The significance of Maillard reaction for species-specific detection gelatine in food industry

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Abstract. Many ingredients derived from animal have been distributed widely in foods, pharmaceutical, and cosmetic formulations which may invites issues due to religious restrictions. Thus, the species-specific detection has become an important issue among Muslims, Jews, Hindus, Vegan, and vegetarian communities. Some methods such as spectroscopy, chromatography, and DNA based method have been applied for this purpose. However, these methods use sophisticated technology, therefore need high skill and cost for industrial practice. Research needs to encourage the development of simple and portable instrument. This paper highlights the potency of the Maillard reaction for species-specific detection of animal derivatives in food, especially for gelatine. Gelatine from different sources revealed different amino acids composition. It will produce various sensory of active compounds such as colour, odour, and taste when subjected to Maillard reaction, depends on reactant substances and conditions of reaction. The differences will be the key principle in species-specific detection of the sources of gelatine.

1. Introduction
Production of food in the world, including quantity, quality, and variant have been affected by the improvement in technology. Several communities such as Hindu, Jews and Muslim have special needs for foods. Besides, Islam encourages all humankind to choose excellent food for their consumption. In Islam, food is confined mainly to the concept of halal and haram. Halal means that permissible according to shariah, while the opposite of halal is haram which means forbidden or prohibited. The status between halal and haram are known as mushbooh. This term refers to doubtful of the halal status. Another term to show the quality of products is thayyib which refer to good quality and fulfil standard processes \cite{1}. In Al Quran, the term of halal mostly follows by thayyib.

Traceability is a big issue in the food area. It has been a concern for producers, consumers and enforcement authorities. Many products coming from pig such as pork, lard, and gelatine have been used in food, pharmaceutical, and cosmetic products as well as for additive and primary materials.
Improvement in technologies has led to the rising possibility of counterfeiting practices. Therefore, authentication of pig derivatives in foods and pharmaceuticals is needed. Analytical methods for authentication of food of animal origin have been reviewed by Abbas et al. [2]. The paper highlighted that chromatographic technique such as liquid chromatography (LC) and gas chromatography (GC) and DNA-based technique beneficial for determination of specific ingredients or substitution ingredients due to the sensitivity, selectivity and high accuracy. Also, non-targeted approaches as spectroscopic techniques such as FTIR, NIR, Raman, NMR and UV-Vis spectroscopy are a potential solution for food screening and systematic control for ensuring food safety.

Basically, gelatine is pure protein, collected from the thermal hydrolysis of collagen, the most common protein in the animal kingdom. Recently, some species have been investigated to find the alternative of gelatine such as fish [3–6], chicken [7,8], duck [9] and goat [10]. However, the most abundant sources of gelatine are pig skin, bovine hide and, pork and cattle bones [10,11]. Gelatine is a high molecular weight polypeptide. It is an important hydrocolloid, which is used in many food products [12]. The amino acid composition and sequence in gelatine are different from one source to another but mainly consist of glycine, proline, and hydroxyproline [12,13].

The species-specific detection of gelatine has been studied over the years. Detection and characterisation methods build on protein analysis such as electrophoretic [13], high-performance liquid chromatography, mass-spectrometer detection [14], and enzyme-linked immune-sorbent assay [15]. Also, a non-destructive method such as FTIR [13,16] and DNA-based method using polymerase chain reaction [17,18] reported as an excellent method in gelatine authentication. A study by Tan et al. [19] reported that the bovine and porcine gelatine successfully differentiated using UV-spectroscopy. A chemical reaction, namely Maillard reaction that able to develop browning effect in gelatine was also introduced as an authentication technique. In this study, the differentiation of bovine and porcine gelatine obtained by the different browning intensities of the Maillard products of gelatine after induced by reducing sugar, ribose.

Many researchers have been investigated the effect of Maillard reaction on foods. It is also known as non-enzymatic browning, which produced various sensory-active compounds, including colour, flavour (aroma and taste) [20] and fluorescent products [21]. This paper highlights the potency of the Maillard reaction for species-specific detection of animal derivatives in food-animal product focusing on gelatine.

2. The Maillard reaction for gelatine authentication

The Maillard reaction is a series of chemical reaction at a high temperature which was common in food processing [20,22,23]. The products knowns as Maillard reaction products (MRPs) can be a combination of high molecular and lower molecular mass compounds [24]. The products were reported to have nutritive values [25–28] and anti-oxidative effect [23,26,28]. It also reported have mutagenic and carcinogenic implication [27]. Maillard reaction that responsible for the development of unique aromas, tastes and brown colour during thermal processing of food can be subdivided into three stages. The first stage is the initial stage involves sugar-amine condensation followed with Amadori rearrangement. The second one is the intermediate stage which includes sugar fragmentation and Strecker degradation which created aldehydes and intermediate compounds and the final stage which includes aldol condensation, aldehyde-amine condensation, and formation of heterocyclic nitrogen compounds [25]. The scheme of the Maillard reaction given in Figure 1.

Many factors affected the Maillard reaction such as types of amino acids and sugars, reaction temperature, heating time, pH and water content [29–32]. The type of amine and carbonyl compounds influence products formed while the reaction temperature, heating time, pH and water content influence the rate of reaction [29]. The concentration and ratio of reactants changed the Maillard reaction trend significantly [33–36]. Also, the peptide chain length as the impact of stability of peptide and degree of hydrolysis of the peptide bond greatly influenced the Maillard reaction [32].
2.1. Sensory active compounds

The study on Maillard reaction system was developed based on sugar-protein/peptide and sugar-amino acid model. Many researchers reported the study on sensory-active compounds of Maillard reaction products. In term of colour formation on animal-based food products, several studies have been reported for peptide [32], meat [37] and gelatine [19,38,39]. Another study investigated the flavour compounds of animal-based food products were reported for pork [40], peptides [23,41,42]. Several studies have reported that the amino acids compositions of gelatine vary according to the species [43,44]. Therefore, different source/type of gelatine responded differently during the Maillard reaction process. Glycine, proline and arginine are the dominant amino acid in gelatine [12]. Based on this presumption, some models of Maillard reaction based on the abundance of amino acids can be developed for gelatine authentication.

2.1.1. Colour. The main characteristic of the Maillard reaction is colour formation. The brown products contain high molecular weight polymer and a residual protein known as melanoidin [45]. Melanoidin is responsible for the characteristic brown colour of foods such as coffee, cocoa, bread, malt, and honey [30]. The colour produced can be evaluated by reading the absorbance in the visible region of the spectrum. Absorption is strong below 400 nm, but continuously falling away at the higher wavelengths [25]. Some models Maillard reaction have been developed for gelatine authentication, as shown in Table 1. Most of the study focuses on the sugar-amino acid model, especially for a glycine-glucose model. This model more adaptive to gelatine authentication since glycine is the most abundant of amino acid in gelatine [43], high solubility in water and ethanol [24], the reactivity of glucose higher than fructose [46]. Also, glycine-glucose models were developed to produce standard melanoidin [25]. The study reveals the system for melanoidin formation adjusted to acidic condition (pH 3.5-6.7) and low temperature (±95°C).
### Table 1. The Maillard reaction models for gelatine authentication based on melanoidins formation

| Model system       | Condition of reaction                                                                 | Reference       |
|--------------------|----------------------------------------------------------------------------------------|-----------------|
| Proline-glucose    | pH 5.8, 110 & 130°C, 1h, different buffer                                             | [36]            |
| Glycine-glucose    | Acidic, different temperature and time                                                | [24,34,46,47]   |
| Glycine-fructose   | pH 3.5, 60°C, A420                                                                     | [24]            |
| Glycine-ribose     | pH 7, 121°C, 1h, A290/420, phosphate buffer                                           | [34]            |
| Gelatine-ribose    | different pH, 95°C, A420                                                              | [19]            |
| Gelatine-different sugar | 95°C, 9h, A420                                                                          | [39]            |

The study of gelatine-sugar was reported successfully differentiate bovine and porcine gelatine based on browning value of Maillard products using UV-Vis spectrophotometer at wavelength 420 nm [19,38]. As stated in the previous section, many variables influence the Maillard reaction. The browning was accelerated by the presence of metal ions (Fe2+ and Cu2+) while Na+ will inhibit the reaction [48]. Effect of Cu2+ to browning intensities of porcine, bovine and fish gelatine was evaluated by [38]. The presence of Cu2+ during non-enzymatic browning of gelatine samples causes an increase in the rate of more than 100% of browning intensities. This study also evaluated the effect of enzymatic hydrolysis on browning intensities. A different source of gelatine produced different peptides fractions among species which might contribute differently towards the development of browning during the Maillard reaction process. Thermal degradation of gelatine generated free amino acids and peptides. Therefore, heating is an essential process in Maillard reaction since it induces peptides formation during protein degradation. The abundance of peptides and amino acids in gelatine solution increase significantly after 60 to 120 minutes of heating [49]. According to Kwak and Lim [48], the colour intensity of MRP:s from essential amino acids was higher than acidic amino acids, while nonpolar amino acids were of intermediate colour intensity. Effect of reducing sugar was evaluated for D-glucose, D-galactose, D-xylose, D-mannose, D-fructose, D-maltose monohydrate, L-mannose monohydrate and L-arabinose [39]. The study reported that reducing sugars have a significant effect on brown colour development. The highest browning value of Maillard products obtained from D-xylose-gelatine model rather than fructose and galactose [50], suggesting that this model is suitable for authentication gelatine purpose.

#### 2.1.2. Flavour

Another characteristic of Maillard reaction is a complex sensation. It builds up principally of smell and taste. In general, odour thresholds are much lower than the taste threshold. Thus flavour tends to be dominated by odour components [25]. The Maillard reaction is responsible for the generation of roasted, toasted or caramel-like aroma [51]. Formation of volatile compounds by the Maillard reaction can be classified into 3 groups as below [52]: (1) Simple sugar dehydration/fragmentation products consist of furans, pyrones, cyclopentenes, carbonyls and acids; (2) Simple amino acid degradation products include aldehydes from Strecker degradation and sulfur compounds; and (3) Volatiles produced by further interactions consist of pyrroles, pyridines, imidazoles, pyrazines, oxazoles, thiazoles and compounds ex aldol condensation.

The most critical factors affecting the reaction rate and flavouring characteristics of the Maillard reaction is thermal [30]. Free amino acids and peptide may be generated as hydrolysis products during the heating of protein or peptides [29]. At relatively low temperatures (80-100 °C), pyrazine, the flavour compounds in cooked foods generally formed. It increases rapidly along with the increase of heating time at 120°C [53,54]. Only one study reported about flavour compounds of Maillard products of gelatine [51]. This study involves the fish skin gelatine hydrolysate-galactose model. Some volatiles obtained and classes of Maillard products, as shown in Table 2. The main pathway to flavour formation in the Maillard reaction was affected by the alkaline condition [35,55].
Table 2. Overview of volatile compounds of gelatine-Maillard products [42,56-59]

| Compounds class | Volatiles | Flavour description |
|-----------------|-----------|---------------------|
| Pyrazines       | Pyrazine  | Cooked, roasted, toasted, baked cereals |
| Alkylpyrazine   | Methyl pyrazine, Diethyl-2,6-pyrazine | Roasty, nutty Peanut, butter, wood |
| Pyroles         | Pyrrole   | Cereal-like |
|                 | 2-Acetylpyrrole | Nut, walnut, bread |
| Aldehydes       | Furfural  | Sweet, caramel |
|                 | Nonanal   | Sweet |
|                 | Benzaldehyde | Fat, citrus, green |
|                 | Benzeneacetaldehyde | Almond, burnt, sugar Apple, stimulant |
| Alcohols        | 2-Ethyl hexanol | Rose, green |
|                 | Cyclohexanol | Champor, methanol |
|                 | Methyl eugenol | Sweet, clove-like, green |
|                 | Phenol | Sweet, tarry odour |
|                 | 2,4-ditert-buthyl phenol | Smoky |
| Ketones         | 3-Heptanone | Soap |
|                 | 5-Nonanone | Baked |
|                 | Cyclohexanone | Ether, grape |
|                 | Acetol acetate | Fruity, buttery, nutty |
| Furans          | 2-Acetylfuran | Balsamic |
|                 | 2-Methylfuran | Chocolate, caramel |
| Sulfur compounds | Dimethyl disulfide | Onion, cabbage, putrid |
|                 | Dimethyl trisulfide | Cabbage, sulfur, gasoline |
| Acetonitrile    | Benzeneacetonitrile | Onion, pungent |

Taste is another characteristic of the food flavour which greatly affected by peptides. Heating induced peptide formation during protein degradation [49]. The Maillard peptides with a molecular weight of 1,000–5,000 Da was reported affecter basic taste qualities beside enhanced mouthfuls and continuity [41]. Strong umami, mouthfuls, continuity, meaty attributes have been demonstrated in cysteine-xylose-soybean peptide model system [60], beef bone protein [61], and soy miso [57].

3. Conclusion

Increasing demand and consumer awareness in halal products and authentication may pave the way for further research and exploration of Maillard reaction as an alternative for species-specific detection of gelatine, as its potential to generate colour, odour and taste. Recently, sensor equipment such as electronic eye, electronic nose and electronic tongue has been used for the rapid detection of chemical components and sensory attributes due to the versatility and accuracy. These devices mimic the human senses of the colour, odour and taste, respectively. The equipment consists of several low-selective sensors in the arrays for detection the volatile compounds or non-volatile compounds depend on the system utilised. The signals recorded as the changes in potential electric as the response of different chemical compounds in the samples. An algorithm has been used for signal processing based on pattern recognition, and multivariate used for data analysis. Therefore, it is possible to implement gelatine authentication using the sensor equipment for simple, rapid and low-cost analysis. Besides, processing conditions (pH, temperature, and heating time) to produce the optimum yield Maillard products, as well as colour and flavour, need to evaluate.

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References
[1] Ab Halim M A B, Kashim M I A B M, Salleh M M M, Nordin N B and Husni A B M 2015 Halal pharmaceuticals. *Soc. Sci.* **10** 490–8
[2] Abbas O, Zadravec M, Baeten V, Mikuš T, Lešić T, Vulić A, Prpić J, Jemeršić L and Pleadin J 2018 Analytical methods used for the authentication of food of animal origin. *Food Chem.* **246** 6–17
[3] Khiazi Z, Rico D, Martin-Diana A B and Barry-Ryan C 2013 Comparison between gelatines extracted from mackerel and blue whiting bones after different pre-treatments. *Food Chem.* **139** 347–54
[4] Monsur H A, Jaswir I, Salleh H M and Alkahtani H A 2014 Effect of pretreatment on properties of gelatin from Perch (Lates nicotilus) skin. *Int. J. Food Prop.* **17** 1224–36
[5] Sucupira N R, Alves Filho E G, Silva L M A, de Brito E S, Wurlitzer N J and Sousa P H M 2017 NMR spectroscopy and chemometrics to evaluate different processing of coconut water. *Food Chem.* **216** 217–24
[6] Yan M, Li B, Zhao X and Yi J 2011 Physicochemical properties of gelatin gels from walleye pollock (Theragra chalcogramma) skin cross-linked by gallic acid and rutin. *Food Hydrocoll.* **25** 907–14
[7] Abdullah S, Noordin M I, Ismail S I., Shaik N, Jasamai M, Wai L., Mustapha N M and Shamsuddin A F 2016 Physicochemical Evaluation and Spectroscopic Characterisation of Gelatine from Shank and Toes of Gallus gallus domesticus. *Sains Malaysiana* **45** 435–49
[8] Mhd Sarbon N, Badii F and Howell N K 2013 Preparation and characterisation of chicken skin gelatin as an alternative to mammalian gelatin. *Food Hydrocoll.* **30** 143–51
[9] Abedinia A, Ariffin F, Huda N and Mohammadi Nafchi A 2017 Preparation and characterization of a novel biocomposite based on duck feet gelatin as alternative to bovine gelatin. *Int. J. Biol. Macromol.*
[10] Mad-Ali S, Benjakul S, Prodpran T and Maqsood S 2016 Interfacial properties of gelatin from goat skin as influenced by drying methods. *LWT - Food Sci. Technol.* **73** 102–7
[11] Sila A, Martinez-alvarez O, Haddar A, Gómez-guillén M C, Nasri M, Montero M P and Bougatef A 2015 Recovery, viscoelastic and functional properties of Barbel skin gelatine. Investigation of anti-DPP-IV and anti-prolyl endopeptidase activities of generated gelatine polypeptides. *Food Chem.* **168** 478–86
[12] Hafidz R M R ., Man Y B C, Amin I and Noorfaizan A 2011 Chemical and functional properties of bovine and porcine skin gelatin. *Int. Food Res. J.* **817** 813–7
[13] Hermanto S, Sumarlin L O and Fatimah W 2013 Differentiation of bovine and porcine gelatin based on spectroscopic and electrophoretic analysis. *J. Food Pharm. Sci.* **1** 68–73
[14] Grundy H H, Reece P, Buckley M, Solazzo C M, Dowle A A, Ashford D, Charlton A J, Wadsley M K and Collins M J 2016 A mass spectrometry method for the determination of the species of origin of gelatine in foods and pharmaceutical products. *Food Chem.* **190** 276–84
[15] Tukiran N A, Ismail A, Mustafa S and Hamid M 2016 Determination of porcine gelatin in edible bird’s nest by competitive indirect ELISA based on anti-peptide polyclonal antibody. *Food Control* **59** 561–6
[16] Cebi N, Durak M Z, Toker O S, Sagdic O and Arici M 2016 An evaluation of Fourier transforms infrared spectroscopy method for the classification and discrimination of bovine, porcine and fish gelatins. *Food Chem.* **190** 1109–15
[17] Ali M E, Razzak M A and Hamid S B A 2014 Multiplex PCR in Species Authentication: Probability and Prospects—a Review. *Food Anal. Methods* **7** 1933–49
[18] Shabani H, Meh dizadeh M, Mousavi S M, Dezfouli E A, Solgi T, Khodaverdi M, Rabiei M, Rastegar H and Alebouyeh M 2015 Halal authenticity of gelatin using species-specific PCR. *Food Chem.* **184** 203–6
[19] Tan T C, Alkarkhi A F M and Easa A M 2012 Assessment of the ribose-induced Maillard
reaction as a means of gelatine powder identification and quality control *Food Chem.* **134** 2430–6

[20] Cerny C 2008 The aroma side of the Maillard reaction *Ann. N. Y. Acad. Sci.* **1126** 66–71

[21] Matiacevich S B and Pilar Buera M 2006 A critical evaluation of fluorescence as a potential marker for the Maillard reaction *Food Chem.* **95** 423–30

[22] Martins S I F S, Jongen W M F and van Boekel M A J . 2001 A review of Maillard reaction in food and implications to kinetic modelling A review of Maillard reaction in food and implications to kinetic modelling *Trends Food Sci. Technol.* **11** 364–73

[23] Liu Q, Niu H, Zhao J, Han J and Kong B 2016 Effect of the Reactant Ratio on the Characteristics and Antioxidant Activities of Maillard Reaction Products in a Porcine Plasma Protein Hydrolysate-Galactose Model System *Int. J. Food Prop.* **19** 99–110

[24] Shen S, Tseng K and Wu J S 1999 An analysis of Maillard reaction products in ethanolic glucose – glycine solution *Food Chem.* **102** 281–7

[25] Nursten H 2005 *The Maillard Reaction* (London, UK: The Royal Society of Chemistry)

[26] Gu F, Abbas S and Zhang X 2009 Optimization of Maillard reaction products from casein – glucose using response surface methodology *LWT - Food Sci. Technol.* **42** 1374–9

[27] Yang S, Kim S, Kim Y, Lee S, Jeon H and Lee K 2015 Optimization of Maillard reaction with ribose for enhancing anti-allergy effect of fish protein hydrolysates using response surface methodology *FOOD Chem.* **176** 420–5

[28] Malgorzata W, Konrad P M and Zielin H 2016 Effect of roasting time of buckwheat groats on the formation of Maillard reaction products and antioxidant capacity *Food Chem.* **196** 355–8

[29] Jaeger H, Janositz A and Knorr D 2010 The Maillard reaction and its control during food processing *Pathol. Biol.* **58** 207–13

[30] Van Boekel M A J S 2006 Formation of flavour compounds in the Maillard reaction *Biotechnol. Adv.* **24** 230–3

[31] Wang H Y, Qian H and Yao W R 2011 Melanoidins produced by the Maillard reaction: Structure and biological activity *Food Chem.* **128** 573–84

[32] Kim J and Lee Y 2009 Study of Maillard reaction products derived from aqueous model systems with different peptide chain lengths *Food Chem.* **116** 846–53

[33] Bell L N 1997 Maillard reaction as influenced by buffer type and concentration *Food Chem.* **59** 143–7

[34] Chen X-M and Kitts D D 2008 Antioxidant Activity and Chemical Properties of Crude and Fractionated Maillard Reaction Products Derived from Four Sugar-Amino Acid Maillard Reaction Model Systems *Ann. N. Y. Acad. Sci.* **1126** 220–4

[35] Martins S I F S and Van Boekel M A J S 2005 Kinetics of the glucose/glycine Maillard reaction pathways: Influences of pH and reactant initial concentrations *Food Chem.* **92** 437–48

[36] Guan Y-G, Wang S-L, Yu S-J, Yu S-M and Zhao Z-G 2012 Changes in the initial stages of a glucose-proline Maillard reaction model system influences dairy product quality during thermal processing *J. Dairy Sci.* **95** 590–601

[37] Tan T C, Alkarkhi A F M and Easa A M 2013 Ribose-induced maillard reaction as a quality index in frozen minced chicken and pork meats *J. Food Qual.* **36** 351–60

[38] Hamizah A, Hammed A M, Asiyambi-H T T, Mirghani M E S, Jaswir I and Fadzillah N A 2017 Evaluation of Catalytic Effects of Chymotrypsin and Cu 2+ for Development of UV-Spectroscopic Method for Gelatin-Source Differentiation *Int. J. Food Sci.* **2017** 1–5

[39] Hamid A H, Nurrulhidayah A F ma., Sani M S A, Muhammad N W F, Othman R and Rohman A 2020 Discrimination of porcine and bovine gelatines based on reducing sugar types on Maillard reaction *Food Res.* **4** 301–6

[40] Benet I, Dolors M, Ibáñez C, Solà J, Arnau J and Roura E 2016 Low intramuscular fat (but high in PUFA) content in cooked cured pork ham decreased Maillard reaction volatiles and pleasing aroma attributes *Food Chem.* **196** 76–82

[41] Ogasawara M, Katsumata T and Egi M 2006 Taste properties of Maillard-reaction products
prepared from 1000 to 5000 Da peptide Food Chem. 99 600–4

[42] Yang C, Wang R and Song H 2012 The mechanism of peptide bonds cleavage and volatile compounds generated from pentapeptide to heptapeptide via Maillard reaction Food Chem. 133 373–82

[43] Hafidz R N R M, Ismail A and Man Y B C 2012 Analytical Methods for Gelatin Differentiation from Bovine and Porcine Origins and Food Products 71

[44] Karim A A and Bhat R 2009 Fish gelatin: properties, challenges, and prospects as an alternative to mammalian gelatins Food Hydrocoll. 23 563–76

[45] Rizzi G 2011 Chemical structure of colored maillard reaction products Food Rev. Int. 13 1–28

[46] Guillermo F and Reyes R 1982 Maillard Browning Reaction of Sugar - Glycine Model Systems: Changes in Sugar Concentration , Color and Appearance Maillard Browning Reaction of Sugar-Glycine Model Systems : J. Food Sci. 47 1376–7

[47] Hayase F, Kim S B and Kato H 1985 Maillard Reaction Products Formed from D-Glucose and Glycine and the Formation Mechanisms of Amides as Major Components has been reported to be mainly in the investigated by the Tenax GC trapping meth- in Volatile components formed by heating diacetyl of a Agric. Biol. Chem. 49 2337–41

[48] Kwak E J and Lim S I 2004 The effect of sugar, amino acid, metal ion, and NaCl on model Maillard reaction under pH control Amino Acids 27 85–90

[49] Qi J, Zhang W wen, Feng X chao, Yu J hang, Han M yi, Deng S lin, Zhou G hong, Wang H hu and Xu X lian 2018 Thermal degradation of gelatin enhances its ability to bind aroma compounds: Investigation of underlying mechanisms Food Hydrocoll. 83 497–510

[50] Hamid A H, Elgharbawy A A, Rohman A, Rashidi O, Hammed H and Nurrulhidayah A F 2019 Optimisation of browning index of Maillard reaction in gelatine powder by response surface methodology (RSM) for halal authentication Food Res. 3 525–9

[51] Karnjanapratum S and Benjakul S 2017 Antioxidative and sensory properties of instant coffee fortified with galactose-fish skin gelatin hydrolysate Maillard reaction products Carpathian J. Food Sci. Technol. 9 90–9

[52] Martins S I F S, Jongen W M F and Boekel M A J S Van 2001 A review of Maillard reaction in food and implications to kinetic modelling 11 364–73

[53] Yu A, Tan Z and Wang F 2012 Mechanism of formation of sulphur aroma compounds from L - ascorbic acid and L -cysteine during the Maillard reaction Food Chem. 132 1316–23

[54] Liu J, Liu M, He C, Song H and Chen F 2015 Effect of thermal treatment on the flavor generation from Maillard reaction of xylose and chicken peptide LWT - Food Sci. Technol. 64 316–25

[55] Yu A and Zhang A 2010 The effect of pH on the formation of aroma compounds produced by heating a model system containing L - ascorbic acid with L -threonine / L -serine Food Chem. 119 214–9

[56] SEPA 2010 Odour Guidance 2010 (Scotland: Natural Scotland Scottish Government)

[57] Inoue Y, Kato S, Saikusa M, Suzuki C, Otsubo Y and Tanaka Y 2016 Analysis of the cooked aroma and odorants that contribute to umami aftertaste of soy miso ( Japanese soybean paste ) Food Chem. 213 521–8

[58] Sanz C, Ansoarena D, Bello J and Cid C 2001 Optimizing headspace temperature and time sampling for identification of volatile compounds in ground roasted Arabica coffee J. Agric. Food Chem. 49 1364–9

[59] Niu Y, Yao Z, Xiao Q, Xiao Z, Ma N and Zhu J 2017 Characterization of the key aroma compounds in different light aroma type Chinese liquors by GC-olfactometry , GC-FPD , quantitative measurements , and aroma recombination Food Chem. 233 204–15

[60] Huang M, Liu P, Song S, Zhang X, Hayat K, Xia S, Jia C and Gu F 2011 Contribution of sulfur-containing compounds to the colour-inhibiting effect and improved antioxidant activity of Maillard reaction products of soybean protein hydrolysates J. Sci. Food Agric. 91 710–20

[61] Song S, Li S, Fan L, Hayat K, Xiao Z, Chen L and Tang Q 2016 A novel method for beef bone
protein extraction by lipase-pretreatment and its application in the Maillard reaction *Food Chem.* 208 81–8