.02 ± 1.35	126.28 ± 1.34	112.47 ± 1.49
TAV	–	–	–	–	–	–	–	–	–
GMP	137.73 ± 1.66	56.07 ± 0.73	257.06 ± 2.44	646.28 ± 3.41	517.83 ± 2.92	487.32 ± 2.59	86.59 ± 0.56	92.99 ± 0.49	83.45 ± 0.97
TAV	1.10 ± 0.01	0.45 ± 0.01	2.06 ± 0.02	5.17 ± 0.03	4.14 ± 0.02	3.90 ± 0.02	0.69 ± 0.00	0.74 ± 0.00	0.67 ± 0.01
IMP	11.99 ± 0.58	8.88 ± 0.69	29.58 ± 0.81	1321.64 ± 5.84	1181.48 ± 4.49	1034.48 ± 3.91	281.02 ± 2.51	345.37 ± 3.48	453.00 ± 4.17
TAV	0.05 ± 0.00	0.04 ± 0.00	0.12 ± 0.00	5.29 ± 0.02	4.73 ± 0.02	4.14 ± 0.02	1.12 ± 0.01	1.38 ± 0.01	1.81 ± 0.02
AMP	210.02 ± 1.87	168.78 ± 1.77	526.79 ± 2.49	196.52 ± 1.79	138.92 ± 1.52	30.12 ± 0.25	57.65 ± 0.36	68.82 ± 0.55	57.98 ± 0.22
TAV	0.42 ± 0.00	0.34 ± 0.00	1.05 ± 0.00	0.39 ± 0.00	0.28 ± 0.00	0.06 ± 0.00	0.12 ± 0.00	0.14 ± 0.00	0.12 ± 0.00
EUC	9.51 ± 0.17	1.30 ± 0.04	18.26 ± 0.24	67.48 ± 0.57	21.18 ± 0.04	19.04 ± 0.04	8.41 ± 0.16	9.01 ± 0.03	16.62 ± 0.22

Results of each sample were significantly differences in content with Duncan's multiple range test based on the relative concentration at $P \leq 0.05$

of glutamic acid are high, indicating that may significantly contribute to umami taste of the soup. Bitter taste-active amino acids, such as histidine, arginine, valine, etc., also have high TAV, which are more pronounced after enzymatic hydrolysis. However, such amino acids are declined in the samples prepare with bovine and chicken bones. Sweet taste-active amino acids, which contribute to sweet taste of the soup, increased rapidly after enzymatic hydrolysis. Although other free amino acids have TVAs of below 1, they may also be involved in the enhancing bitter and sweet tastes at their subthreshold concentrations. These results suggest that the synergistic effect between each taste-active amino acid leads to a satisfactory taste.

Concentrations and TAVs of 5'-nucleotides are shown in Table 4. Only a few samples contained nucleotides with TVA of greater than 1. However, the nucleotides content in the sample increased sharply after Maillard reaction. IMP has TVA of greater than 1, indicating that it may contributes a significant impact on flavor.

IMP and GMP are stronger umami taste enhancers than MSG (Kawai et al. 2002). The synergistic effect of taste-active 5'-nucleotides and umami taste-active amino acids (Glu and Asp) may greatly increase the umami taste of the soups. The equivalent umami concentrations (EUC) (g MSG/100 g), which is linked to umami concentration, was proposed by a Japanese scholar, Yamakochi in 1971, to formulate the relationship between taste intensity of MSG-IMP mixture and that of MSG alone (Yamaguchi et al. 1971). The relationship is as follows:

$$Y = \sum a_i * b_i + 1218 \left(\sum a_i * b_i \right) \left(\sum a_j * b_j \right)$$

where Y is the EUC of sample in g MSG/100 g, a_i is the concentration (in g/100 g) of each umami taste amino acid

(Glu or Asp), a_j is the concentration (g/100 g) of each umami taste 5'-nucleotide (5'-IMP, 5'-GMP or 5'-AMP), b_i is the relative umami concentration (RUC) of each umami taste amino acid with respect to MSG (Glu = 1; Asp = 0.077), b_j is the RUC of each umami taste 5'-nucleotide with respect to 5'-IMP (5'-IMP = 1; 5'-GMP = 2.3; 5'-AMP = 0.18), and 1218 is a synergistic constant. By substituting the contents of umami amino acids and nucleotides into the formula, the freshness can be quantified and compared. At low concentrations (50–100 mg/100 ml), AMP contributes to sweet taste, but not umami taste; however, the synergistic effect between AMP and IMP can contribute to umami taste (Fuke and Ueda 1996). The EUC value was increased after enzymatic hydrolysis, indicating that the enzymatic hydrolysis can strongly enhance umami taste, and reached its maximum after Maillard reaction. The ratio between EUC values of 5'-GMP and that of 5'-IMP is 2.3, and the 5'-GMP content in sample No. 13 is high so the EUC score was the highest at 67.48 g MSG/100 g, indicating that Maillard reaction could improve the umami taste and contributed greatly to the umami taste of the sample.

Analysis of soluble solids

The amount of soluble solids can indicate the contents of soluble nutrients, such as amino acids, nucleotides, etc., in the sample. In the sample containing mixed chicken and bone marrow extracts, the content of soluble solids was not high due to the lack of additionally bone marrow extracts. However, when chicken was replaced by bone marrow extracts, which is viscous and water-soluble, the sample had increased soluble solid content.

Fig. 1 Changes in peptides distribution in 18 samples

Analysis of sensory evaluation

The results from sensory evaluation of 18 samples are shown in Fig. 2. Three samples, sample Nos. 11, 12 and 17, had the highest scores for bitter and fatty tastes. Because bone marrow extracts are highly concentrated product that can provide higher fatty taste to soup. Sample Nos. 13, 14 and 15 have the highest umami and kokumi tastes scores, in consistent with their taste-active compounds contents. This indicates that the higher the content of umami taste-active substance, the more pleasant the taste of the soup. The overall sweet taste score is generally high due to the presence of chicken, thereby may compliment to some possible undesirable tastes of bones extracts. Samples after enzymatic hydrolysis and Maillard reaction had improved scores for other tastes rather than that for bitter taste, thus indicating that they contribute to the improved taste of the soup.

To examine the influence of each taste on the overall flavors of 18 samples, partial least squares regression (PLSR) was employed to analyze the correlation between the sensory scores and the taste substances in different samples; and the PLS2 model was established. The first two PLS2 models were obtained. The main component cumulative interpretation variance reached 88.9%, so the experiment only discussed PC1–PC2, and the results are shown in Fig. 3. As shown in Fig. 3, six sensory indicators from different samples were distributed along the PC1 axis; variables distributed along the PC2 axis could explain changes in different taste substances. Umami and kokumi tastes that were located at the lower right corner of the plot are positively correlated. Previous studies have also shown that kokumi could promote umami taste. In addition, a synergistic effect between the nucleotides has been found to contribute to increased umami taste. The plot also indicates that the umami is positively correlated with many other umami substances, such as nucleotides (GMP, IMP, AMP), free amino acid (Asp) and peptides with molecular weight of < 500 Da. This result is inconsistent with the sensory evaluation. Moreover, the umami taste is significantly and positively correlated with EUC and Glu ($P < 0.05$), while negatively correlated with some bitter taste-active amino acids. Sweet taste, located at the upper right corner of the plot, is positively correlated with umami and kokumi tastes ($P < 0.05$). Precursors such as Ser, Gly, Ala, 1000–1500 Da peptides also contribute to sweet taste. The undesirable fatty and bitter tastes, which are negatively correlated with other desirable tastes, are located at the lower left corner of the plot. However soluble solids content, His, Ile and 500–1000 Da peptides were positively correlated with fatty and bitter taste. The content of soluble solids is directly proportional to the amount of bone

Fig. 2 Sensory flavor profile of samples made from porcine bone extracts (a), samples made from bovine bone extracts (b), samples made from chicken bone extracts (c)

extracts, thus too high amount of bone extracts can contribute to strong fatty taste.

All test indicators and sensory scores were weighted by a certain weight (Kai et al. 2015), and the final total score was obtained. The effects of three types of bone extracts treated by different treatment methods on chicken soup were evaluated, and the best bone extract and treatment were selected. First, the sensory evaluation indicators were added and then averaged. Samples with taste-active amino acids, nucleotides and peptides with contents of 18%, as well as with EUC of 18%, soluble solids content of 10% and sensory evaluation score of 18% were used for the calculation, and the final scores are shown in Fig. 4. Sample No. 13, into which MRPs of porcine marrow extract was added, has the highest score of 80.40.

Fig. 3 The connection between taste substances and sensory of 18 samples by PLSR

Fig. 4 The final score for 18 samples

Conclusion

In summary, this study demonstrates that porcine bone extract contains higher nucleotides content than other two extracts. The contents of nucleotides and small peptides increase after enzymatic hydrolysis, while reach their maximum values after the Maillard reaction. The Maillard reaction resulted in decreased amino acids content in bone extracts, such content, however, remained higher than those in untreated samples. The result from sensory evaluation is closely linked with to the contents of taste-active substances. A significant positive correlation between fatty taste in sensory evaluation and soluble solid content was also observed. Finally, we concluded that porcine bone

extract after Maillard reaction best contributes to desirable taste of soup and was selected for subsequent experiments.

References

- Bai YH, Chen X, Zhao DB (2011) Processing of enzymolysis of compound proteinase named protamex on pork bones. *Food Ind* 1:88–91
- Cerny C (2008) The aroma side of the Maillard reaction. *Ann NY Acad Sci* 1126:66–71
- Chiang PD, Yen CT, Mau JL (2006) Non-volatile taste components of various broth cubes. *Food Chem* 101:932–937
- Dai Z, Wu Z, Jia S, Wu G (2014) Analysis of amino acid composition in proteins of animal tissues and foods as pre-column

- o-phthalaldehyde derivatives by HPLC with fluorescence detection. *J Chromatogr B* 964:116–127
- Dang Y, Gao X, Ma F, Wu X (2015) Comparison of umami taste peptides in water-soluble extractions of Jinhua and Parma hams. *LWT Food Sci Technol* 60:1179–1186
- Dong XB, Tang (2013) Combinatorial enzyme hydrolysis of chicken bone extracts and analysis of the volatile flavor compounds of hydrolysate. *J Nucl Agric Sci* 5:629–634
- Dong XB, Li X, Zhang CH, Wang JZ, Tang CH, Sun HM, Jia W, Li Y, Chen LL (2014) Development of a novel method for hot-pressure extraction of protein from chicken bone and the effect of enzymatic hydrolysis on the extracts. *Food Chem* 157:339–346
- Fuke S, Ueda Y (1996) Interactions between umami and other flavor characteristics. *Trends Food Sci Technol* 7:407–411
- Han Y, Wang X, Cai Y, Li ZY, Zhao L, Wang HM, Jin JH, Cai YM, Xu LP, Zhu LT (2017) Sensor-array-based evaluation and grading of beef taste quality. *Meat Sci* 129:38–42
- Jie Z, Liu AJ, He LR, Wang Y, Zhao Y (2010) Preparation of beef flavors by enzymatic hydrolysis of beef bone and analysis of its component by GC-MS. *Modif Food Sci Technol* 26(03):306–310
- Jing-Kai QI, Zhang YF (2013) Study on enzymatic hydrolysis of beef bone and detection of free amino-acid in enzymatic hydrolysate. *China Food Add* 1:109–115
- Kai HU, Zhang XH, Song LS, Yang JD (2015) Study on sensory evaluation of chicken flavor. *Food Res Dev* 36:26–27
- Kato H, Rhue MR, Nishimura T (1989) Role of free amino acids and peptides in food taste. *ACS Symp* 388:158–174
- Kawai M, Okiyama A, Ueda Y (2002) Taste enhancements between various amino acids and IMP. *Chem Senses* 27(8):739
- Kong Y, Yang X, Qi D, Zhang YY, Sun BG, Chen HT, Sun Y (2017) Comparison of non-volatile umami components in chicken soup and chicken enzymatic hydrolysate. *Food Res Int* 102:559
- Lin M, Wang J, Liao Y, Zhou X (2016) Structure-activity relationship between peptides and flavor in chicken broth. *Food Sci* 37(3):12–16
- Lv DP, Lv GL, Shi ZX, Zhu RJ (2009) Analysis of mechanism of IMP synthesis. *China Condiment* 6:36–40
- Mori H, Iida A, Fujio T, Teshiba S (1997) A novel process of inosine 5'-monophosphate production using overexpressed guanosine/inosine kinase. *Appl Microbiol Biotechnol* 48:693–698
- Ninomiya K (1998) What is umami? *Food Rev Int* 14:123–138
- Qiao J, Wang G, Li W, Li X (2017) A deep belief network with PLSR for nonlinear system modeling. *Neural Netw* 104:68–79
- Rotzoll N, Dunkel A, Hofmann T (2006) Quantitative studies, taste reconstitution, and omission experiments on the key taste compounds in morel mushrooms (*Morchella deliciosa* Fr.). *J Agric Food Chem* 54:2705–2711
- Song S, Li S, Fan L, Hayat K, Xiao Z, Chen L, Tang Q (2016) A novel method for beef bone protein extraction by lipase-pretreatment and its application in the Maillard reaction. *Food Chem* 208:81
- Sun FD, Kong BH, Han Q, Chen Q, Liu Q (2013) Influence of different initial pH and heating time on characteristic of the porcine bone protein hydrolysate Maillard products. *Sci Technol Food Ind* 22:106–99
- Sun HM, Wang JZ, Zhang CH, Li X, Xu X, Dong XB, Hu L, Li CH (2015) Changes of flavor compounds of hydrolyzed chicken bone extracts during Maillard reaction. *J Food Sci* 12:C2415–C2426
- Tan BN, Mei-Hu MA, Wei T (2010) Protease hydrolysis of bovine bone power. *Food Sci* 31(10):20–25
- Xi F, Sun HM, Lee HY, Dong UA (2016) Effect of irradiation on the degradation of nucleotides in turkey meat. *LWT Food Sci Technol* 73:88–94
- Xia XF, Wang K (2007) Osseine and its application. *Meat Ind* 7:22–25
- Yamaguchi S, Ninomiya K (2000) Umami and food palatability. *J Nutr* 130:921S–926S
- Yamaguchi S, Yoshikawa T, Ikeda S, Ninomiya T (1971) Measurement of the relative taste intensity of some L- α -amino acids and 5'-nucleotides. *J Food Sci* 36:846–849
- Yang HH, Guang-Hua LU, Chen W, Liu JC (2016) Determination of amino acids in water by o-phthalaldehyde(OPA) precolumn derivatization and reversed-phase high performance liquid chromatography. *Adm Techn Envir Monit* 28(04):35–38
- Zhao CJ, Schieber A, Gänzle MG (2016) Formation of taste-active amino acids, amino acid derivatives and peptides in food fermentations—a review. *Food Res Int* 89(1):39–47
- Zhen GU, Yang Y (2013) Research progress in flavor components of edible fungus. *Sci Technol Food Ind* 34:363–367

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