The flavor chemistry of pork broth: a review

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Abstract. Pork is widely consumed in the world. The unique and attractive flavor is one of the major drivers of consumer liking for pork. Even though the flavor of pork products varies heavily depending on the processing and cooking method, pork broth is very popular in East Asian countries and could serve as a perfect model for studying the flavor chemistry of pork. While quite a number of studies have been carried out on this topic, only a few meet the basic criteria of modern flavor chemistry approaches. By reviewing these publications, 12 volatile compounds, including 4 sulfur containing compounds, 4 aldehydes, 1 alcohol, 1 ester, 1 lactone, and 1 carboxylic acid, were selected as the major aroma active components in pork broth. While the taste of pork broth mainly comes from the basic tastants such as amino acids, organic acids, inorganic minerals, and nucleotides, the role of taste modifiers in pork broth has yet to be investigated. More research is needed to further clarify the flavor chemistry of pork broth.

1. Introduction
Pork is one of the most commonly consumed meats worldwide. According to a review from the Food and Agriculture Organization (FAO) of the United Nations, a total of 118.7 million tons of pig meat were produced in 2017, accounting for 36% of the world’s meat output throughout the year (http://www.fao.org/3/i9286EN/i9286en.pdf). The flavor, tenderness, and juiciness are the three most important drivers for consumers’ favor over pork [1].

To date, quite a number of studies on pork flavor has been carried out and published. Unfortunately, most of those studies were from decades ago and research techniques employed were considered relatively outdated. On the other hand, with tremendous progresses has been achieved in flavor chemistry in the past decade, it is necessary to review recent progress on the flavor chemistry of pork with up-to-date concepts to achieve a better understanding on the flavor of pork products.

While pork is consumed both freshly cooked and preserved, processing such as curing and smoking extended the shelf life of pork and confers distinct flavors to pork products. Different processing conditions and curing agents applied would alter the ingredient and taste of pork; As our research focuses mainly on the chemistry of cooked pork [2], these factors will not be included in this review. Among the countries with the highest pork consumption, East Asian countries prefer moisture cooking methods to process fresh pork. One good example is the pork broth, which the boiling of pig flesh and bones with water makes a palatable stew with intense meaty flavor. Because of its simplification in both raw material preparation and cooking method application, pork broth is also a perfect model for the study of pork flavor generation [3]. The aim of this review is to summarize recent progress on the chemistry behind pork broth flavor.
2. Aroma of pork broth

The research on meat flavor dates back to the early 1960s when Hornstein and Crowe discovered that similar meaty odor of cooked lean meats was generated from the dialyzable portion of the cold water extracts during heating, while the characteristic flavor of beef and pork came from their fat [4]. Batzer et al. also attempted to isolate and characterize the flavor precursors in beef; Through column chromatography and gel filtration, they isolated a fraction of relatively light molecules containing peptides, carbohydrates, and unidentified phosphates as the flavor precursors [5]. Since then, a series of research has been carried out to study the change of water-soluble flavor precursors induced by heating in pork, beef, and lamb. Relied upon the quantitative analyses of the amino acids, carbohydrates, non-amino acid nitrogen compounds, phosphoric acid esters, and nucleotides, the changes induced by heating were identified, and the importance of these constituents as precursors of the odor and flavor were discussed [6-10]. However, still there is a lack of consensus on the exact formation mechanism of meat flavor from the precursors.

Raw and unprocessed meat has nearly no flavor except for some bloody and metallic taste, but their appealing flavor is developed from complicated chemical reactions taking place during thermal processing. Therefore, the introduction of heat with different cooking methods will inevitably affect the aroma profiles of the final pork product.

So far, over 1000 volatiles have been identified in meat and meat products [11]. During the past several decades, plenty of research has been published on the aroma active components of cooked pork. In the majority of those works, the volatile fraction was extracted by either solid phase microextraction (SPME) or simultaneous distillation and extraction (SDE), characterized with gas chromatography-mass spectrometry (GC-MS), and the tentative identification was achieved by searching from public database such as National Institute of Standards and Technology (NIST). Through those measures, up to a hundred volatiles could be found from a processed pork product. For example, Elmore et al. identified 96 volatile compounds in the boiled pork with two-fibre solid phase microextraction (SPME) coupled with GC-MS [12]. Xie et al. also discovered over 80 aroma compounds in the roasted mini pig using SDE and SPME [13]. However, though such works were good examples of the rough profiling of volatiles, they are by no means an exact characterization of the odor active components. There are several reasons for that: 1) the vast majority of volatiles from foods are actually odorless by themselves, 2) for volatiles that are odor active, their concentration in foods might be lower than their odor threshold to be detected by our sensory organs, thus plays no role in the formation of the overall aroma of the foods. To address those problems, the concept of key food odorants (KFO) was introduced by Dunkel et al. [14]. After a systematic review of the complete decoding of the aroma profile of 226 foods, a total of 227 KFOs in any of the food samples analyzed was identified; For each individual food item, only 3 to 40 KFOs were responsible for its distinctive odor. By focusing on the KFOs, the odor landscape could be effectively simplified from more than 10,000 volatiles to roughly 230 KFOs.

2.1. Characterization method for aroma active components

The identification of the KFOs can act as a targeting method for characterization of the odorants in pork. In order to acquire a more accurate aroma profile of cooked pork, it is necessary to incorporate the technique of Gas Chromatography-Olfactometry (GC-O) combined with aroma extract dilution analysis (AEDA) to determine the presence of key odorants. The introduction of GC-O can effectively simplify the process of characterization by ruling out the odor inactive volatiles.

To ensure the quality of data acquired, we set the following criteria to select for the data to be included in this review.1) the volatile fraction of the samples was separated from non-volatiles by solvent-assisted flavor evaporation (SAFE). 2) The odor quality of the SAFE extracts was assessed by GC-O and the odor contribution was analyzed by aroma extraction dilution analysis (AEDA). 3) The identity of the aroma principles should be unequivocally characterized by comparing the retention indices and aroma quality with the authentic standards.
2.2. Characterization of aroma active components

Based on the criteria set above, a total of four publications were selected for the characterization of key aroma components in pork broth. Takakura et al. boiled pork thighbone with removed marrow in tap water and strained through a paper towel to acquire the clear pork stock. The volatile compounds were isolated with SAFE and analyzed through GC-MS. With aroma dilution analysis, they identified 15 aroma active compounds. Among those compounds, acetol, octanoic acid, δ-decalactone, and decanoic acid were determined to be the main aroma contributors in the pork soup through addition and omission experiments [3]. Wang et al. examined the volatile compounds in the stewed pork broth of the white pig. They used authentic standards to identify and quantify the acquired compounds. By applying SAFE-GC-MS, the volatile constituents and their relative abundance in the white pig broth were identified with the help of mass spectrum and retention indices. Among those identified volatile compounds, the key aroma contributors are selected through GC-O and assigned the odor qualities [15]. Zhao et al. investigated the flavor of pork broth made from black pigs by identifying and quantifying the volatile compounds that contributed to the special flavor. Among the 104 volatiles detected, 27 odor active compounds were characterized [16]. Lastly, Wang et al. examined aroma compounds in the pork broth under different cooking conditions. However, among 78 compounds found, only 12 of them were characterized as predominant aroma active compounds by AEDA [17]. Taken these results together, 58 odor active compounds were identified from pork broth, including 29 KFOs and 29 non-KFOs.

The 29 KFO were listed in Table 1. It includes 4 organic acids, 1 alcohol, 12 aldehydes, 2 esters, 3 ketones, and 6 sulfur-containing compounds. As those compounds have already been demonstrated to be KFOs, it is very likely that they were responsible for the aroma of pork broth. The non-KFO odor active compounds in the pork broth were shown in Table 2. It is composed of 2 organic acid, 2 alcohol, 8 aldehydes, 2 esters, 4 ketones, 1 pyrazine, and 10 sulfur-containing compounds. Although their contribution to pork broth aroma cannot be totally ruled out, it is unlikely for them to play a significant role in the aroma profile as they have not been characterized as KFOs. Among all the KFOs and non-KFOs, aldehydes and sulfur-containing compounds are the predominate ones. The aldehydes are primarily formed through lipid degradation during thermal treatment; The saturated and unsaturated aldehydes that are within 6-10 carbons are the major volatile compounds of the cooked meat. On the other hand, the sulfur-containing compounds are formed through the Millard reaction which provides the meaty flavors for the meat products. Aldehydes were also shown to be able to interact with the Millard reaction intermediates to influence the formation of sulfur-containing compounds [18].
### Table 1. Aroma active compounds in pork broth (KFO)

| No. | Group | Compound | CAS No. | Odor quality | Identification method | Ref. |
|-----|-------|----------|---------|--------------|-----------------------|------|
| 1   |       | Acetic acid | 64-19-7 | Sour | RI, MS, S | [3] |
| 2   | Acid  | 3-Methylbutanoic acid | 503-74-2 | Animal, cheesy | RI, MS, S | [3] |
| 3   |       | Octanoic acid | 124-07-2 | Oily, green, pungent | RI, MS, S | [3] |
| 4   |       | Decanoic acid | 334-48-5 | Fatty, sweet | RI, MS, S | [3] |
| 5   | Alcohol | 1-Octen-3-ol | 3391-86-4 | Mushroom | MS, RI, S, odor | [15, 16] |
| 6   |       | Vanillin | 121-33-5 | Vanilla | RI, MS, S | [3] |
| 7   |       | 3-(methylthio)propanal | 3268-49-3 | Cooked potato | RI, odor, MS, S | [16, 17] |
| 8   |       | Nonanal | 124-19-6 | Oily, sweet melon, floral | RI, S, odor, MS | [15, 16] |
| 9   |       | Hexanal | 66-25-1 | Green, cut-grass, grass | RI, S, odor, MS | [15, 16] |
| 10  |       | (E)-2-Heptanal | 2074-05-7 | Fatty | RI, S, odor, MS | [16] |
| 11  |       | Phenylacetaldehyde | 122-78-1 | Rose | RI, S, odor, MS | [16] |
| 12  | Aldehyde | (E)-2-Nonenal | 18829-56-6 | Cucumber, fatty | MS, RI, S, odor | [15, 16] |
| 13  |       | (E, E)-2,4-nonadienal | 5910-87-2 | Fatty | RI, S, odor, MS | [15, 16] |
| 14  |       | (E)-2-decenal | 3913-81-3 | Fatty | RI, S, odor, MS | [16] |
| 15  |       | (E, E)-2,4-decadienal | 25152-84-5 | Fatty | RI, S, odor, MS | [16] |
| 16  |       | (E, E)-2,4-Decadienal | 25152-84-5 | Fennel, fatty | RI, S, odor | [15] |
| 17  |       | (E)-2-Undecenal | 53448-07-0 | Gypsum, bug, fatty | RI, S, odor | [15] |
| 18  | Esters | γ-decalactone | 706-14-9 | Peach, boiled sugar | RI, S, odor | [15, 16] |
| 19  |       | Ethyl acetate | 141-78-6 | Fruity | RI, odor, MS | [17] |
| 20  | Ketone | δ-decalactone | 705-86-2 | Sweet, milky | RI, MS, S | [3] |
| 21  |       | 1-penten-3-one | 1629-58-9 | Pungent | RI, odor, MS | [17] |
| 22  |       | 4-Hydroxy-2,5-dimethyl-3(2H)-furanone | 3658-77-3 | Caramel | RI, S, odor | [16] |
| 23  | Sulfur compounds | Methanethiol | 74-93-1 | Sulphur, gasoline, rotten egg | RI, odor, S | [15, 16] |
| 24  |       | 2-Methyl-3-furanthiol | 28588-74-1 | Cooked meat, Boiled meat | RI, S, odor | [15, 16] |
| 25  |       | 2-Furfurylthiol | 98-02-2 | Sesame, Boiled meat | RI, S, odor | [16] |
| 26  |       | Dimethyl trisulfide | 3658-80-8 | Sulphur, meaty, cooked cabbage, Onions | RI, odor, MS | [15, 16] |
| 27  |       | Dimethyl disulfide | 624-92-0 | Onions | RI, odor, MS | [17] |
| 28  |       | 3-(methylthio)propionaldehyde | 3268-49-3 | Boiled meat, boiled potato | RI, S, odor | [15] |
| 29  |       | Furan-2-ylmethanethiol | 98-02-2 | Boiled meat, boiled potato | RI, S, odor | [15] |

*MS, identified by mass spectral database; RI, agreed with the retention indices published in literatures; Odor, agreed with the odor descriptors published in literatures; S, the analytical parameters including MS, RI, and odor characteristics all agreed with those of the authentic standard chemicals used."
| No. | Group       | Compounds                        | CAS No.   | Odor quality                      | Identification method * | Ref. |
|-----|-------------|----------------------------------|-----------|-----------------------------------|-------------------------|------|
| 1   | Acid        | Nonanoic acid                    | 112-05-0  | Waxy, fatty                       | RI, MS, S              | [3]  |
| 2   | Acid        | Dodecanoic acid                  | 143-07-7  | Camphor                           | RI, MS, S              | [3]  |
| 3   | Alcohol     | Acetol                           | 116-09-6  | Mushroom-like, green              | RI, MS, S              | [3]  |
| 4   | Aldehydes   | 1-Octanol                        | 111-87-5  | Fatty, oxidized oil-like          | RI, MS, S              | [3]  |
| 5   | Aldehydes   | 5-(Hydroxymethyl) fural          | 67-47-0   | Musty                             | RI, MS, S              | [3]  |
| 6   | Aldehydes   | Benzaldehyde                      | 100-52-7  | Almond-like, roasty               | RI, MS, S              | [3]  |
| 7   | Aldehydes   | Pentanal                          | 110-62-3  | Green, grass                      | RI, S, odor, MS        | [15, 16] |
| 8   | Aldehydes   | (E)-2-Hexanal                    | 6728-26-3 | Green, fatty                      | RI, S, odor, MS        | [16] |
| 9   | Aldehydes   | Heptanal                          | 111-71-7  | Fruity, Sweet melon               | MS, RI, S, odor        | [15, 16] |
| 10  | Aldehydes   | (E)-2-Hepental                    | 18829-55-5| Onion, fatty                      | MS, RI, S, odor        | [15] |
| 11  | Aldehydes   | Phenethyl alcohol                 | 60-12-8   | Muscat, Hamburg                   | MS, RI, S, odor        | [15] |
| 12  | Aldehydes   | (E, E)-2,4-Nonenal               | 5910-87-2 | Gypsum, bug, fatty                | MS, RI, S, odor        | [15] |
| 13  | Ester       | methyl palmitate                  | 112-39-0  | Sweet                             | RI, MS, S              | [3]  |
| 14  | Ester       | Propanoic acid ethyl ester       | 105-37-3  | Fruity                            | RI, MS                 | [17] |
| 15  | Ketone      | 2-Pentadecanone                   | 2345-28-0 | Sweet                             | RI, MS, S              | [3]  |
| 16  | Ketone      | 2-butanone                        | 78-93-3   | Green                             | RI, odor, MS           | [17] |
| 17  | Ketone      | 2-Undecanone                      | 112-12-9  | Fennel, parsley, fatty            | MS, RI, S, odor        | [15] |
| 18  | Pyrazine    | 3-Hydroxy-2-butanone              | 51555-24-9| Yogurt                            | RI, S, odor            | [15, 16] |
| 19  | Pyrazine    | 2-Ethyl-3-Methylpyrazine          | 15707-23-0| Sesame                            | MS, RI, S, odor        | [15] |
| 20  | Pyrazine    | 2-Mercaptothiophene               | 7774-74-5 | Sesame                            | RI, S, odor            | [16] |
| 21  | Sulfur      | 2-Thiophene carboxaldehyde       | 98-0303   | Sulfur                            | RI, S, odor, MS        | [16] |
| 22  | Sulfur      | 2-Acetylthiazole                  | 24295-03-2| Sesame, roasted                   | RI, S, odor, MS        | [16] |
| 23  | Sulfur      | 2-Acetylthiazole                  | 24295-03-2| Sesame                            | MS, RI, S, odor        | [15] |
| 24  | Sulfur      | 4-Methyl-5-thiazoleethanol        | 137-00-8  | Sesame                            | RI, S, odor, MS        | [16] |
| 25  | Sulfur      | Methyl ethyl disulfide            | 20333-39-5| Onions                            | RI, odor, MS           | [17] |
| 26  | Sulfur      | Diethyl disulfide                 | 110-81-6  | Garlic                            | RI, odor, MS           | [17] |
| 27  | Sulfur      | 2-Thiophenethiol                  | 7774-74-5 | Braised meat, boiled leaves        | RI, S, odor            | [15] |
| 28  | Sulfur      | 3-Hydroxymethylthiophene          | 71637-34-8| Grass                             | MS, RI, S, odor        | [15] |
| 29  | Sulfur      | Bis(2-methyl-3-furyl) disulfide   | 28588-75-2| Boiled Meat                       | RI, S, odor            | [15] |

* MS, identified by mass spectral database; RI, agreed with the retention indices published in literatures; Odor, agreed with the odor descriptors published in literatures; S, the analytical parameters including MS, RI, and odor characteristics all agreed with those of the authentic chemicals used.

Table 2. Aroma active compounds in pork broth (Non-KFO)
2.3. Quantification of aroma active components in pork broth
By combining SAFE, GC-O and AEDA, the aroma principles of the pork broth could be identified. However, some of those compounds might exist at concentrations under their corresponding odor thresholds. To gain precise information on their relative contribution to the pork broth flavor, their natural concentrations need to be determined and compared with their odor threshold.

In Table 3, the odor activity values (OAV) of the odor principles of pork broth were calculated by dividing the concentration of the aroma compounds with their odor thresholds acquired from literature [19]. Among the 29 KFO volatiles identified, 12 of them have odor activity values greater than 1 (Fig. 1), which suggests that they are supposed to be the major contributors to the aroma of pork broth.

Table 3. Concentration and OAV of aroma active components in pork broth (KFO)

| Compounds                        | CAS No.   | Concentration (ppm) | Odor threshold (ppm) | Odor activity value (OAV) | Ref.     |
|----------------------------------|-----------|---------------------|----------------------|--------------------------|---------|
| Dimethyl trisulfide              | 3658-80-8 | 0.0316              | 0.000016             | 1975                     | [17, 20]|
| Decanoic acid                    | 334-48-5  | 6.50                | 0.006                | 1083.333                 | [3, 21] |
| 2-Methyl-3-furathiol             | 28588-74  | 0.00339             | 0.000004             | 848.25                   | [16, 22]|
| 1-Octen-3-ol                    | 3391-86-4 | 0.011737            | 0.0001               | 111.37                   | [16, 23]|
| (E, E)-2,4-nonadienal           | 5910-87-2 | 0.017082            | 0.00019              | 89.9                     | [17, 20]|
| Dimethyl disulfide               | 624-92-0  | 0.1005              | 0.0022               | 45.682                   | [17, 24]|
| δ-Decalactone                    | 705-86-2  | 0.77                | 0.051                | 15.1                     | [3, 20] |
| Hexanal                          | 66-25-1   | 0.14712             | 0.01                 | 14.712                   | [17, 20]|
| 3-(Methylthio) propanol          | 505 - 10 - 2 | 0.006649        | 0.0014               | 4.749                    | [16, 20]|
| (E,E)-2,4-decadialen            | 25152-84-5 | 0.000345         | 0.000077             | 4.481                    | [16, 20]|
| Ethyl acetate                    | 141-78-6  | 2.78253             | 0.87                 | 3.198                    | [17, 24]|
| Nonanal                          | 124-19-6  | 0.01                | 0.008                | 1.25                     | [3, 20, 24]|
| Vanillin                         | 121-33-5  | 0.10                | 0.21                 | 0.476                    | [3, 20] |
| (E)-2-nonenal                    | 18829-56-6 | 0.000317        | 0.00069              | 0.459                    | [16, 20]|
| Octanoic acid                    | 124-07-2  | 1.10                | 4.959                | 0.222                    | [3, 25] |
| Phenylacetaldehyde               | 122-78-1  | 0.000884            | 0.004                | 0.221                    | [16, 26]|
| Acetic acid                      | 64-19-7   | 0.04                | 1.0                  | 0.040                    | [3, 27] |
| 3-Methylbutanoic acid            | 503-74-2  | 0.03                | 1.2                  | 0.025                    | [3, 20] |
| (E)-2-decenal                    | 3913-81-3 | 0.000680            | N/A                  | N/A                      | [16]    |
| 1-penten-3-one                   | 1629-58-9 | 0.17633             | N/A                  | N/A                      | [17]    |
2.4. Key aroma components in pork broth

The aroma components in pork broth were formed during heating treatment. The major precursor for the aroma compounds could be divided into two categories: water soluble and lipid soluble. The Millard reaction between reducing sugars and amino acids, as well as the lipid oxidation and degradation, together contribute to the overall flavor of meat [18].

As shown in Fig. 1, the major contributors to the aroma of pork broth could be narrowed down to 12 compounds. Among all the 12 compounds, dimethyl trisulfide had the highest OAV values, this comes with no surprise as dimethyl trisulfide is such an important odorant and has been found as key odorants in a wide variety of foodstuff such as beef broth [28], chicken [29], cheese [30], and coffee [31]. Dimethyl disulfide has a similar aroma profile but has a more improved odor threshold (Table 3), and it has been found as a key odorant in pork [32], blackberries [33], and some liquors [34]. Dimethyl trisulfide and dimethyl disulfide are supposed to be generated from sulfur-containing amino acids, especially methionine and its derivatives. The existence of 3-(Methylthio) propanol in pork broth should be investigated since they were mostly found in fermented foods, especially in beer and wine [35, 36]. 2-methyl-3-furanthiol is a very potent food odorant from Millard reaction with intense coffee like smell, and has previously been found in heated meat [37].

The majority of 12 compounds were fatty acids oxidation products, and these include decanoic acids, 1-octen-3-ol, (E, E)-2,4-nonadienal, δ-decalactone, hexanal, (E, E)-2,4-decadienal, and nonanal. Lipids play an important role in generating the odor and flavor of food products. However, with its low volatility, the lipids contribute to the flavor by acting as the precursors of volatile compounds that invest in the aroma profile [38]. Unsaturated fats, as the main precursors of the fatty acid oxidation reaction, react with oxygen to form fatty acid hydroperoxides through free radical chain mechanism [39]. Hexanal, 1-octen-3-ol, (E, E)-2,4-nonadienal, and (E, E)-2,4-decadienal arise from the n-6 fatty acids oxidation, and nonanal comes from the oxidation of n-9 fatty acids [40]. Since n-6 and n-9 fatty acids formed the major fatty acids presented in pork [40], the oxidation products are supposed to be present in higher levels after thermal treatment. The details of those transformations have been well reviewed in the formation of chicken aroma [41].

3. Taste of pork broth

Compared to the large amount of research carried on aroma, the taste profile of pork broth was less studied and there was a lack of data about the taste contributing compounds in pork broth.
3.1. Basic taste active components in pork broth

Takakura et al. proposed a pork stock model by mixing basic taste active compounds in the pork broth. By using the combination of chemicals, they were able to mimic the taste of pork broth, and the specific concentration of each compound was also determined [3]. On the other hand, Hou et al. studied the influence of the aging time of pork on the makeup of taste profile. In these two studies, the basic tastants were listed in Table 4, from which it is clear that the basic taste active compounds of pork broth include amino acids, organic acid, minerals, and nucleotides [42].

Table 4. Basic taste active components in pork broth

| Group       | Compounds      | Sample Type                  | CAS No.   | Taste quality | Concentration (mg/100ml) | Ref.  |
|-------------|----------------|------------------------------|-----------|---------------|--------------------------|-------|
| Amino acid  | Taurine        | Pork stock model             | 107-35-7 | N/A           | 3.36                     | [3]   |
|             | L- Threonine   | Pork stock model             | 72-19-5  | Sweet         | 1.11                     | [3, 42]|
|             | L-Serine       | Pork stock model             | 56-45-1  | Sweet         | 1.79 ± 0.16              | [3, 42]|
|             | Glycine        | Pork stock model             | 56-40-6  | Sweet         | 0.82                     | [3, 42]|
|             | L-Alanine      | Pork stock model             | 56-41-7  | Sweet         | 1.67 ± 0.14              | [3, 42]|
|             | L-Valine       | Pork stock model             | 72-18-4  | Bitter        | 1.00                     | [3, 42]|
|             | L-Leucine      | Pork stock model             | 61-90-5  | Bitter        | 1.51 ± 0.15              | [3, 42]|
|             | L-Proline      | Pork stock model             | 147-85-3 | Sweet         | 1.72 ± 0.16              | [3, 42]|
|             | Monosodium glutamate | Stewed pork rib broth | 142-47-2 | N/A           | 2.38                     | [3]   |
| Organic acid| Lactic acid    | Pork stock model             | 50-21-5  | Sour          | 1.48                     | [3, 42]|
|             | Potassium dihydrogen phosphate | Pork stock model | 7778-77-0 | N/A           | 7.28 ± 0.60              |       |
| Minerals    | Calcium chloride | Pork stock model            | 7440-70-2| Salty         | 8.79                     | [3]   |
|             | Potassium chloride | Pork stock model           | 7440-09-7| N/A           | 26.1                     | [3]   |
|             | Magnesium chloride | Pork stock model          | 7786-30-3| N/A           | 3.34                     | [3]   |
|             | Sodium chloride | Pork stock model             | 7440-23-5| N/A           | 400                      | [3]   |
|             | 5’-CMP         | Stewed pork rib broth       | 63-37-6  | Umami         | 4.07 ± 0.03              | [42, 44]|
|             | 5’-GMP         | Stewed pork rib broth       | 5550-12-9| Umami/Meaty   | 0.59 ± 0.05              | [42, 44]|
| Nucleotides | 5’-IMP         | Stewed pork rib broth       | 131-99-7 | Umami         | 3.65 ± 1.15              | [42, 44]|
|             | 5’-AMP         | Stewed pork rib broth       | 149022-20-8| Umami        | 2.42 ± 0.22              | [42, 44]|

There are limited studies about the taste compounds in pork broth, however, because of the resemblance between pork broth and beef soup and extensive research conducted on the latter, it serves as a good reference for our research. General taste components in beef soup include amino acids, peptides, organic acids, and inorganic salts. Monosodium glutamate and inosine-5’-monophosphate were considered to be the flavor enhancer; while aspartic acid and adenosine-5’-monophosphate also contribute the flavor. Taste activity values and omission tests allowed the
identification of taste active components of the stewing beef juice, which are: inosine-5’-monophosphate (IMP), adenosine-5’-monophosphate (AMP), glutamic acid, aspartic acid, lactic acid, succinic acid, carnosine, creatinine, creatine, hypoxanthine, alanine, cysteine, sodium potassium, magnesium chloride and phosphate [43]. Two of the peptides, anserine and carnosine, which aim to enhance the taste of the soup as buffering substances are also likely to present in pork broth [42]. It is very likely that pork broth will have a very similar composition and the results were in good agreement with our summary listed in Table 4.

3.2. Taste modifiers in pork broth

The identified taste active compounds are the main contributors of the taste profile. However, the overall brothy taste of pork broth should come from more than just the basic taste active compounds. There should have existed other components (taste modifiers) that could help provide the dense and complex taste of the meat broth. Unfortunately, there is very little study available on taste modifiers from pork broth; however, more results are available from beef broth.

Tikk et al. investigated the development and degradation products of IMP. Just like in the beef broth, IMP is an important tastant that provides the broth with a meaty and brothy taste. However, Tikk et al. discovered that, during the aging of pork, the concentration of IMP decreases along with an increase in its degradation products ribose and hypoxanthine (Fig. 2), which are important constituents in the overall flavor of pork. The sensory change was accompanied by an expansion in bitterness and saltiness taste [45].

Shima et al. identified a novel taste modifier in beef broth and the structure was determined by NMR and mass spectrometry to be N-(1-methyl-4-hydroxy-3-imidazol-2,2-ylidene) alanine. (Fig. 2). They showed that the compound could be formed from the dehydration of creatinine and lactic acid or the deamination between creatinine and alanine, which are the abundant amino acids in both beef broth and pork broth[46]; In a separate research conducted by Ottinger and Hofmann [47], another taste enhancer in beef broth was isolated and identified. The compound N-(1-carboxyethyl)-6-(hydroxymethyl) pyridinium-3-ol (Fig. 2) is confirmed with a synthetic reference compound. This compound was verified to be the natural taste enhancer produced through thermal processing. These two taste enhancers presented in beef broth is a good indication that there might be components with similar structures that are contributing to the unique brothy taste of pork soup according to the fact that the taste precursors are quite similar in beef and pork.

![Figure 2. Structures of taste modifiers found in beef broth.](image)

Because of the presence of organic acid in pork meat, as well as the additional lactic acid produced from anaerobic respiration of the tissues and bacteria after the pigs are slaughtered, the sourness could potentially influence the flavor. However, some peptides in cooked pork are able to cover the sourness taste. An experiment conducted by Okumura et al. studied the extract acquired from pork loins that are vacuum cooked at 60°C for 6 hours with 20 days of aging. The aging process at 4°C allowed the pork to produce more free amino acids and other aroma precursors to enrich the flavor of the products. Three short peptide sequences identified were found to increase greatly during aging. Among the three peptides, APPPPAEVHEV from pork extract were concluded to be interacting with the proton sensitive channels on people’s tongue membranes, inhibiting the sour taste substances from reaching
the proton sensitive channels which act as sourness receptors [48]. Therefore, we can make a confident prediction that this particular peptide will also present in cooked pork broth to cover unpleasant sourness while enhancing umami taste at the same time. In addition, Mishimura et al. investigated the significant increase in the brothy taste intensity of pork due to aging process. To be specific, the aging process was done by storing porcine muscles at 4°C for 12, 6, and 2 days after they are slaughtered. Overall, the levels of free amino acids and oligopeptides in the meats were higher after conditioning, so we can conclude that the aging process is a necessary step for a better taste of the pork soup[49]. On the other hand, the taste could also be modulated by “secondary metabolites”. The peptides associate with meats could be taste-active. Nonetheless, most of the prior studies did not focus on the dipeptide and tripeptide in protein sequences that might contribute to the unique taste of pork broth. Thus, it is very likely that there are more taste active components in pork meat that have not been detected[50]. It is important to conduct more research on other taste active metabolites in order to gain a comprehensive flavor profile of pork broth.

4. Conclusion
In summary, pork broth contains a variety of components that together provide the brothy and attractive flavor. Those aroma active components and taste active components are mostly the products resulting from the heat processing. Given that there are ample studies related to the analysis of pork broth flavor, most of those works failed to identify the compounds that are truly contributing to the flavor profile. For example, Takakura et al used only one column when doing the gas chromatography -mass spectrometry, and the injector temperature was 200°C, which tends to induce thermo-degradation and produces artifacts that could have influence the analysis. On the other hand, many studies identified hundreds of compounds from GC-MS, but without the introduction of GC-O and AEDA, it is likely that many identified compounds are not contributing to the actual aroma profile of the pork broth. The brothy taste of pork broth mainly comes from the basic tastants, including amino acids, peptides, organic acids, nucleotides, and mineral ions. However, the contributions from taste modifiers have yet to be further investigated. It is evident that future studies on pork broth are needed.

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