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Research on Pork Jerky Obtained Through Fermentation with *Pediococcus acidilactici*

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Pediococcus acidilactici was used to ferment fresh pork. After fermentation, the pork jerky was subjected to sensory evaluation and the levels of pH, free amino acids, and volatile compounds were measured. The results showed that the fermented pork jerky had a better sensory evaluation score (score: 93.2), lower pH value (3.54), and more free amino acids (39.24 mg/100 g). Furthermore, in the fermented pork jerky, the content of three acids (18.552%) was high, which lowered the pH of the pork jerky and inhibited growth of pathogens. Moreover, some new compounds produced, including 3-hydroxy-2-butanone (49.095%), 2,3-butanediol (2.790%), 2-ethyl-1-hexanol (2.400%), oxalic acid isobutyl hexyl ester (2.280%), phenylethyl alcohol (0.953%), and eucalyptol (0.659%), contributed to the flavour of pork jerky. Overall, our results demonstrated that *P. acidilactici* can be used for the production as well as improvement of the quality and flavour of fermented pork jerky.

INTRODUCTION

Traditional pork jerky, which is a special product of China, is usually produced in Sichuan, Guizhou, Zhejiang through being cooked with many kinds of spiceries and then baked. It is usually hard in texture and poor in colour because of the dehydration of meat during the cooking and baking process [Konieczny *et al*., 2007]. Substances, including nitrite, aginomoto, and preservative, which are harmful to human health, are used to improve the colour and extend the shelf life of pork jerky [Sun & Ma, 2004]. It has been reported that the texture, colour, and flavour of the prepared pork jerky could be improved through fermentation with lactobacillus; in addition, the stability and safety of pork jerky could also be enhanced by the comprehensive effects of microbial metabolites during the fermentation process without the addition of nitrite, aginomoto, or preservative [Li & LV, 2005].

In recent years, there have been some reports on fermenting raw pork to fermented meat products, including dry sausage [Visessanguan *et al.*, 2006], semi-dry sausage [Porto-Fett *et al.,* 2008], salami [Tian *et al.,* 2012; Porto-Fett *et al.*, 2010], ham [Zhu *et al.,* 2014], and *soongchimchae* [Cho *et al.,* 2011]. However, to the best of our knowledge, there have been no studies on the fermentation of raw pork to pork jerky.

In general, fermented jerky is evaluated using parameters such as sensory evaluation, pH, and contents of free amino acids and flavour compounds [Wang *et al.,* 2010]. In the present study, pork was fermented with *Pediococcus acidilactici* and the parameters, including sensory evaluation, pH, and contents of free amino acids and flavour compounds were evaluated.

MATERIALS AND METHODS

Materials

Biochemical-grade yeast extract and peptone were purchased from Beijing Aoboxing Biotech. Co. Ltd. (Beijing, China) and Chengdu Changshou Biotech. Co. Ltd (China), respectively. All other reagents, including glucose, lactose, sodium chloride, and ninhydrin, used in this study were of research grade.

P. acidilactici

The lactobacillus *P. acidilactici,* preserved in our laboratory which was effective for the fermentation of pork jerky through our previous experiments, was used in the experiments. Prior to use, the organism was cultured in liquid enlargement medium containing beef extract, 2.5 g; peptone, 5 g; yeast extract, 2.5 g; glucose, 5 g; lactose, 2.5 g; NaCl, 2.5 g; and water, 500 mL, with a pH of 6.8 [Li, 2012].

Preparation of pork jerky meat

Pretreatment of pork

Raw pork tenderloin was purchased and immersed in cold water for 1 h. Subsequently, the pork was precooked for 10 min and turned over to ensure uniform heating, and cooled after sieving. Then, the pork was sliced using a kitchen knife to an approximate size of 3 cm × 4 cm × 0.5 cm.

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Fermentation of pork

A total of 5% (V/V) of the enlargement medium cultured *P. acidilactici* (initial concentration of 10^7×CFU/mL) was inoculated into the liquid enlargement medium. After incubation at 35°C for 24 h at 100 rpm, which was favourable for *P. acidilactici* growth and fermentation, the fermentation broth was obtained.

Subsequently, 25 g of the pretreated pork slices were added to a sterilised beaker containing 50 mL of the fermentation broth at a pH of 5.5. After sealing with a plastic wrap, the beakers were cultured at 35°C for 58 h for the fermentation of pork jerky. In addition, the inoculated fermentation broth cultured under the same condition was used as the control.

Cooking and baking of pork

After removing from the fermentation broth, the fermented meat was boiled for 10 min to end the fermentation process and gently agitated during cooking for uniform ripening of the pork. The samples were considered ready after baking at 50°C for 120 min and subsequent cooling. The pork meat precooked, cooked, and baked, but not fermented, was used as the control and named as fresh pork.

Determination of the properties of pork jerky

Sensory evaluation

A trained panel consisting of eight people evaluated some of the sensory properties of the fermented pork jerky and fresh pork, including flavour, mouth feel, texture, and colour. The panel scored the samples according to the evaluation standard [Wang *et al.,* 2010].

Determination of the pH value

The pH values were evaluated for fresh pork, pork jerky, and inoculation medium before and after fermentation using a pH meter (pHS-3C, Chengdu Fangzhou Technology Experiment Equipment Co., China). A total of 1 g of the solid samples was ground in a mortar, soaked in 10 mL of distilled water for 30 min, and filtered.

Determination of the content of free amino acids

The free amino acid contents of the samples, including fresh pork, pork jerky, and inoculation medium before and after fermentation, were determined using the colorimetric method of ninhydrin [Zhang, 2005]. Accordingly, ninhydrin was added to the samples under acidic conditions and the absorbance of the solution was ascertained at 570 nm.

Determination of the content of volatile compounds

Headspace solid-phase microextraction

A headspace solid-phase microextraction (HS-SPME) holder (Supelco Inc., Shanghai, China) for manual sampling, combined with gas chromatography–mass spectrometry (GC–MS) (Agilent Technologies, USA), was used to perform the experiments. Teflon covers and a 75-μm carboxen/polydimethylsiloxane fibre were purchased from Supelco Inc. Before initial use, the fibre was preconditioned for 2 h on an Agilent 6890–5975 gas chromatograph at an injector temperature of 230°C. Then, the minced samples of fresh pork and pork jerky (3 g) were respectively placed in a 15-mL vial at room temperature, and the vial was sealed with a Teflon cover, heated at 60°C in a water bath for 30 min, and mixed at intervals. The HS-SPME fibre was inserted for sampling for 40 min, which was adequate to extract the volatile compounds from the samples and introduce them into the GC–MS injector for desorption for 5 min.

GC–MS analysis

The GC–MS analysis was performed on an Agilent 6890 gas chromatograph coupled with a 5975 mass spectrometer (Agilent Technologies, USA). The carrier gas was helium with a flow rate of 1.1 mL/min. The separation was performed on a DB-WAX 30 m × 0.25 mm × 0.25 μm capillary column (Agilent Technologies, USA). The initial oven temperature was 35°C for 1 min, which was ramped to 100°C at the rate of 8°C/min and held for 3 min; subsequently, the temperature was ramped to 120°C at the rate of 3°C/min and held for 2 min; finally, the temperature was ramped to 230°C at the rate of 5°C/min and held for 5 min. The mass detector was operated at 230°C in an electron impact mode at 70 eV. The ion-source temperature was 230°C, while the transfer line temperature was 150°C. The chromatograms were recorded by monitoring the total ion currents in the 20–350 mass range.

Data analysis

The data obtained were analysed using MSD Productivity ChemStation Data Analysis Software (version G1701DA). Identification of volatile compounds was confirmed by comparing their mass spectra with those in the National Institute for Standards and Technology (NIST, Search Version 2.0) and Pesticides Retention Time Lock (RTLPEST, Parts number G1672AA, version A.03.00) mass spectral library. Determination of the percentage composition was based on peak area normalisation (expressing the area of a given peak as a percentage of the sum of the areas of all the peaks) without the use of correction factors.

RESULTS AND DISCUSSION

Sensory evaluation of the fermented pork jerky

According to the evaluation standard [Wang *et al.,* 2010], the trained panel consisting of eight people scored the flavour (total score of 60), mouth feel (total score of 20), texture (total score of 10), and colour (total score of 10) of the samples. As shown in Table 1, the sensory evaluation score (including flavour, mouth feel, texture, and colour) of the fermented pork jerky was 93.2, which was obviously better than that of the fresh pork (which was not fermented; score: 83.0), indicating that the flavour, mouth feel, texture, and colour of the pork jerky were improved after fermentation.

pH of the pork jerky

As shown in Figure 1, the pH values of both pork jerky and inoculation medium decreased after fermentation. The pH of the pork jerky was 3.54, which was distinctly lower than that of fresh pork (pH: 6.42), because *P. acidilactici* has

TABLE 1. Sensory properties of fermented pork jerky and fresh pork.

Sensory properties	Pork jerky		Fresh pork	
	Description	Score	Description	Score
Flavour (total score of 60)	Had strong flavour of meat and unique flavour of sauce	56.0	Had flavour of sauce and strong flavour of meat	52.3
Mouth feel (total score of 20)	Chewable, soft, and did not stick to teeth	19.0	Did not stick to teeth, but was not very easy to chew	16.1
Texture (total score of 10)	Some muscle fibres fractured; the structure was a little loose, but formed	9.2	Muscle fibres were complete; the structure was compacted and formed	6.1
Colour (total score of 10)	Uniform colour of red sauce	8.8	Regular colour of red sauce	7.5
Total score		93.2		83.0

Note: According to the evaluation standard [Wang *et al*., 2010], the trained panel consisting of eight people scored the flavour (total score of 60), mouth feel (total score of 20), texture (total score of 10), and colour (total score of 10) of the samples.

TABLE 2. Content of free amino acids in the pork samples and inoculation medium before and after fermentation.

	Pork jerky	Fresh pork	Medium after fermentation	Medium before fermentation
Content of free amino acids	39.24 mg/100 g	25.27 mg/100 g	22.30 mg/mL	2.74 mg/mL

Note: The free amino acid contents of the samples were determined using the colorimetric method of ninhydrin [Zhang, 2005]. Accordingly, ninhydrin was added to the samples under acidic conditions and the absorbance of the solution was ascertained at 570 nm.

a strong ability to produce various acids during fermentation. As a result of the low pH of pork jerky, the growth of pathogens such as *Listeria* spp., *Staphylococcus aureus, etc.* could be inhibited, making the samples safer and preserving them for a longer duration.

Free amino acid content before and after fermentation

The content of free amino acids (which can be easily assimilated by humans) is an important parameter for the evaluation of the nutritional value of pork [Chen & Liu, 2004]. As can be seen from Table 2, the content of free amino acids in pork jerky fermented with *P. acidilactici* was 39.24 mg/100 g, exhibiting an increase of 13.97 mg/100 g, which was more than half of that noted in fresh pork (25.27 mg/100 g). This increase in the free amino acid content was due to the degradation of many proteins in pork to free amino acids by protease produced by *P. acidilactici* during fermentation, as noted in our previous experiments.

Volatile compound content in pork jerky

The volatile compound contents in fresh pork and pork jerky are shown in Table 3. As shown in Table 3, a total of 15 kinds of volatile compounds, including acids, alcohols, aldehydes, esters, alkanes, ketones, and benzene ring compounds, were identified in the fresh pork and fermented pork jerky samples. However, the number of species of volatile compounds was not very high because the samples were thoroughly cooked and baked, resulting in the volatilization of some of these compounds.

A total of six and twelve volatile compounds were found in fresh pork and pork jerky, respectively, whereas two volatile compounds, namely, butanoic acid (No. 3) and benzaldehyde (No. 17), were observed in both fresh pork and pork jerky. The compounds detected only in fresh pork were 1-pentanol (No. 6) and hexanal (No. 16). Among them, the total content of hexanal (No. 16), which was generated by the oxidation of lipids, reached the highest percentage of 63.578%. In general, hexanal is considered to have a fragrance odour of grass and apple, with the characteristic odour of oils [Chen & Jiang, 2009]. It disappeared in the pork jerky which might be because that the hexanal was transformed to other compounds with the mechanism of the *Pediococcus acidilactici*.

Some new compounds, including three acids, four alcohols, one ester, one alkane, one ketone, and one benzene ring compound, were produced during the fermentation of pork jerky. Among them, the three acids, including acetic acid (No. 1), propanoic acid (No. 2), and octanoic acid (No. 4), with a total content of 18.552%, lowered the pH of the pork jerky, thus inhibiting the growth of pathogens. The alcohols produced were 3-methyl-1-butanol (No. 5), which is obtained from leucine; 2-ethyl-1-hexanol (No. 7) (2.400%), which has been detected as a flavour compound in fermented foods such as Jinhua ham [Zhao, 2013]; 2,3-butanediol (No. 8–12; 2.79%), which is a kind of chiral compound usually added to spirit to improve flavour and might react with acetic acid to produce 1,3-butane-

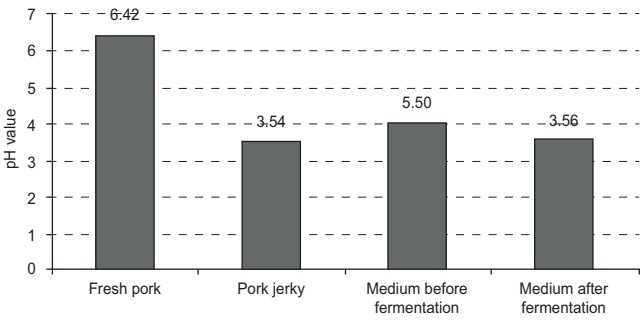

FIGURE 1. The pH of pork samples and inoculation medium before and after fermentation.

TABLE 3. Volatile compound content in fresh pork and pork jerky.

No.	Volatile compounds	Retention time	Fresh pork	Pork jerky
	Acids			
1	Acetic acid	19.827		8.671%
2	Propanoic acid	23.557		8.788%
3	Butanoic acid	26.944	2.912%	1.447%
4	Octanoic acid	33.23		1.193%
	Alcohols			
5	3-Methyl-1-butanol	10.314		4.056%
6	1-Pentanol	13.418	1.135%	
7	2-Ethyl-1-hexanol	21.617		2.400%
8	2,3-Butanediol, [R-(R*,R*)]-	23.981		0.275%
9	2,3-Butanediol, [R-(R*,R*)]-	24.333		1.443%
10	2,3-Butanediol	24.41		0.261%
11	2,3-Butanediol, [R-(R*,R*)]-	25.446		0.672%
12	2,3-Butanediol, [R-(R*,R*)]-	25.496		0.142%
13	Phenylethyl alcohol	34.877		0.953%
	Ester			
14	Oxalic acid isobutyl hexyl ester	7.273		2.280%
	Alkane			
15	Eucalyptol	9.421		0.659%
	Aldehydes			
16	Hexanal	9.248	63.578%	
17	Benzaldehyde	23.05	0.782%	3.270%
	Ketone			
18	3-Hydroxy-2-butanone	13.454		49.095%
	Benzene ring compounds			
19	1,3-Dimethyl benzene	5.995		1.731%

dioldiacetate, improving the flavour of cream [Zhao, 2008]; and phenylethyl alcohol (No. 13), which has a weaker pleasant sweet rose-like fragrance and might be degraded to aldehyde by phenylalanine and subsequently reduced to phenylethyl alcohol [Zhao & Ding, 2001]. Ester is a well-known flavour contributor to fermented foods, and only one kind of ester (oxalic acid isobutyl hexyl ester; No. 14; 2.280%) was detected in the fermented pork jerky, because the esters in fermented pork jerky were volatilized after baking. With regard to alkanes, due to their higher threshold value, their contribution to the overall flavour of pork jerky was not significant. However, some branched--chain alkanes, such as 2,4,10,14-tetramethyl-pentadecane and 2,6,10,14-tetramethyl-pentadecane, have been reported to have a pleasant flavour [Benincasa *et al.*, 2003]. Among the detected alkanes, eucalyptol (No. 15) had branched--chain structures, and is usually used as a toothpaste perfume and therefore might contribute to the flavour of pork jerky. With respect to ketone, 3-hydroxy-2-butanone (No. 18) was not detected in fresh pork, but was found in fermented pork jerky (49.095%), contributing to the flavour of pork jerky. This ketone naturally exists in butter, cocoa, wine, and strawberry and has a pleasant aroma of milk when highly diluted and a strong butter, fat, and butter-like flavour.

The GC–MS analysis revealed that three acids, namely, acetic acid (No. 1), propanoic acid (No. 2), and octanoic acid (No. 4), were found in high contents (18.552%) in pork jerky, which lowered the pH value of pork jerky, thus inhibiting the growth of pathogens. Furthermore, other new compounds, which were only detected in pork jerky, including 3-hydroxy-2-butanone (No. 18; 49.095%), 2,3-butanediol (No. 8–12; 2.790%), 2-ethyl-1-hexanol (No. 7; 2.400%), oxalic acid isobutyl hexyl ester (No. 14; 2.280%), phenylethyl alcohol (No. 13; 0.953%), and eucalyptol (No. 15; 0.659%), contributed to the flavour of pork jerky.

CONCLUSION

The results of the present study showed that *P. acidilactici* could effectively ferment fresh pork to pork jerky. Fermentation of pork jerky produced more nutritious free amino acids and three acids, namely, acetic acid, propanoic acid, and octanoic acid, which lowered the pH of pork jerky, thus inhibiting the growth of pathogens. Furthermore, some new compounds produced, including 3-hydroxy-2-butanone, 2,3-butanediol, oxalic acid isobutyl hexyl ester, phenylethyl alcohol, and eucalyptol, contributed to the flavour of pork jerky. In conclusion, the fermentation method described in the present study can be used for the production of pork jerky with improved quality and flavour.

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