Effects of microwave heating on physicochemical properties, microstructure and volatile profiles of yak meat

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ABSTRACT
The effects of microwave cooking on the changes of physical properties, protein denaturation, microstructure and volatiles of yak meat were investigated. Various microwave power settings were used for cooking the yak longissimus meats, and SDS-PAGE, cooking loss, colour difference, shear force, microstructure and volatile flavour compounds of longissimus muscle were evaluated. Cooking losses (37.03–45.92%) and shear forces (257.20–315.57 N) in microwave heated meats were higher and lower, respectively, than these in boiled meats (p < .05). Cooking loss, a* values, and shear force significantly (p < .05) increased as the prolonged microwave cooking time, while L* value decreased (p < .05) and more muscle fibres fractured and contracted. High power (700 W; 100%) microwave cooked yak meat had higher L* values, but lower a* values and shear force than meats cooked at medium (560 W; 80%) or low (420 W; 60%) settings. Significant higher cooking loss and volatiles were found in medium power cooked meats compared to high and low power groups. The results suggested that microwave cooking could yield yak meat product with better texture and volatiles attributes but higher cooking loss and deolorization compared to conventional boiling cooking, and maybe an applicable processing method to obtain high quality yak meat products.

1. Introduction
Yak (Bos grunniens) is one of the domestic animals in the world, with 94.5% of population distributed around Himalayas in China, and minors found in Mongolia and Russia (Tian et al. 2013; Bao et al. 2015). Due to the extreme climate of their habitat, yak meat possesses unique attributes compared to other animal meat. Yak meat is high in protein and low in fat with sufficient contents of healthy fatty acids such as eicosapentaenoic acid and docosahexaenoic acid (Wang et al. 2012b; Tian et al. 2013), which is considered as a healthy food material with few contaminations of pesticide and veterinary drug residues (Unpublished data). In recent years, yak meat has gained growing demands in most areas of China for its high edible quality and food safety. However, due to the inconvenience of transportation and seasonal grazing in high altitude areas, as well as the backward processing technology of yak meat, there are few studies on yak meat processing to be reported, and only a few meat products are commercialized. Improvements in processing technologies are highly demanded for obtaining better quality of yak meat products.

Heating is one of the most common method to process raw meat into an edible state in industry (Sreenath et al. 2008), which causes myofibrillar degeneration, muscle fibre contraction, sarcoplasmic protein agglutination and gelation, and dissolution of collagen in connective tissue (Tornberg 2005). Use of microwave for heating has increased largely in the domestic household in the last few decades due to the convenience of using microwave ovens (Mingos and Baghurst 1991). In industry, microwave heating is performed at a frequency of 915 or 2450 MHz, which is successfully used in ready-made, pre-packaged, frozen or prechilled products (Venkatesh and Raghavan 2004; Huang and Sites 2010). When microwave energy penetrates the food matrix, dipolar rotation of polar solvents and conductive migration of dissolved ions cause molecular friction which completes the conversion of high frequency electromagnetic energy to thermal energy, instead of direct heat transfer (Oliveira and Franca 2002; Wang et al. 2012a), thus the internal temperatures of foods are rapidly increased. Traditionally, thermal processing usually employs water or steam as heat medium, and heat transfer relies on diffusion of heat from the surfaces. However, microwave heating can be generated throughout the volume of the food matrix, which results in thoroughly heated and rapid heating rates. In addition, microwave also has the merits of high nutrient retention rate and energy saving due to a sharp reduction in heating time (Albi et al. 1997; Rodriguezestrada et al. 1997).

Microwave cooking has been applied for studying the influence on quality of various raw meat (Conchillo et al. 2005; Roberts and Lawrie 2010; Chen et al. 2015; Liu et al. 2018). Nevertheless, research on yak processed meat products by microwave heating technology has rarely been reported. Our laboratory compared the effects of microwave and other processing methods on the quality of yak meat patties (Chen et al. 2016), but to the best of our knowledge, the effect of microwave heating at various conditions (power settings and time duration) on cooked yak meat physicochemical and...
flavour quality has never been reported. The objective of this study was to investigate the changes of protein denaturation, cooking loss, colour, shear force, microstructure, and flavour of microwave cooked yak meat by comparing with conventional boiled cooking meat. The discovery from this work may provide basic and reliable suggestions for improvement and control of microwave cooking conditions on meat products.

2. Materials and methods

2.1. Samples preparation

Yak meat samples were collected from the longissimus of three healthy yaks (age 3) after slaughter at Hongyuan local slaughterhouse in Sichuan province (China). Samples were immediately sealed into clean plastic bags, blast froze at −18°C for 2 h, and then transferred at 4°C to the laboratory. Yak meat was cut into a dimension of 3 cm × 3 cm × 1.5 cm samples, and subjected to analysis.

2.2. Determination of the optimum heating position in microwave

The heating efficacy of microwave at different sites is not uniform due to the variation of electric field intensity within the chamber with a stationary base. The microwave oven (Galanz, China) has a stable output power of 700 W. Three output power sets including high (700 W; 100%), medium (560 W; 80%), and low (420 W; 60%) were selected for following experiments. To determine the optimum site that yak meat samples were heated, the heating efficiency at nine selected sites (distributed as Figure 1) in microwave chamber were evaluated under three power settings (high, medium, and low) for various heating time (90–310 s). The heating efficiency was determined by the temperature change on certain amount of water after microwave heating. Sixty mL of water (20°C) were heated under designed power settings and times, then the temperature of water was measured immediately using a thermocouple metre (Ebro Armaturen Co., LTD, German).

2.3. Microwave treatments

Samples were boiled for various time point (2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, and 5.5 min) and analysed by SDS-PAGE. The end point time (EPT) of boiled samples with protein completely denatured was used as control to compare with samples subjected to microwave treatments at 3 power outputs with various heating time. Microwave cooking conditions were set as high power for 20–60 s, medium power for 30–80 s, and low power for 50–100 s. Yak meat samples were placed and heated at the optimum site with the best heating efficiency in microwave oven. By comparing with boiled water cooked yak meat, the effects of microwave cooking conditions on quality of yak meat were investigated via SDS-PAGE electrophoresis, cooking loss, colour, shear force, microstructure and flavour compounds. The EPT was determined by comparing total numbers of protein bands in samples with different boiling time, where the first time point that number of protein bands remain unchanged.

2.4. SDS-PAGE electrophoresis

SDS-PAGE electrophoresis of yak meat protein has followed the method reported by Suzuki et al. (1990) with minor modifications. Protein brands were separated by 12% polyacrylamide resolving gel with 4% stacking gel. Briefly, two grams of cooked yak meat samples (microwave cooking or boiling) were grinded and homogenized in 20 mL of 0.5 mol L−1 (pH 7.8) Tris-HCl buffer. Supernatant was collected after centrifuge at 8000 × g (Eppendorf, German) for 10 min. Samples were diluted with loading buffer and denatured at 95°C for 5 min. Isolated proteins supernatant (10 µL) were loaded per lane. The separation was completed after 3 h at voltage of 100 V (current: 50 mA). The gel was stained with Coomassie Brilliant Blue R-250 for 1 h, and then destained overnight. The gel pictures were taken using a Bio-Rad gel imager (Hercules, CA, USA).

2.5. Determination of cooking loss

The cooked yak meat samples were cooled to room temperature, and the cooking loss of samples was calculated by the difference in weight between before and after cooking.

2.6. Color analysis

The effects of cooking on yak meat colour difference were measured by a colorimeter (Konica Minolta Co., Ltd, Japan) and expressed as L* (lightness), a* (redness), and b* (yellowness) values. After cooking, the colour readings of the meat samples were measured at the internal section (3 different positions) after cutting.

2.7. Shear force measurement

The shear force of yak meat samples was determined by a texture analyser (XT plus, Stable Micro Systems, UK), equipped with a HDP/BSW probe, according to the method of Ketnawa and Rawdkuen (2011). Meat samples were diced into a dimension of 3 cm (length) × 2 cm (width) × 1 cm (height). The probe...
was applied at speed of 2.0 mm s⁻¹ through the samples perpendicularly. The maximum shear force was recorded as force required to cut the sample.

### 2.8. Microstructure observation

The microstructure of yak meat was observed using a reverse-phase microscopy (IX71, Olympus, Japan). Boiled or microwaved yak meat was sliced (0.5 cm³ thickness), and immediately fixed in 4% paraformaldehyde for 4 days at 4°C. The dehydration was done with a serial of increasing ethanol (75%, 85%, 95% and 100%, v/v) for 45 min each time. The samples were then waxed, paraffin embedded and H&E stained. The picture was taken by a digital camera under microscope and analysed with image software package.

### 2.9. Determination of flavour components

Gas chromatograph-mass spectrometer (Thermo Fisher, USA) was used to determine the change of flavour compounds with slightly modified method of Watanabe et al. (2008). Briefly, meat samples were minced using a homogenizer and incubated with distilled water for 5 min at 60°C. Then, the SPME fibre was inserted for absorption of volatile compounds at 60°C for 40 min. The injection port temperature was 230°C with a splitless mode. The separation of compounds was performed on a HP-5MS capillary column (30 m × 0.25 mm × 0.25 μm; Agilent, USA) and helium was used as carrier gas at a flow rate of 1.0 mL min⁻¹. The oven temperature programme starts with 1 min of a held at 40°C for 1 min, increase to 130°C at a rate of 5°C min⁻¹, followed by increasing to 200°C (8°C min⁻¹). Finally, a rapid increase to 250°C at a rate of 12°C min⁻¹ and held for 7 min. The column was couple with a mass spectrometer that operated on electron ionization mode (70 eV, 220°C). Mass spectra obtained by scanning from m/z 33–500. The compounds were tentatively identified by comparing with the mass spectra NIST database and marked when the matching ratio is greater than 800.

### 2.10. Statistical analysis

All the experimental measurements were triplicated. Statistical analysis was carried out by utilizing SPSS 21.0 software package (IBM, USA). Data were processed with analysis of variance at 95% of confidence level and significant differences between treatments were tested with Duncan’s method. The level of significance was set at a p value less than .05. The SDS-PAGE electrophoresis bands and their molecular weights were processed by Image Lab 5.0 software. The principal components of volatile data in cooked yak meat were obtained by Principal Component Analysis (PCA) using SPSS 21.0 software package (IBM, USA).

### 3. Results and discussion

#### 3.1. Optimization of microwave cooking protocol

The heating efficiency of different sites in microwave chamber was measured (Figure 2). The differences in changes of temperature of water at nine sites demonstrated that the output energy in microwave chamber was not uniform. However, no matter the water was heated at each site one by one (Figure 2(a) or at the same time (Figure 2(b)), site #2 showed the highest heating efficiency. Therefore, meat samples were placed at site #2 of microwave chamber in the following experiments.

#### 3.2. SDS-PAGE patterns

SDS-PAGE patterns of yak meat during cooking by boiling water are shown Figure 3(a). The result showed that yak meat protein pattern was not changed after boiled in water for 4 min. There were a total of ten heat stable proteins identified in yak meat cooked in boiling water. They distributed from 14 to 33 kDa with specific molecular weights of 14.0, 15.2, 16.6, 20.2, 23.4, 26.2, 28.1, 29.2, 30.8, and 32.4 kDa. Therefore, the EPT of yak meat by boiling water was defined as 4 min.

To determine the minimum time that requires to fully cook the yak meat using microwave with different power outputs, the cooking time ranged from 20 to 70 s were screened, and the organoleptic changes of yak meat were evaluated (Figure 4). Raw yak meat samples were still bloody and not edible after cooking under high power (100%) for 20 and 25 s, and under medium (80%) for 30 and 40 s, under low (60%) for 50 and 60 s. Ultimately, longer microwave treatment times were selected for each power outputs: high (700 W) for 30, 40, 50, and 60 s; medium (560 W) for 50, 60, 70, and 80 s; low (420 W) for 70, 80, 90, and 100 s.

SDS-PAGE patterns of yak meat samples cooked under different microwave treatments are shown in Figure 3(b). The result showed the same protein patterns of yak meat cooked by microwave as cooked in boiling water until the EPT of 4 min. This is according with the previous finding that microwave cooking will not produce/destroy proteins compared to traditional boiled water cooking (Han et al. 2014). Additionally, current results also suggested that all the microwave treatments could cook meat far more effective than boiled water, even with microwaved at low (420 W) power output for 70 s, compared with boiled in water for 4 min to reach the EPT.

#### 3.3. Cooking loss

Cooking loss is directly linked to the quality of meat in the aspects of flavour, colour, and texture (Aaslyng et al. 2003). It is an important indicator of cooked meat on holding moisture and flavour compounds. Increased cooking loss is corresponding to the decreased juiciness and yield of meat products. Table 1 shows the effects of microwave treatments on cooking loss of yak meat. The results revealed that at the same microwave power, cooking loss increased with the extension of the microwave heating time. This is in accord with previous studies found that cooking loss increase with extended heating time in salmon and chicken breast muscle (Palka and Daun 1999; Palka 2003). High, medium or low power treatments had significant difference (p <0.05), and cooking loss value of yak meat cooked by microwave treatments was greater compared to meat cooked in boiling water. This is consistent with the report from Alfaia et al. (2010). The larger cooking loss may
be caused by rapidly thermal shrinkage of muscle and the changes of microstructure, and these were proved by our following findings about the muscle microstructure. Among the three power outputs, the medium power treatments resulted in the highest cooking loss, while high power microwave for short-time (30 s) had the best ability to hold water in yak meat. Namely, under same heating power, the cooking loss had augmented tendency with heating time extension. This is account for the combination of medium power output and its cooking time causing most reduction in water holding capacity via rapid protein denaturation and aggregation. Other researchers also found that meat with lower cooking loss was cooked under more rapid heat rate for short treatment time (Vasanthi et al. 2007; Nikmaram et al. 2011; Kılıç et al. 2014). The cooking loss of high power treatments was larger than medium power treatments for 50 and 60 s, and that of medium power groups was also higher than low power groups for 70 s and 80 s, showing that yak meat processed relatively low power were conducive to desirable yield under same heating time.

3.4. Instrumental colour evaluation

Customers pay great attention to the colour of meat products, and colour affects their purchase intent more than any other quality factors (Mancini and Hunt 2005). The colour of meat

Figure 2. (a) Heating efficiency of different sites determined one by one in microwave chamber. (b) Heating efficiency of different sites determined at the same time in microwave chamber. Values are presented as mean ± SD of at least triplicate measurement. Bars with different lowercase indicate significant differences among the heating sites (p <.05).
products majorly depends on the amount of myoglobin and its chemical forms (Livingston and Brown 1981). Generally, meat products with better colour, relatively high in $L^*$ and $a^*$, and low in $b^*$ values are more accepted by customers (Young and West 2001). The effects of microwave treatments on colour of yak meat are shown in Table 2. By comparing treatments under the same power outputs or with control, $a^*$ value significantly ($p < .05$) increased as the prolonged microwave cooking time, and meats cooked under low power output had the highest $a^*$ value. Similar trend in increases of $b^*$ value was also found under same power outputs as time extended, however, the differences in most of the $b^*$ values among three power outputs were not significant ($p > .05$). On the contrary, $L^*$ values decreased significantly ($p < .05$) as microwaving time extended under same cooking power. Those results suggested that microwaving heating had much more obvious effects on $L^*$ and $a^*$ values but not $b^*$. All yak meat samples cooked by microwave were observed with lower $L^*$ and higher $a^*$ and $b^*$ values compared to boiling water cooking.

This finding suggested that microwave cooking did not show any more benefits in maintaining desirable colour in yak meat comparing with traditional boiling water cooking.

**Table 1.** Effects of microwave treatments on cooking loss and shear force of cooked yak meat.

| Treatment condition | Cooking loss(%) | Shear force(N) |
|---------------------|-----------------|----------------|
| Boiled in water     | 35.98 ± 0.00^a  | 316.85 ± 3.40^a |
| High (700 W; 100%)  | 30 s 37.03 ± 0.67^fg  | 259.73 ± 0.13^g  |
|                     | 40 s 38.75 ± 0.16^ef  | 259.83 ± 5.29^fg  |
|                     | 50 s 40.09 ± 0.22^de  | 265.69 ± 4.56^fg  |
|                     | 60 s 40.66 ± 0.00^cde  | 276.03 ± 6.62^a  |
| Medium (560 W; 80%) | 50 s 39.82 ± 0.85^de  | 265.42 ± 1.87^f  |
|                     | 60 s 40.48 ± 0.00^cde  | 257.20 ± 11.85^g  |
|                     | 70 s 43.51 ± 1.41^b  | 268.04 ± 6.46^def  |
|                     | 80 s 45.92 ± 2.39^a  | 287.04 ± 6.08^c  |
| Low (420 W; 60%)    | 70 s 38.91 ± 1.14^ed  | 274.64 ± 0.00^e  |
|                     | 80 s 41.01 ± 1.71^ed  | 274.06 ± 0.80^de  |
|                     | 90 s 44.08 ± 1.51^de  | 304.20 ± 7.01^b  |
|                     | 100 s 42.58 ± 0.33^abc  | 315.57 ± 0.64^a  |

Note: Values are presented as mean ± SD of at least triplicate measurement. Data followed by different superscript letters within a column indicate significant differences among treatments ($p < .05$).

**Figure 3.** (a) SDS-PAGE patterns of yak meat during cooking by boiling water. (b) SDS-PAGE patterns of yak meat cooked by different microwave treatments.

**Figure 4.** Effects of microwave treatments on organoleptic quality of yak meat.
Microwave cooking generates heat by affecting the polar molecules in a food matrix via the transformation of electromagnetic field energy into thermal energy. Comparing to conventional cooking methods that require the process of transport heat from sources to the product, microwave cooking leads to a more rapid heating rate (Gowen et al. 2006). Therefore, in meat cooking, myoglobin undergoes faster oxidation and denaturation, followed by formation of ferrihemochrome, and produces a colour change to orange, rather completely, and meat colour was changed more obviously.

### 3.5. Shear force

The shear force characteristics of yak meat cooked by microwave are given in Table 1. Shear force directly related to the mouth feel of meat when people taste it. It reflects the tenderness of meat products, where lower shear force corresponding to better chewing quality. Shear force is mainly affected by the distribution and status of connective tissue and myofibrillar protein (myosin and actin). As the microwave time extended, the shear force increased significantly (p <.05) among same power setting groups. This may due to less denaturation of protein (myosin and actin). As the microwave time extended, distribution and status of connective tissue and myofibrillar protein (myosin and actin) were inferred to better chewing quality. Shear force is mainly a measure of meat products, where lower shear force corresponding to better chewing quality. Shear force directly related to the toughness of meat products, where lower shear force corresponding to better chewing quality. Shear force directly related to the toughness of meat products, where lower shear force corresponding to better chewing quality.

### 3.6. Microstructure performance

During meat products processing, denaturation of proteins and changes of muscle fibre greatly affect the texture of finish products. After microwave or boiling water cooking, the microstructures of yak meat were changed remarkably (Figure 5). Compared to the raw meat, there were enlarged gaps between muscle fibres and muscle bundle due to their shrinkage, as well as protein denaturation, destruction of cell membranes. Solubilization of connective tissue was also observed in cooked yak meat. As shown by Figure 5, microwave cooked yak meat exhibited less muscle fibre structure damaged than water bath cooking, which ascribed to the much longer cooking time (4 min versus 30–100 s) when using conventional boiling. This is corresponded to the results from shear force, which suggests that yak meat cooked by microwave yields higher tenderness compared to water bath cooking. The previous study also suggested that microwave cooking causes less muscle structural damaged compared to boiling or roasting (Hsieh et al. 1980). As cooking time extended under same microwave power settings, yak meat showed more gaps and fractures between muscle fibres. This suggested microwave time had significant effects on changing of yak meat microstructure. Comparing the fibres and muscle bundle of samples under same heating time, we found that low power treatment is beneficial for maintaining the structure of muscle fibres and fasciculus. Therefore, choosing relatively high power and short time microwave condition is ideal for retaining optimum tenderness and chewiness of yak meat.

### 3.7. Flavor compounds

A total of 87 volatiles in cooked yak meat were identified by GC-MS, which consisted of 10 categories of compounds, alkanes (17), aldehydes (13), alcohols (12), acids (11), esters (6), amino acids (4), aromatics (4), alkenes (1), and others (13) (Table 4). The volatile profiles of yak meat cooked by water bath were analysed as control.

It was found that 28 volatile components were detected in the water bath cooked sample and accounted for 88.96% of the total volatiles identified. Four compounds including chloroform (0.54%), 2-methylpropanal (0.54%), butyric acid monoglyceride (0.69%), and dimethyl sulphide (0.64%) were not discovered in microwave cooked yak meats. In yak meat cooked with high power microwave, there were 27, 39, 42, and 41 volatile compounds detected (30, 40, 50, and 60 s), which accounted for 86.50%, 92.78%, 93.91%, and 96.85% of the total compounds identified, respectively. In the medium power for 50, 60, 70, 80 s cooked groups, 38, 31, 34, and 35 volatiles were identified, which contributed 96.97%, 97.56%, 97.78%, and 98.52% to the total compound profile, respectively. In the low power setting microwave samples (70, 80, 90, and 100 s), 38, 34, 36, and 30 volatile components were detected with GC-MS and these represented 83.48%, 94.30%, 93.73%, and 94.87% of the total volatile identified in all samples. There is a trend in increasing amount of volatiles in meat microwaved with longer time among same power setting groups. However, volatile components detected in medium power groups were more than high and low power treatments.
under same heating time. There were more compounds generated from yak meat after microwave cooking compared to boiling water, especially when meats were cooked at high or medium power for longer time. This indicates that yak meat cooked by microwave has better overall flavour than boiling water cooking.

The first two principal components of volatile substances obtained by PCA are plotted in Figure 6. PC 1, accounting for 39.1% of total volatiles, was essentially an aspect of benzaldehyde, octanal, methyl mercaptan, n-hexanaldehyde, pentanaldehyde, nonanal, 2-butanone, alanylglycine. Principal component 2 accounting for 16.5% of total volatiles was mainly related to n-tetradecane, n-hexanol, 2-phenylfuran, acetone, myristic acid, capric acid. PC 3 explained for 11.0% of all the data, was a function of 3-hydroxy-2-butanone, propanoic acid. To sum up, aldehydes, ketones, acids are the most abundant aroma substances of microwaved yak meat. The major sources of yak meat flavour compounds are proteins and fats. During heating, various odour substances can be generated through Maillard reaction and lipid oxidation (Li and Yu 2011). Those compounds affect the overall flavour of final cooked meat products by direct contributors or by react with other compounds. For instance, microwave for extended time rise to the smoking temperature of lipid, which causes oxidation and the release of small molecules including alcohols, aldehydes, ketones, acids, ethers etc (Berdague et al. 1991). What’s more, microwave heating had effects on free radical formation (Rouit et al. 1996), and free radicals induced oxidation of protein and fat to produce small molecule substances.

Aldehydes in yak meat are mostly saturated and unsaturated types, which are products from unsaturated oleic acid and linoleic acid. Long chain aldehydes detected in microwaved samples such as nonanal, decanal, undecanal, tetradecanal, hexadecanal give aroma of waxy, citrus, fat, and floral, respectively. Branched-chain saturated short chain aldehydes are usually with smells of fragrance, fruity, nuts, and cheese incense and sweat, such as 2-methyl butyraldehyde, 2-methyl propionaldehyde, 3-methyl butyraldehyde that detected in all samples. Acids are mainly derived from the steatolysis and fatty acids produced during fat oxidation, it is generally believed that they contribute little to meat-savor because of the high threshold. Ketones are products from alcohol oxidation and play a role in enhancement of meat flavour. Some ketones have sweet and fruity flavours such as 2-heptanone produced from linoleic acid. Diketone usually brings a meaty and milky
Table 3. Relative percentages of flavour compounds in cooked yak meat identified by GC-MS.

| Number | Compounds by class | Boiling water | 700W | 560W | 420 W |
|--------|--------------------|--------------|------|------|-------|
| 1      | Alkanes            |              |      |      |       |
| 2      | Trichloromethane   | 0.54         |      |      |       |
| 3      | Propylene Oxide    | 4.02         | 4.68 |      |       |
| 4      | Octane             |              | 1.07 | 0.93 | 0.5   |
| 5      | Pentylcyclopropane |              | 0.98 |      |       |
| 6      | Nonane             | 0.54         |      |      |       |
| 7      | 2-methylpropanol   |              |      |      |       |
| 8      | 2-methyl-5-ethylheptane | 0.97 |      |      |       |
| 9      | N-tridecane        | 0.29         | 0.24 | 0.47 | 0.36  |
| 10     | N-dodecane         |              | 0.39 | 0.27 | 0.12  |
| 11     | N-tetradecane      |              | 0.24 | 0.2  | 0.22  |
| 12     | 4,6-dimethyldecane |              | 0.13 |      |       |
| 13     | 2,7,10-trimethyl dodecane | 0.15 |      |      |       |
| 14     | N-pentadecane      |              | 0.15 |      |       |
| 15     | Hexadecane         |              |      |      |       |
| 16     | N-octadecane       |              |      |      |       |
| 17     | 1-nitrohexane      |              |      |      | 0.15  |
| 18     | Aldehydes          |              |      |      |       |
| 19     | Pentanaldehyde     |              |      |      |       |
| 20     | 3-methyl butyraldehyde |          |      |      |       |
| 21     | 2-methyl butyraldehyde |          |      |      |       |
| 22     | N-hexanaldehyde    | 11.51        | 19.4 | 22.31| 17.74 |
| 23     | N-heptanaldehyde   | 1.84         | 3.37 | 3.22 | 2.76  |
| 24     | Benzaldehyde       | 1.67         | 1.91 | 2.47 | 2.49  |
| 25     | Octanal            |              | 4.26 | 5.02 | 5.06  |
| 26     | Nonanal            | 7.51         | 11.63| 12.62| 12.79 |
| 27     | Decanal            | 0.14         | 0.24 | 0.2  | 0.22  |
| 28     | Undecanal          |              | 0.12 | 0.45 | 0.22  |
| 29     | Hexadecanal (palmitaldehyde) | 0.15 |      |      |       |
| 30     | Tetradecan         |              | 0.16 | 0.49 | 0.08  |
| 31     | Alcohols           |              |      |      |       |
| 32     | Methyl mercaptan   | 1.99         | 1.83 | 1.88 | 1.86  |
| 33     | 2,3-butanediol     |              |      |      |       |
| 34     | Isoamyl alcohol    |              |      |      |       |
| 35     | 2-methyl-2-propanol |            |      |      |       |
| 36     | N-hexanol          |              |      |      |       |
| 37     | 1-heptanol         |              |      |      |       |
| 38     | 2-octanol          | 0.54         | 0.67 | 0.98 | 1.09  |
| 39     | (E)-2-octen-1-ol   |              |      |      |       |
| 40     | 1-nonyl alcohol    |              |      |      |       |
| 41     | Linalool           |              |      |      |       |
| 42     | Lauril alcohol     |              |      |      |       |
| 43     | Acids              |              |      |      |       |
| 44     | Acetic acid        | 0.86         | 2.32 | 2.34 | 1.11  |
| 45     | 4-hydroxybutyric acid |        |      |      |       |
| 46     | Isovaleric acid    |              |      |      |       |
| 47     | Caprylic acid      | 1.06         | 0.47 | 0.54 | 0.4   |
| 48     | Capric acid        | 1.23         | 0.37 | 0.59 | 0.71  |
| 49     | Lauric acid        |              | 0.29 | 0.23 | 0.39  |
| 50     | Myristic acid      |              | 0.09 | 0.23 | 0.09  |
| 51     | Propanoic acid     | 2.70         | 3.94 | 2.75 | 2.77  |

(Continued)
| Number | Compounds by class | Boiling water |       |       |       |       |       |       |       |       |       |
|--------|--------------------|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|        |                    | 700W         | 560W  | 420 W | 700W  | 560W  | 420 W | 700W  | 560W  | 420 W | 700W  | 560W  | 420 W |
| 52     | 3-aminobutyric acid| –            | –     | –     | –     | –     | –     | 0.3   | –     | –     | –     | 0.55  | 0.33  | 0.54  |
| 53     | DL-β-aminobutyric acid| –            | –     | –     | –     | –     | –     | 0.41  | –     | –     | –     | 0.62  | 0.69  | 0.52  |
| 54     | Ketones            |              |       |       |       |       |       |       |       |       |       |       |       |
| 55     | acetone            | 3.83         | 4.24  | 3.72  | 2.86  | –     | –     | –     | –     | –     | –     | 2.71  | 1.88  | 0.75  |
| 56     | 2-butanoate        | 4.97         | 5.17  | 5.79  | 8.01  | 6.22  | 6.89  | 5.25  | 4.75  |       |       |       |       |
| 57     | 2-heptanone        | 11.78        | 37.54 | 51.95 | 7.4   | 0.32  | 0.34  | 0.3   | 0.28  |       |       |       |       |
| 58     | 6-methyl-5-hepten-2-one| 0.34         | –     | –     | –     | –     | –     | –     | –     | –     | –     | 0.18  | 0.37  | 0.28  |
| 59     | 2-methyl-3-octanone| 0.39         | 0.2   | –     | –     | –     | –     | –     | –     | –     | –     |       |       |       |
| 60     | Esters             |              |       |       |       |       |       |       |       |       |       |       |       |
| 61     | Vinyl acetate      | –            | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 62     | Butyric acid monoglyceride| 0.37         | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 63     | Isoamyl acetate    | –            | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 64     | Phthalic acid, hex-3-yl isobutyl ester| 0.37       | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 65     | Isobutyl phthalate-5-methylhex-2-ester| 0.22         | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 66     | Amino acids        |              |       |       |       |       |       |       |       |       |       |       |       |
| 67     | Glycylglycine      | –            | –     | 0.39  | 0.27  | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 68     | Alanyl-glycine     | 4.91         | 3.96  | 3.41  | 4.59  | 0.34  | 0.3   | 0.28  | 0.18  | 0.3   | 0.39  | 0.25  | 0.41  |       |
| 69     | N-acetyl-L-alanine | –            | –     | –     | –     | –     | –     | 0.07  | –     | –     | 0.23  | –     | –     | –     |
| 70     | Alanyl-leucine     | –            | –     | –     | –     | –     | –     | 0.08  | –     | –     | 0.3   | –     | –     | –     |
| 71     | Aromatics          |              |       |       |       |       |       |       |       |       |       |       |       |
| 72     | Toluene            | 2.03         | –     | –     | –     | –     | –     | 0.66  | –     | –     | –     | –     | –     |       |
| 73     | Ethyl benzene      | –            | –     | –     | 0.13  | –     | –     | 0.09  | –     | –     | –     | –     | –     |       |
| 74     | 2,6-di-tert-butyl-4-sec-butylphenol| 0.11       | –     | –     | –     | –     | –     | 0.15  | –     | –     | –     | –     | –     |       |
| 75     | Aromatics          |              |       |       |       |       |       |       |       |       |       |       |       |
| 76     | Alkenes            |              |       |       |       |       |       |       |       |       |       |       |       |
| 77     | 2-octene           | –            | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 78     | Dimethyl disulphide| 0.24         | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 79     | Dimethyl sulphone  | –            | –     | 0.22  | 0.17  | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 80     | Others             |              |       |       |       |       |       |       |       |       |       |       |       |
| 81     | Urea               | –            | –     | 0.09  | –     | –     | –     | 0.05  | –     | –     | –     | 0.07  | 0.15  |       |
| 82     | Ethanolamine       | –            | –     | –     | –     | –     | –     | 0.18  | –     | –     | 0.14  | –     | –     | –     |
| 83     | Ammonium carbamate | –            | –     | –     | 13    | 15.97 | –     | 16.21 | –     | 18.86 | –     | –     | –     | –     |
| 84     | Methoxyphenolxime  | 32.42        | 14.3  | 6.08  | 3.52  | 0.78  | 1.26  | 1.39  | 1.22  | 1.67  | 1.21  | 1.65  | 1.49  | 0.94  |
| 85     | Tetramethylpyrazine| –            | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     | –     |       |
| 86     | 2-phenylfurane     | –            | –     | 0.47  | 0.67  | 0.43  | 0.38  | 0.4   | 0.31  | 0.39  | 0.4   | 0.39  | 0.32  |       |
| 87     | N(4-methoxybenzoyl) adenosine| 3.19       | 1.7   | 0.83  | 0.51  | 0.1   | 0.06  | 0.05  | 0.05  | 0.37  | –     | 0.05  | 0.25  | –     |
flavour, while 6-methyl-5-hepten-2-one; 2-butanone, and acetone have a pleasant spicy and sweetness flavour. Esters were barely found in water boiled yak meat, however, microwave cooking resulted in five esters. Those ester compounds, such as isobutyl-5-methylhexyl 2-aphthalate and isobutyl hexanyl 3-aphthalate, would bring a fruity and light lipid flavour (Sabio et al. 1998). Peptides are very important flavour compounds in meat products, such as varieties of low molecular peptides in Panna ham. They are small molecules from protein hydrolysis by endogenous enzyme in meat muscle system. Some small peptides with lipophilic side chains are bitter; especially dipeptides with a lipophilic amino acid (such as leucine, isoleucine, alanine, phenylalanine) (Sforza et al. 2001). There were also varieties of other nitrogen-or sulfur-containing heterocyclic compounds identified. However, those compounds have a high threshold of detection, and are not major flavour contributors of yak meat.

The results of GC-MS measurements of the boiled water bath and microwave treated samples showed that the content of volatile components in the yak meat of microwave treatment was greater than that of the yak meat treated by the boiling water bath (except samples cooked by high power for 30 s or low power for 70 s), indicating that microwave heating could give meat product more flavour. The volatile compounds detected in low power treatment of yak meat were less than that of the microwave treated by the boiling water bath (except samples cooked by high power for 30 s or low power for 70 s), indicating that microwave heating could give meat product more flavour. The volatile compounds detected in low power treatment of yak meat were less than that of high and medium power treatment groups, which shows that if the microwave treatment of fire-power is weak, even if extension of heating time to improve the meat flavour does not benefit.

4. Conclusions

In summary, microwave cooking could effectively and rapidly denature yak meat protein and shorten the cooking time, and did not affect the protein bands in SDS-PAGE electrophoresis compared to boiling water cooking. However, microwave processing deteriorated the meat colour quality by decreasing L* values and elevating a* values, and increased meat cooking loss. Additionally, microwave processing improved the texture quality by lowering meat shear force and alleviating the heat damage to muscle fibre structure in comparison with water cooked meat. Relatively high microwave power processing enhanced the contents of volatiles in yak meat. This study suggested that microwave at higher power-output setting with short time cooking may be a preferential selection for yak meat processing.

Disclosure statement

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